THE SCIENCE OF SAVING VENICE

One hundred years ago, St Mark’s Square flooded less than 10 times a year; since 2000, this has happened over 60 times a year. Venice is also at risk of being catastrophically flooded in a severe storm surge in the Adriatic Sea, as in 1966. And then there is climate change, which poses one of the biggest threats to the survival of Venice in the next 100 years, global average sea level could rise by at least 88cm and as much as 88cm. Many of the natural dynamics of lagoon processes that have shaped and maintained the city for centuries and made the Venice lagoon one of the Mediterranean’s most precious wetlands are threatened by widespread degradation.

This book is the distillation of the current state of scientific knowledge about the nature and causes of the threat to Venice, and about proposed solutions.

It is the fruit of a three-year research project based at Cambridge University, and a conference held there in 2003 that was attended by over 130 scientists from around the world. CORILA was the project’s Venice partner.

BY CAROLINE FLETCHER AND JANE DA MOSTO
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THE 16 million visitors who come to Venice annually see restoration going on everywhere. This is a city where property values are booming and monuments are expertly guarded by the Superintendencies, the responsible government officials. But the deeper reality is less happy. Time is running out for this loveliest of cities. The frequency of flooding is increasing, and Venice is essentially no better protected from an extreme weather event than it was at the time of the great flood in 1966.

The arguments over whether mobile barriers between the lagoon and the Adriatic are necessary or actually damaging have divided the citizens of Venice and Italian politicians into camps so fiercely opposed that one is reminded of the Montagues and Capulets. The moderate have held back from discussions, not knowing where the truth lies. Vital protective measures have certainly been delayed by at least a decade, and comprehensive long-term planning, which Venice needs to the same degree as The Netherlands, has languished.

The science contained in this book presents a timely distillation of current research and potential solutions. Venice in Peril hopes that those who have the power to take decisions about the future of Venice will feel that they now can do so on the basis of more certain knowledge.

This book reveals that the great majority of scientists believe Venice must have some sort of mobile barrier to protect it from extreme flooding events, but it also makes clear how many other factors are threatening the lagoon, and why the ecologists are right to be seriously worried about its health. Venice cannot be saved without investment in both barrier and lagoon. To ask people to choose between them is a false dichotomy.

Above all, this book shows that scientists will be crucial to the future of Venice. Italy has for years under-invested in research in all areas of life, and people are beginning to realise how much this threatens the country’s place in the world. Science for Venice is one of those areas. If we want our great-grandchildren to see this incomparable achievement of man, we have to accept that there is no final solution to its problems. It will always be work in progress and it will always be expensive – but it is a price worth paying.
Crisis

“Oh Venice! Oh Venice! When thy marble walls
Are level with the waters, there shall be
A cry of nations o’er thy sunken halls,
A loud lament along the sweeping sea!”

George Byron, Ode On Venice

CENTURIES ago, on each Ascension Day, the Doges of Venice would perform a ceremony called ‘the marriage to the sea’. Dropping a consecrated ring into the waters of the Venetian lagoon, they declared, ‘Desponsamus te mare’ – ‘We wed thee, Sea’. Today, city and sea are still as intimately bound together as ever. But theirs is a marriage in crisis.

The first real wake-up call for Venice came on the fateful night of 3 November, 1966, when a violent storm surge from the Adriatic swept over the city, flooding it to nearly 2m above normal water level in its labyrinthine canals, and left it with no electricity, black oil oozing out of the cisterns, and alleyways strewn with rubbish and the corpses of pigeons and rats. The flood threw a harsh spotlight onto the crumbling city, which was slowly but surely sinking into the waters of the lagoon that gave it life.

THE ‘VENICE PROBLEM’

The ‘Venice problem’ was quickly declared to be of national interest and a priority for action. Italy has since enacted several laws to safeguard the city and lagoon, and a great deal of restoration and protection work against flooding has, and is, being done. This is largely financed by the government (as described in the Appendix). But Venice suffers from far more than flooding, and the task of solving the city’s many problems is an extremely difficult one. Scientific and political debates about what to do to protect the city and
VENICE, the city that inspired (see above) an extraordinary advantage – from reed huts on stilts, the settlement developed into a maritime superpower and splendid city. The interventions of man throughout Venice’s history have focused on maintaining the symbiotic relationship between the city and its lagoon. Now at the beginning of the 21st century, Venice’s survival is threatened by rising waters and a disappearing ecosystem. Ecosystem degradation and loss of functions that gave life to Venice, right Scientists are working to address the growing number of challenges to the city’s survival

THE NEED FOR INFORMED DIALOGUE

The message from the 2003 Cambridge conference is clear: Most participants agree that the threat of global sea level rise means that Venice’s only hope for the future is to be able to block out the Adriatic; the need arises – although the barriers are considered neither a final, nor a sole, solution to the city’s woes. Without more well-funded and integrated analyses of the complex scientific issues involved, an appreciation that there is much more to know and a greater willingness to collaborate openly, sharing both problems and solutions, Venice’s future is very uncertain.

Crisis

AN INTERNATIONAL CONFERENCE

FOR decades, scientists and engineers have been studying the dynamics of the lagoon and city, trying to understand how the two interact, what is happening to them today, and how flood protection and other measures might impact on them. Despite the huge amount of research conducted over the years, there is still a great deal that is not fully understood. Additionally, past studies often suffered from a lack of coordination and their findings lacked effective dissemination.

To instigate an informed debate about the city and lagoon across a wide range of disciplines, a four-day international conference was held in September 2003 at Cambridge University, England, and hosted by Churchill College. Instigated and supported by the Venice in Peril Fund, the conference invited around 130 scientists, engineers and other stakeholders from Italy and around the world – the first time such an international gathering had been held since UNESCO called experts together in 1969 in response to the 1966 Venice flood. The scientific and technical papers of the meeting are being published by Cambridge University Press in a peer-reviewed book, Flooding and Environmental Challenges for Venice and its Lagoon: State of Knowledge.

The research effort is immense, with hundreds of experts working on the problem from all over Italy and the world. Their work is vital in helping the many stakeholders to make their decisions about the future of Venice. The chapters that follow aim to summarise the state of scientific and technical research at the start of the 21st century, explaining what is known about the city and lagoon, what is still open to debate and further study, and how scientific expertise can inform policy for Venice in the future. While there is still much more to be learned in the next decades of this century, solutions are required now, and fast.
Summary of conclusions

SETTING
- Venice lagoon is a rich and semi-natural ecosystem, inextricably linked to the life of the historic city and a unique ecosystem within the Mediterranean panorama.
- The lagoon emerged 4–6,000 years ago and 1,000 years of human actions and interventions have had a profound effect on its physical structure and ecology.
- Today, the lagoon is at risk of becoming a marine bay, due to erosion of sediments and stronger water exchanges with the Adriatic Sea.
- The water deepens, the city is more vulnerable to flooding and associated urban decay.
- Vital lagoon habitats have already been lost and those that remain are under threat – and with them, the natural dynamics that the city depends on.

FLOODING
- Flooding is caused primarily by storm surges – winds that drive water into the lagoon.
- Many man-made changes have inadvertently reduced the lagoon’s resistance to incoming waters, against a background of sea level rise – hence higher tides.
- It is not a new phenomenon for Venice, but the damaging effects of flooding create an insatiable demand for urban maintenance and are gradually driving the population away.
- The idea that Venice is sinking comes from the extraction of groundwater in the mid-20th century, which caused major land subsidence. This has now been stopped and Venice has returned to subsiding naturally and gradually.
- Barriers at the inlets will protect Venice from extreme water levels; other measures are being taken to protect the city from medium-high tides and ‘chronic’ flooding.

REMEDIES
- All projects to restore the lagoon and protect the city must work in a symbiotic way.
- There are two kinds of measures: ‘local’ measures within the city and the islands, and ‘diffuse’ measures across the entire lagoon environment.
- Local measures offer vital opportunities to improve the city’s infrastructure and restore its buildings.
- Some remedial measures are highly experimental and their effects will only be learned in the long-term.
- Restoring the saltmarshes is key to the future health of the environment, its unique wildlife and the resilience of the entire lagoon system.
- Most scientific authorities are in agreement that the most viable way to protect Venice from extreme flood events is to create a barrier.

BARRIER
- To protect against extreme flooding, construction has begun for the MOSE scheme of mobile barriers and breakwaters at the lagoon inlets.
- Further measures are needed to reverse the degradation of the lagoon system, to complement and mitigate the negative impacts of the barrier system.
- Venice can benefit from experience gained in reducing flood risk in other places, notably flexibility during implementation, institutional rigour and unexpected benefits/adaptations of the system.
- This is a new phase for science in Venice, where some old questions are sharpened by implementation of the barriers and many new questions arise.
- The long-term options for Venice will need to be considered in the context of uncertainty over future global environmental change.
Human-induced climate change poses one of the biggest long-term threats to the survival of Venice – sea level could rise locally by at least 8cm and as much as 70cm by 2100.

Predicting sea level rise is extremely complex and there is much uncertainty regarding the scale of impact it will have, also depending on adaptation and mitigation measures.

Radical ideas for saving the city include raising the ground level by up to 30cm.

The future health and survival of the city and lagoon depend on creating a balance between the needs of the environment, industry, agriculture, tourism and the Venetians.

Scientists need to work better among themselves as well as to support greater stakeholder interaction if sustainable policies are to be developed.
“Venice is inconceivable without its lagoon; it would not, could not, exist without its lagoon.”

UNESCO RAMSAR Report, 2003

VENICE lies in the shallow waters of a coastal lagoon connected to the northern tip of the Adriatic Sea. First occupied in the fifth century, it grew by the 14th century to be the magnificent centre of a major maritime power. Today, it is a World Heritage Site, and the lagoon is recognised as a wetland of international importance. From the beginning, Venetians have managed and modified their watery environment to suit their changing needs, and the lagoon has adapted slowly. But the scale of intervention in the 20th century, and its environmental impact, has been so great that both city and lagoon are now in serious decline. The relationship between man and the environment, city and lagoon, has changed from co-existence to a type of conflict.

THIS CHAPTER EXPLORES
- THE SETTING OF VENICE IN A MARSHY LAGOON
- THE PHYSICAL HABITATS OF THE LAGOON
- HISTORIC CHANGES TO THE LAGOON
- THEIR IMPACT ON ITS PHYSICAL AND BIOLOGICAL STRUCTURE

Left: Seen from above: Venice, lagoon and sea are interdependent.
VENICE lies at the northern tip of the Adriatic Sea, itself a northerly extension of the Mediterranean. The city is sited at the heart of a tidal lagoon, about 50km long and 20km wide. A strip of land separates the lagoon from sea, protected by sea walls and cut by three inlets; several settlements are smushed along here. Twice daily, tides flush the lagoon waters, and their ebb and flow shapes both lagoon and city.

17,000 years ago, during the last great ice age, the landscape was very different. The sea was 100 metres lower than it is today and this region was dry land. The seas rose as the ice age ended, and by 6,000 years ago the coast looked much as it does today. Lagoon systems formed along the new coastline as sediments carried down by the rivers built up banks and barriers, and marshes and mudflats developed in the water trapped behind them. Venice lagoon and the Lagoon of Grado to the north are the only surviving examples; all the others have either silted up or been washed away by the sea.

On such geological timescales lagoons are unstable, constantly evolving systems. Their destiny is to merge with either land or sea. Left to nature, Venice’s lagoon would eventually have disappeared. The fact that Venice still exists is due to centuries of human intervention – as we shall see later.

A PRECIOUS ECOSYSTEM

Venice’s lagoon is a complex and delicate environment, a place of ‘transition’ between terrestrial and aqueous environments, fresh and saltwater systems, and its physical form and biology are the result of their interactions. It is fed by freshwater and sediments from the rivers and surrounding land, and also by the ebb and flow of sea water through the inlets. Waves and currents shape its contours: so do the plants that anchor the soft, muddy sediment, and the creatures that feed among them.

Overcome by the spectacular urban architecture, it is easy to overlook the fact that Venice’s lagoon is a world-renowned wildlife habitat. It is the largest wetland in Italy and one of the most important coastal ecosystems in the whole of the Mediterranean. Tides rise and fall far more than elsewhere in the Mediterranean, creating a unique ecosystem that supports a rich biodiversity – some plant species exist only here; a few types of bird and fish depend on Venice for key stages in their lifecycle and many species common in the lagoon are rare elsewhere in the Mediterranean. Many important waterbirds, such as the redshank and the Sandwich tern, breed here. And more birds overwinter here than anywhere else in Italy – thousands of dunlin, for example, stop off for the winter to feed on the mudflats. The lagoon is actually a fine mosaic of different habitats, each shaped by local conditions – the salinity of the water, or whether it is calm and shallow or subject to fast-flowing currents.

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UNDERTANDING THE COMPLEXITY

This is ostensibly one of the most studied areas of the world – due to its compelling and longstanding integration of man and nature, its unique biodiversity, as well as the government resources and public institutions’ attentions to safeguarding Venice since the latter 20th century. However, there is still much to learn: advances in supporting scientific theory, experimental techniques, physical, chemical and biological monitoring programmes are improving our understanding of the phenomena. Meanwhile, the lagoon is changing faster than ever before and human intervention is on an unprecedented scale. It is a difficult challenge to achieve a solid knowledge base against which to interpret the impacts, past and future, of human activities. Much work has and is being done. Much more has yet to be done.

The changes in the lagoon are a result of a very complex mix of natural processes and human intervention. To really grasp today’s challenges for Venice, we need to be able to understand the inter-action between the city, the physical processes that take place in the lagoon and Adriatic Sea, and the chemical and biological ‘metabolism’ of the lagoon. Scientists observe and monitor the changes in the lagoon in order to understand the processes occurring, but separating the cause from the effect in such a dynamic and complex system is problematic.

““The lagoon is one of the most studied environments in the Mediterranean, yet research is still needed to gain an integrated and deeper understanding of its dynamics”

Pierluigi Vianelli, Dept. of Environmental Sciences, Università di Parma
VENICE’s lagoon is very shallow for most of its area: the average water depth is only about one metre. Natural creeks and channels wind across its bed, carrying tidal waters between sandbanks, mudflats and saltmarshes. Artificial navigation channels cut deep into the lagoon bed, some as deep as 20 metres. There are four main physical habitats, defined in relation to the tides. Some 60 percent of the lagoon lies permanently under water; 25 percent is periodically exposed to varying degrees by falling tides (marshlands and mudflats). The rest consists of islands, in principle always above water, although increasingly vulnerable to flooding.

A. Under water Open waters and shallows including the natural creeks and dug channels that cut across the lagoon. The deeper navigation channels are marked out by distinctive trios of wooden stakes. Seagrasses grow in the shallows. They help to stabilise the lagoon bed and are a nursery for fish reproduction.

B. Mudflats Low-lying areas exposed only at low tide. They drain off the minor channels (tidal creeks) and influence saltmarsh accretion and erosion processes. Although they may look uninviting, they are rich in invertebrate life (including worms and clams – the latter are economically significant) and are important as feeding grounds for birds.

C. Saltmarshes Higher-level areas, partially covered with water only at high tide. They are irregularly distributed around the lagoon and range in size from a few square metres to several hectares. Their salt-tolerant plant communities support a rich and diverse wildlife.

D. Islands These areas are not normally affected by high tides: the islands (including Venice), islets and the three strips of land separating the lagoon from the Adriatic (Pellestrina, Lido and Cavallino), fronted by a sea wall.

E. Drainage basin

F. Fish farm

G. Sea wall

H. Adriatic Sea

This illustration does not represent a real view, but brings together the main habitats and surroundings of the lagoon.
VENICE was founded in the fifth century, after peasants fleeing from the barbarians found shelter on the small marshland islands of the lagoon. Over the following centuries, the city grew in size and importance. The original cluster of 118 islands was built upon and gradually joined together linked by bridges, connected by canals. More marshland was drained. By the 14th century, Venice was the centre of a wealthy and powerful European trading empire. Venetians depended on their watery environment for food, transport and protection – the shallow marshy waters of the lagoon were famously ‘too shallow for invading ships, too deep for marching armies’. The lagoon itself was continually refreshed by the tides, purifying and oxygenating the water. The lagoon waters flushed the canal thoroughfares twice daily and carried away the sewage, which became nutrient for the lagoon’s plant and animal life. Venetians harvested the shellfish and fish, and hunted the wildfowl. Many of the traditional techniques persist to this day and fishing still supports the local economy.

INDUSTRY ARRIVES
In the 20th century, the pace of change accelerated. Industry arrived at Marghera on the adjacent mainland and the port was moved nearby. Large areas of marshland were drained for the industrial zones, airport and agriculture. The outer reaches of the lagoon were closed off to protect fish-farms, and new islands were created. Much deeper navigation channels were dug to bring far larger ships – giant oil tankers and container ships – into the new port and industrial zone.

All these interventions have had major long-term consequences. The natural extent of the lagoon has shrunk by over 20 percent, and its physical structure and hydrodynamics (water flow) has been changed for the worse: habitats such as saltmarshes have been lost and water flows are now greater, which increases erosion. In particular, scientists have identified the deep navigation channels as major culprits in causing erosion and distorting the pattern of the tidal currents and trapping sediments, taking them away from the inter-tidal areas.

CHANGING THE LAGOON
Underlying this intimate relationship between citizens and lagoon was a kind of compromise between natural forces and human needs. Natural processes, working over geological timescales, were gently shifting the lagoon to land, as the sediments brought by the many large rivers that fed into it accumulated. But the growing city depended on canal navigation for the trade that brought it wealth and power, and for its protection. So a remarkably bold series of modifications began in the 15th and 16th centuries to keep the lagoon under water. Seven river mouths were diverted along canals to north and south. Over the next couple of centuries, the diversions were adjusted further as the problem of silting up shifted to new areas, or land began to erode.

The last great works of the Venetian Republic (which ended in 1797) were the conterminazione lagunare, which officially fixed the lagoon boundaries, and built the murazzi, great sea walls designed to keep the Adriatic out. From the mid-19th to early-20th century, long jetties were built at each of the inlets to accentuate the tidal current which kept sediments from clogging up new navigation channels.

“A history of intervention”

Ever since people have lived in the lagoon, they have altered it to suit their needs. Now the scale of human activity threatens to destroy it.
MAPS, surveys and other historical evidence all show that the lagoon is progressively evolving towards a marine landscape. The waters are becoming deeper, marshes and mudflats are disappearing, erosion increasing, and the water has become as salty as the sea.

It is difficult to quantify the change accurately, owing to the complexity of the processes and in some cases to a lack of data, but the problem arises from a shift in the balance of sediments entering and leaving the lagoon.

**SEDIMENT LOSS**

Sediment characteristics underpin many of the lagoon’s physical habitats and determine their health status. Sediments range from fine mud and fluvial silts to coarser sand and their behaviour varies accordingly. They are stirred up and redistributed by currents, deposited again elsewhere or swept out to sea on the tides. But while sediments are accumulating in some areas of the northern lagoon, in others they are eroding and overall, a great deal of sediment is disappearing from the lagoon system. So the dynamics are extremely complex. Measuring the lagoon’s ‘sediment budget’ – the material gains and losses over time – is essential to determining the fate of the lagoon in the modern era. Yet it remains a hugely difficult task. Although while most experts believe there is an annual net loss to the sea, estimates vary as much as ten-fold.

Sediment loss has been identified as a key factor in the process of evolution from lagoon to bay. Diverting the rivers to prevent Venice from silting up has created the opposite problem – starving the lagoon of this sediment source. The long jetties designed to stop the inlets silting up with sediments have played their part in the sediment deficit. General deepening of the lagoon (explained in the next chapter) and deeper canals make currents stronger. Changes in current flows also mean that a great deal of silt and sand are drawn into the navigation channels from the adjacent shallows, which causes further erosion and has to be removed by costly dredging. The total volume of water in the lagoon is said to have doubled in the past century, notwithstanding the reduction in total area, mentioned above.

**Lagoon to sea**

Venice’s lagoon is becoming deeper and more like a sea bay. Its physical structure and ecology are deteriorating, making the city increasingly vulnerable to storm surges and causing species loss in the lagoon.
Scientific surveys show that saltmarshes and mudflats are down to a third of their extent (about 47 km²) at the end of the 19th century. Around 20 percent of the lagoon's plant and 50 percent of its bird species have been lost since 1930. Species that live on the bottom of the lagoon were particularly affected, as much of the intricate sub-structure of winding creeks and meandering canals within the shallows have been destroyed by stronger currents and wave erosion. This lagoon 'physiology' (habitats and structures) is vital to slowing the flow of currents in the lagoon, and their irregular form moderates wave energy. They are also critical to the chemical and biological functioning of the system.

Tidal creeks wind their way through a maze of tiny 'islands' of salt-tolerant vegetation on the marshes, specially adapted to the alternating wet and dry phases. As tidal creeks and natural channels disappear, 'ponds' within the marshes are expanding and joining up with the open water and further fragmenting the marsh structures.

Ecological impacts

Venice's saltmarshes and mudflats are disappearing, starved of sediment and eroded by waves as the lagoon deepens.

Venice's lagoon is fed by a large drainage basin – a 1,850-km² area – and despite the redention of many key rivers, there are still some river systems and associated canals that flow into the lagoon. They bring with them toxic metals, pesticide residues and nutrients from industry, agriculture and urban areas.

In the past, the lagoon trusted primarily in tidal exchanges with the Adriatic and chemical breakdown by micro-organisms to cope with this influx. Micro-organisms in the mud and water broke down organic matter and waste water was diluted by the daily tides. But the input, since the last century, of persistent and potentially toxic metal and synthetic compounds, as well as greater quantities of other contaminants, has meant that the lagoon's natural waste treatment system can no longer cope. Control of industrial waste and agricultural run-off started in earnest in the 1990s, and a major integrated waste-water treatment plant is currently being built. But there is still an urgent need for the sewage inputs to the lagoon and canals of Venice to be more strategically addressed.
The Science of Saving Venice

Effect of excess nutrients

In a healthy system, seagrasses grow on the lagoon bed, helping to anchor the sediment and moderate wave action. Sunlight and oxygen penetrate the shallow water and support their growth through photosynthesis. When excess nutrients enter the system, algae reproduce rapidly causing ‘blooms’ that consume available oxygen dissolved in the water. Tougher seaweeds like Ulva rigida thrive. Less vigorous seagrasses are smothered by these and, cut off from sunlight, they are unable to photosynthesise, and so die.

As seagrass vegetation dies off, there is nothing left to anchor the sediment. It is swept up by currents and clouds the water, further decreasing sunlight penetration. The lagoon bed becomes smooth and no longer dampens wave actions. Erosion therefore increases in a feedback loop, making it increasingly hard for seagrass recolonisation.

Nitrogen and phosphorus compounds are vital nutrients for a healthy ecosystem. But if there is too much, the system suffers. A process called eutrophication begins – the nutrients fuel explosions of growth in certain algae, robbing the water of oxygen and starving out other species. In the 1980s, Venice lagoon suffered terribly from dense algal blooms every spring, clouding the water and suffocating life on the lagoon bed. Populations of a larger invasive seaweed called Ulva rigida also exploded, and soon accounted for some 80 per cent of vegetation growth. It had to be harvested regularly to stop it choking the lagoon.

Tough new regulations on industry and agriculture finally brought the nutrient overload under control in the 1990s, but although phosphates and ammonium levels have reduced, high quantities of nitrates still persist. It still isn’t fully understood why the seaweed explosions died away, so logically it remains possible that they may return.

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TOXIC TIME BOMB?

Venice is one of Italy’s main ports, and major chemical/pestrochemical industries are still present at Marghera. Both the port and the industrial complex were allowed to develop unchecked from the 1950s, and used to discharge their waste directly into the lagoon. As well as the catastrophic risk of oil spills or chemical explosions in the lagoon, a longer-term threat exists. Toxins (such as mercury, copper, arsenic and lead) and persistent substances such as organochlorine pesticides and dioxins have accumulated in the lagoon sediment and canals, storing up problems for the future. Uncontrolled dumpsites in Marghera, created in the 1970s, are still so toxic that they must be capped and isolated from the lagoon system. Erosion and dredging stirs up the sediment, sending pollutants back into the system. Our understanding of the effect these contaminants have on individual species is improving, but their impact on whole ecosystems is now a major area of scientific study. In addition, as analytical methods improve and more contaminants are measured, new threats to the system (e.g. endocrine disrupters) are emerging.

Preserving the lagoon’s unique ecology, while still maintaining the industry and port and other productive activities, has been, and will continue to be a major challenge.

EXPOSED TO THE TIDES

Long-term studies confirm that the primary threat to the lagoon comes in its physical degluation – which strips away important habitats. Where there was once a complex mosaic of habitats, there is increasingly a scoured flat bay. The sediment deficit, the scouring of the navigation channels, and the decline of the biological communities, have all led to the loss of key physical features and habitats, and deepening of the lagoon.

But deepening is also the result of global sea level rise and the natural and human-induced sinking of the land. In the 15th century, Venice lost some 23cm in height relative to the water level. As the waters deepened and the tides’ impact grows, the problems of flooding increase. This is an immediate threat that must be confronted.
“No degree of flooding is acceptable in a city of Venice’s supreme importance”
Anna Somers Cocks, Chairman, Venice in Peril

OF all Venice’s problems, flooding is the most obvious and immediately alarming – water overflows the embankments and seeps up through the drains. There are two types of acqua alta (literally ‘high water’): fairly routine inundation of the lowest areas of the city and rare but devastating extreme events. While acqua alta has been a part of Venice’s history since its foundation, flooding is on the increase, and it is doing great damage to the city, both physically and socio-economically. More flooding is the result of a combination of natural forces (winter storms, combined with long-term processes of rising sea level and subsiding land) and man-made changes to the lagoon that have reduced its natural defences and caused the land to subside.
Why does Venice flood?

Venice floods for many reasons: it is subject to storm surges, the land is sinking, global sea level is rising, and changes to the lagoon and its inlets have reduced its capacity to moderate water levels in the city.

In winter months, confined to the Adriatic Sea, tides usually vary by a few centimetres. But tides alone are not the reason that Venice floods. The main influence comes from low pressure weather systems and associated winds, which create storm surges that effectively push more water into the lagoon.

Two wind systems in particular create these surges. The Bora (from the north-east) acts locally to drive a high surge of water across the lagoon—sometimes creating a difference of up to 20 cm in water level between northern and southern parts of the lagoon. The south-easterly Sirocco wind, from the Sahara, forces surges up the long narrow ‘funnel’ of the Adriatic Sea, towards the lagoon. Water rushes through the three inlets and sweeps across it to the city—arriving at the Grand Canal about 45 minutes later.

It was a very unusual combination of conditions—low pressure, persistent rain and high winds—that caused the tragic flood of 1966, which took water levels in Venice nearly two metres higher than usual. Most people believe it is now only a matter of time until the next disaster and there have been several incidents of grave (but not catastrophic) flooding since then.

Floodings are large and are therefore vulnerable to tides only a little above average. Today’s mean water level (70 cm above the 1897 reference level) is calculated as a mean annual value, taken by averaging all the tidal maxima and minima for a whole year. It is important to bear in mind that today’s mean water level has always varied widely, not just over hours and months, but over longer timescales, which can make it difficult to deduce an emerging pattern or trend. Historical water levels have been estimated using archaeological data from Roman times to the 13th century. Items excavated at differing levels are interpreted in terms of their assumed function; so a boat relic probably marks water level whereas household objects would have been situated a little higher than water levels in canals. From about the 13th-century buildings were often aligned with a ‘C’ to show average high tide levels. This level is also marked naturally by a green line of algal growth and some ingenious extrapolation has been done by observing representations of the green line in 18th-century paintings. Instrumental measurements began in Venice in 1870, and in 1887 a fixed reference point was established at Punta della Salute, at the entry to the Grand Canal. Like the Venetians themselves, this reference level is used for expressing water level throughout the book.

Average water level in Venice (commonly but inaccurately referred to as average sea level) is calculated as a mean annual value, taken by averaging all the tidal maxima and minima for a whole year. It is important to bear in mind that today’s mean water level is about 25 cm above the Punta Salute reference zero—the combined result of sea level rise and land subsidence. The lowest parts of the city now lie less than half a metre above today’s mean water level (70 cm above the 1897 reference level) and are therefore vulnerable to tides only a little above average.

Storm surge of November 4, 1966

During the main surge, waters rose more than 1.9 m above reference sea level, and beyond the instrumental measuring levels of the time. This was followed by a series of ‘scares’, lower but still high tidal surges that are determined by the water oscillating in the blind end of the northern Adriatic basin, and which mean that severe storms can have effects for days.

MEASURING SEA LEVEL

LIVING so intimately with the sea, Venetians have always been careful observers of water levels in the city. Sea levels in Venice have always varied widely, not just over hours and months, but over longer timescales, which can make it difficult to deduce an emerging pattern or trend. Historical water levels have been estimated using archaeological data from Roman times to the 13th century. Items excavated at differing levels are interpreted in terms of their assumed function; so a boat relic probably marks water level whereas household objects would have been situated a little higher than water levels in canals. From about the 13th century buildings were often aligned with a ‘C’ to show average high tide levels. This level is also marked naturally by a green line of algal growth and some ingenious extrapolation has been done by observing representations of the green line in 18th-century paintings. Instrumental measurements began in Venice in 1870, and in 1887 a fixed reference point was established at Punta della Salute, at the entry to the Grand Canal. Like the Venetians themselves, this reference level is used for expressing water level throughout the book.

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Sinking city, rising seas

Natural processes are causing Venice to sink gradually, while the seas are rising around it. But human actions greatly accelerated the process in the 20th century.

SINKING LAND

It was inevitable that Venice would sink. The land itself is subsiding naturally as the ancient sediments of the coast settle. Also, the movement of the Earth’s crust (on a geological timescale), is driving this part of Italy down under the Alps. Together these processes cause Venice to sink by about 0.5mm each year, although the exact amount varies over time, from place to place – the northern and southern parts of the lagoon have registered rates of subsidence of a few mm/year.

That the city has not sunk more is thanks to a layer of highly stable, consolidated clay, known as caranto, which lies several metres below the surface. This clay layer formed about 6,000–10,000 years ago as the seas, which once covered this region, retreated. Venice’s foundations consist of wooden stakes anchored in this layer and the natural irregularity of the caranto is one of the reasons why ground levels vary around Venice.

Archaeological studies have calculated a loss in height relative to sea level in the order of 1–1.5mm a year. Architectural studies on the Basilica of St Mark’s confirm this, revealing an estimated reduction in the margin between ground level relative to sea level of about 1.4cm per century.

GROUNDWATER EXTRACTION

The rate of land subsidence in the lagoon accelerated dangerously in the last century. From the 1920s, industries started to settle on the mainland perimeter in the area known as Marghera, and the port of Venice was also relocated here. The huge volumes of water needed to support these activities were pumped out of deep aquifers (natural underground reservoirs) beneath the lagoon. Unfortunately, it was not realised for decades that these aquifers were an important ‘cushion’, buoying up the land on which Venice rested. Land began to subside dramatically, as can be seen from a comparison with measurements at Trieste, which is subject to the same ‘background’ subsidence and sea level rise.

In less than 50 years, from the 1920s to 1970, Venice had sunk by approximately 10cm more than Trieste. Alerted by geotechnical specialists, who attributed this dramatic drop to groundwater pumping in 1970, the government banned it and the subsidence rate adjusted back to normal within a few years as the aquifers refilled. However, the damage had largely been done in terms of Venice’s protective margin against flooding and the land rebound was relatively small (2cm) as the basal clay on which the city rests had been irreversibly compacted.

CITY ON STILTS

As Venice moved from temporary refuge to permanent city in the ninth century, people found a radical solution to building on the unstable marshy land. They drove wooden piles – long, sharpened poles of alder, oak and larch – into the more stable subsoil of clay under the lagoon. These piles preserved the wood and stabilised the foundations (partly thanks to friction). An astonishing number of pilings were used: the Rialto Bridge is built on 10,000, the Chiesa della Salute on the Grand Canal more than a million.

A layer of oak was laid across the piles to form a foundation. Above this was placed a layer of Istrian stone, a tough marble from the mainland that is impermeable to water. This provided a protective barrier against the lagoon waters. Above the water line, lighter-weight materials – brick, wood and plaster – were used. This reduces the compaction effects of the buildings and confers flexibility as the various ground layers shift continually.
Sinking city, rising seas continued

CLUES FROM CANALETTO

CANALETTO’s meticulous paintings of Venice in the 18th century provide a unique historic record of the city’s relationship to the water, because of their accuracy. Canaletto and his student and nephew Bellotto used a ‘camera obscura’ to paint their scenes. This device reflects a mirror image of the view onto paper, which can then be traced on – the picture is in essence a photograph. Modern photographs from the same viewpoint have been used to compare water levels – and reveal where ground levels have changed.

The Punta della Dogana example shown here illustrates the difference clearly. The bases of the columns to the right show that the whole pavement has been raised, and still the water is higher up. The rise was calculated as 70–110mm over two centuries.

RISENG SEAS

Subsidence of the city has been accompanied by a gradual worldwide sea level rise. In line with rising global average temperature, seawater volume expands and land-based ice melts, raising sea levels across the world. This global process is known as ‘eustasy’. Concerns for Venice’s future are in part based on predictions of a global rise of about 8–88cm by the year 2100, but the regional implications have yet to be worked out. At least for the time being, sea level rise in the Adriatic region seems to have slowed down (Chapter 6 explores this in more detail).

Although it is the extreme events that Venice fears most, it must also cope with and plan for a general and gradual rise in water levels. Since the 1966 flood, people have moved from vulnerable ground-floor homes, but stores and workshops remain at risk. The city’s highest land is no more than 2m above sea level, and much of the city lies much lower than that. Areas that were once safe, now flood, and low-lying areas are flooding with increasing frequency.

“Venice has lost a century in its battle with the sea”

Prof Albert Ammerman, archaeologist, Colgate University, USA
Flooding more frequently

Flooding in Venice is occurring more often. In winter, what was once an occasional event is now an almost daily occurrence in some parts of the city.

The first record of acqua alta dates back to 1240, when waters were ‘above man height’ in the streets. It is something people have learned to live with but, increasingly, the dampness and complications caused in daily life are becoming unbearable. Today, in winter, raised walkways (passarelle) are out most of the time in the low-lying areas and along strategic routes, such as from the railway station. Water wells up from drains to pool in the city’s squares and courtyards, and may flow over the canal banks. Many entrances to buildings, schools, shops, store-rooms and church crypts flood, while most ground-floor dwellings have been abandoned. Even emergency services are jeopardised by high waters when water level in the canals leaves too little space under bridges for the fireboats and ambulances.

The present situation is significantly worse compared with 100 years ago. Of the ten highest tides (above 140cm) recorded in the century to 2002, eight occurred after 1960. In the winter of 2002 alone, in the space of three weeks (14 November–8 December) there were ten flood events above 110cm, five above 120cm and one above 140cm. But the picture is complex due to irregularity within the general trend. In the whole of 2003, water level did not rise above 110cm. Only by comparing data over many years can meteorologists be sure that the frequency of flooding is not just linked to some cyclical trend but a permanent change.

Scientists have linked increased flooding to the rise in average sea level attributable mainly to the episode of human induced subsidence, and to changes in the lagoon’s physical structure, which affects the entry and movement of water within it. Changes in the shape of the inlets, loss of salt-marshes and deep navigation channels have contributed to a greater volume of water and stronger current entering the lagoon when pushed by the tide and winds. A small effect is also attributed to the reduction in total area of the lagoon, due to land reclamation and other interventions, so the greater volume of incoming water has less area in which to spread itself. Even when the tide is not particularly strong, high water regularly tops the protective layer of Istrian stone on the canal-side buildings to eat away at the plaster and brickwork physically (wave and propeller energy) and chemically (salts corrosion). The city is under siege.

“Venetians have been getting their feet wet for centuries”

Paolo Costa,
Mayor of Venice
VENICE’s architectural problems are not new. The battle to maintain the delicate fabric of the city has been relentless. Up until the 19th century, canals were filled in, buildings demolished and rebuilt in the face of changing water levels, but Venice’s ‘forma urbis’ and architectural heritage is now under strong preservation orders. Today, the city’s extreme fragility is startlingly obvious – especially the many crumbling buildings that have been abandoned as a result of the collapse in the local population and the relocation of many offices and businesses to the mainland.

The main decay is caused by the destructive action of sea water. Since the tidal exchange between the lagoon and Adriatic has become stronger, salinity of the canal water is the same as the sea. On many buildings, water level now comes above the impermeable Istrian stone base for most of the time, soaking into the porous brickwork, wood and plaster. Dissolved salts degrade the building fabric as they crystallise within the walls. Air pollution used to be a problem and corroded the marble facades of Venice’s palaces. But Venice was one of the first Italian cities to convert to methane power generation (instead of coal and oil) and industrial emissions are being controlled.

TRAFFIC WAVES
Buildings are also challenged by waves set up by speeding boats carrying people and goods through the city’s canals. The intensity of the waves has been estimated as adding a few centimetres to the mean water level. While the waves attack surfaces above water, the action of propellers below water creates a sucking force, eroding cement and foundations. Stirred up sediment clogs the canals and obstructs the ancient sewage system on which Venice still relies.

The impact on the people of Venice is enormous: the inconvenience of flooding, and the ongoing damage to their fragile buildings, and the overwhelming presence of tourists have meant that many Venetians have abandoned the historical centre as a place to live or work. In the 1950s the city boasted a population of 150,000. Today, it is closer to 65,000. If future generations are to be drawn back to the city, remedies are urgently needed to mitigate flooding and urban degradation.

FLOODING IS CAUSED PRIMARILY BY STORM SURGES – WINDS THAT DRIVE WATER INTO THE LAGOON
Many man-made changes have inadvertently reduced the lagoon’s resistance to incoming waters, against a background of sea level rise – hence higher tides
It is not a new phenomenon for Venice, but the damaging effects of flooding create an insatiable demand for urban maintenance and are gradually driving the population away.
The idea that Venice is sinking comes from the extraction of groundwater in the mid-20th century, which caused major land subsidence. This has now been stopped and Venice has returned to subsiding naturally and gradually.

Barriers at the inlets will protect Venice from extreme water levels; other measures are being taken to protect the city from medium-high tides and ‘chronic’ flooding.

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Remedies

“Our goals are to restore and re-equilibrate the lagoon, and eliminate the causes of environmental degradation”

Maria Giovanna Prva, President, Venice Water Authority

THE complex problems of Venice and its lagoon must be understood as a whole, since the health of one depends critically on the health of the other. An integrated programme of defences has been outlined to protect Venice from the acque alte, and to reverse the degradation of the lagoon environment. The urgent and constant need for interventions to restore and preserve the fabric of both city and lagoon, and to protect them from floodwaters, go hand in hand. There are enormous technical challenges, which involve establishing priorities, recognising the different timescales for action and managing uncertainty. Much of the work involves tested engineering approaches but some of it is experimental in nature.

THIS CHAPTER EXPLAINS
■ ‘LOCAL’ MEASURES TO PROTECT VENICE AND THE OTHER ISLANDS
■ THE RESTORATION OF VENICE’S BUILDINGS AND INFRASTRUCTURE
■ BUILDING NEW SALTMARSHES; THE RESTORATION AND CONSERVATION OF REMAINING ONES
■ OTHER ‘DIFFUSE’ MEASURES IN THE LAGOON
■ THE NEED FOR FLOOD CONTROL OVER AND ABOVE THESE MEASURES

Left: Building maintenance is a constant necessity from the foundations upwards
Defending the city

Protecting Venice from flooding requires a high degree of planning and coordination. The current programme of works is also a great opportunity to renew the city’s infrastructure.

AN integrated system of defences has been outlined to protect Venice from the acqua alta. These are classified into:

- **Local** (city and other inhabited islands)
- **Coastal** and large-scale engineering (the barrier scheme and shoreline reinforcement).

The Comune determines safeguarding policy, while the Consorzio Venezie Nuova is charged by the Venice Water Authority with planning, designing and implementing them – as far as the lagoon is concerned. Insula SpA does the same for the urban areas of Venice and the islands. Both work with regional and local authorities and other key bodies.

The proposed scope of works is vast: embankments and walls are being raised against the rising waters; canals require dredging; kilometres of buildings and canal embankments need to be restored from the foundations up, the entire sewage system and underground drains need to be repaired and modernised. Out in the lagoon, the sea walls need strengthening, while flood barriers and associated works are to be built. It is an extraordinary, ambitious programme, calling for more integrated analyses of the past 30 years’ acquired scientific knowledge, sharing of data and careful monitoring of the effects and impacts of interventions – during and after implementation.

DEBATING THE PRIORITIES

There is considerable debate in Venice about which of these safeguarding measures should take priority, and indeed whether they are all necessary to protect the city. Some scientists and engineers feel that the mobile barriers (discussed in Chapter 3) need to be built immediately to eliminate the risk of another devastating flood like 1966. They argue that tackling environmental degradation of the lagoon can be dealt with separately over a longer timescale. Others, who oppose the barriers, would prefer to see the local and diffuse measures prioritised to combat the chronic flooding problem and deal with the environmental degradation.

LOCAL DEFENCES

Local defences are designed to protect the built-up areas from flooding. The first of these measures involves raising pavements, bridges, embankments and walkways as well as subsidising anti-flood measures for the ground floor of many buildings, especially in the lowest-lying areas of the city and other islands. The stated aim is to defend the city against medium-high flooding levels (up to 1.10m above the reference level) and, where possible as high as 1.20m.

Historically, Venetians have responded to rising water levels by knocking down old buildings and building new ones, or by simply filling in canals, and raising the floors and pavements. There has been much discussion about whether it is possible just to continue this habit to keep pace with the waters. But, in the opinion of many experts, the limit has been reached if the architectural glories of Venice are to be preserved, as raising pavements any further will destroy the elegant proportions of the buildings and eliminate features such as the bases of columns. Doing so would create a different Venice, and it is not an option that most people are prepared to accept for this World Heritage Site. With local defences only of the order of 1.10m, the barriers will be vital in defending Venice’s iconic buildings and residents from extreme floods.

Another category of local defence works is known as insulae (islets), which go beyond simply building up ground levels and include the impermeabilisation of an entire islet area within the city, via complex interventions on the drainage system, use of one-way valves and special materials to block the seepage of underground waters.

More ambitious schemes to raise whole buildings or entire areas of land using innovative technologies are still technically uncertain, but they remain a long-term option (See Chapter 6).
Curing Salt Damage

Saltwater and sea air attack both above and below the water line. In the past, Venetian builders created a damp-course at the base of their buildings, using non-porous Istrian stone. The underwater depth of the stone facing was determined by the then high tides, with a built-in safety margin. Now that margin has been lost. Saltwater penetrates and rises in the brickwork. Once the water evaporates, the salt left in the wall crystallises, expanding and so increasing pressure on the bricks, which crumble along with plasterwork. Extensive research has resulted in the development of innovative chemical and physical treatments to protect the brickwork and block salt invasion. Some verge on pure alchemy, others are simpler – for example the use of outer plasterwork as a ‘sacrificial layer’ in which the salts concentrate and crystallise, rather than staying within the brickwork.

Maintaining Venice has been a constant challenge ever since the city was built — water and sea air are naturally corrosive, while modern pollution also attacks marble and plasters. Venetians have worked hard to preserve their city — although urban maintenance took a back seat in the post-World War Two period, efforts were intensified following the shock of 1966. Despite the past 30 years’ work, there is still much to be done to restore and maintain the city’s urban fabric.

In the 1990s, Venice Town Council linked up with key service industries — water, gas, electricity and telecommunications — to form a company called Insula, to develop and run a massive integrated project to protect and restore the city. Raising ground levels for local flood protection was synergised with renewing the city’s ageing root-and-branch infrastructure, and dredging the canals. Periodic dredging operations have been performed since ancient times to permit navigation and to maintain acceptable hygienic conditions. From the early 1960s to late 1990s, however, the dredging was interrupted, except for some minor interventions, and a layer of sediment up to 1m thick accumulated in the network. Canal dredging to improve water circulation and navigability is now combined with repairing building foundations, increasing the number of septic tanks and the renewal of the culvert system. Disruption to the city’s life is enormous — pipelines are being laid, bridges and walkways are being rebuilt, canals are drained while workmen replace and consolidate the brickwork and inject it with innovative chemicals.

Once canals are dredged, the foundations are accessible and repair work is more easily done. An extensive programme of work on dredging and repairing the canals is underway, and urgently needed modernisation of the sewage network, to include a collection and treatment system for the historical centre, is being discussed. Venice has no sewage treatment: traditionally the city discharges its waste untreated into the lagoon, relying on the tides to flush the canals clean. But today many wastewater outlets, constructed centuries ago, are covered by mud in undredged canals or clogged by fine sediments, stirred up by boat traffic and the tides. This weakens buildings as the old pipes disintegrate and release their contents within the walls. Fluctuations in water pressure can also damage foundations and canal banks. On the mainland around the lagoon, new treatment plants and modern sewers are already being put in place to stop the influx of nutrient-loaded sewage into the lagoon.

Repairing and renewing the city

Work to rescue Venice’s crumbling fabric was given new impetus with the Special Laws, which led to the development of a large-scale programme of restoration, renewal and flood protection.
Rescuing St Mark’s Square

ST MARK’S Square, Venice’s iconic landmark and symbol of its past glory, is the target of a special programme of flood protection and repair. It is an example of the insulae approach to improving defences against medium-high tides. Work is proceeding in small sections, so that the Square remains accessible to the thousands of daily visitors.

Phase One, started in 2003, consists of repairing and raising 150m of quayside walls to +110cm to stop waves and floodwaters from flowing over the banks. The pavement within the Square cannot be raised any further, or the architectural proportions of its unique buildings will be ruined.

Phase Two consists of reorganising and modernising the existing network of pipes and drains underneath the Square, and fitting one-way valves to stop the backflow of water up to the surface. Underground conduits will be completely restored where they have collapsed. A waterproof layer may be added to prevent seepage through the subsoil, but this is subject to further research. A new rainwater collection system linked to a pumping station will actively pump water back out to the lagoon at high tides.
Protecting the lagoon

A second layer of ‘diffuse’ measures covers flood defences and environmental restoration across the lagoon. They help to protect Venice, mitigate the tides and revive the lagoon’s degrading habitats.

EROSION, high waters and wave motion are gradually transforming the lagoon into a marine bay. It is losing its physical characteristics and habitats. The ‘diffuse’ measures proposed across the lagoon seek to reduce the height and impact of high tides and, in addition, to restore the lagoon morphology. This second line of defence aims to restore the natural defences that have made possible Venice’s long history, working with nature rather than against it. The lagoon’s physical and biological structures used to help dampen the effect of acqua alta but over the last century so much has been damaged and eroded that the seas flow more freely into the lagoon and easily penetrate the canals of Venice. The measures will have an impact on the water levels but cannot solve the flooding problem, although they may reduce the frequency of flooding. They will, however, play an important role in reversing the degradation of the lagoon.

The ‘diffuse’ measures include works on saltmarshes, further investigation and pilot studies to quantify the potential of opening areas to tidal exchange, filling in dredged navigation canals and modifying inlets. Additional measures aimed at protecting the lagoon rather than influencing flooding include improving the ecological quality in some areas; controlling the release of pollution from sediments and especially from the dump sites where industrial wastes were previously disposed; planting seagrass to help consolidate muds; improving water quality; protecting and reintroducing saltmarshes. There is no one solution to protecting Venice and its lagoon as a combination of approaches is needed. Also, these proposed measures are not all feasible, but do form part of the debate of which remedies should be undertaken as a priority and over what timescale.

The northern lagoon seen from the bell tower on the island of Torcello – this area best conserves the original characteristics of Venice lagoon.
Revitalising the saltmarshes

In the debate on the future of Venice lagoon there seems to be a common aim: guaranteeing the conservation of this unique system. Experimental restoration work is taking place in 20 locations.

As described in Chapter 2, the lagoon's saltmarshes and mudflats are still disappearing at an alarming rate as a result of reclamation, erosion, pollution, and natural and human-induced subsidence. Reconstructing lost saltmarshes and protecting and restoring the existing ones is a major technical challenge. Their natural forms are the result of evolving conditions, an intricate balance of interacting processes – the energy of the waves and the ability of the structures to dampen them, the amount and flow of sediment in the system, the biological mix of species. Any attempts to reconstruct or restore these habitats must be based on an understanding of how the natural system works. It requires innovative thinking – and many of the techniques being tried out are highly experimental. It is, anyway, impossible to return to the lagoon as it once was: it is deeper and more open to waves than before, and the dynamics of flow are now quite different.

Restoring Old Marshes

To restore the existing marshes to health, it is vital to protect their eroding edges and give them time to build up again. A range of experimental techniques are being tried, using wooden piles, gabions (wire cages containing rock or other material), artificial sandbars and beaches. Other experiments include measures to encourage sedimentation and new growth: sediment fences, spraying the marsh with nutrients and depositing new organic matter at the edges, and transplanting vegetation. Water quality can be improved by re-opening tidal creeks. Polluted mudflats are being capped to prevent their sediments being stirred up into the water column.

Creating New Marshes

In some areas new marshland is being created using dredged material, taken from navigation channels in the lagoon and near the inlets. By the end of 2000, 15 percent of total ‘marshes’ in the lagoon was of this type. These are highly managed systems, with solid edges to prevent the unstable sediment from being washed away again by the waves. There is already concern that their steep edges mean they are not linked with mudflats that grade into natural saltmarshes. They are distinctly different in character from the other marsh areas, their structure a ‘cruder’ version, with less physical and biological complexity. The question is whether they develop into stable, complex communities over time which are comparable to the Venetian saltmarshes.

These are long-term experiments, and the results will not be apparent for decades. They require continual monitoring and testing by scientists to follow their progress. Lessons have already been learnt. For example, there is now a move away from using hard structures to using degradable materials and engineering solutions that are closer to the natural structures and processes.

The illustration over the page shows some of the key restoration projects. As a summary diagram, it does not reflect any one place – these measures are being tried out in many different locations.

Hypothetical Measures

Re-opening areas of the lagoon

In the last century, the area of lagoon open to the tides shrank by about 20 percent. The fish farms, situated at the lagoon periphery to the north and south, are now separated from the lagoon by embankments, isolated from the eb and flow of the tide. Other areas of the lagoon were made into artificial islands, mainly in the 1960s, in anticipation of an industrial expansion that never happened. These are to be opened up by digging tidal creeks through them, and planting them with vegetation to encourage the return of saltmarshes, as part of the Fusina water treatment system.

Opening these areas would allow the tidal waters to be dissipated over a larger area. But studies have shown that it would only slightly reduce water levels. Also, the farms are protected by powerful interest groups, including recreational hunting.

Navigation channels

There has also been much debate about filling in the major navigation channels (notably the Canale dei Petroli that links the Adriatic to Marghera, via the Malamocco inlet) which are widely considered to be a major cause of erosion processes in the central lagoon. As the monsoon, inter-tidal sediments are resuspended by the influence of the currents in the deep channels, which is where they re-deposit, only to be lost from the system as they are carried out to sea by the strong currents.

Filling in the channels would reduce the amount of sediment lost from the inter-tidal areas and impede the dissipation of water entering the lagoon at high tide. But these channels carry important traffic to and from the Port of Marghera, and there is equal pressure to keep them open and dredged – studies have shown that filling-in the Canali dei Petroli would have little influence on the water level and flooding of Venice.
Experiments in restoring saltmarsh

This summary illustration shows a range of restoration techniques being tried out around the lagoon. Applications need to be monitored for their effectiveness in developing stable, healthy saltmarsh communities in order to guide future projects. Techniques are being shared around the world, especially with the North Sea (Germany, Holland and UK) and Chesapeake Bay (USA).

Protecting the edges
The areas where restoration is being trialled are afflicted by eroding edges, where the deepening lagoon and greater expanse of open waters produce higher and more powerful waves, which batter the marsh banks. Invasive seaweeds have also killed off vegetation that helped protect the margins via their root systems. Eroding shallows are another problem, as the disappearing mudflats used to dampen the force of the waves and supply sediments and ecological relationships to nourish the marshes.

A. Hard gabions (wired crates of stones) have been tried in more exposed areas, but can cause local wave action and thus increase local erosion. They also interrupt the natural process of exchange between the marsh and adjacent mudflats.

B. Biodegradable gabions (sacks of sediment and/or bark) planted with pioneer vegetation are designed to dampen wave forces while they degrade gradually, allowing natural protective saltmarsh regrowth to take their place.

C. Simple woven brushwood fences help to protect edges and increase sediment trapping by 1–3 cm a year. They require constant maintenance.

D. Wooden pilings are considered an alternative to hard gabions.

Restoring the vegetation
E. By replanting helps to stabilise the lagoon bed – by trapping sediment in the shallows and triggering the process of rebuilding the marsh.

Feeding the marshes
F. Boats can be used to replenish marshes with a fine spray of sediment.

Dredging the tidal creeks
G. Excavating is done to improve flow through the marshes, to facilitate water and nutrient exchange.
Measures at the coast

The proposed programme of protective measures continues at the coast, to restore existing defences and alter the inlets to increase their dampening effect on the incoming tides.

THE coast is the lagoon’s first natural defence against the sea — waves lose their energy as they break on beaches that form a barrier across the lagoon. But erosion has progressively reduced the beaches to the point where some have disappeared altogether, as has the dune belt behind them. These natural structures reduce wind action and trap windblown sand, and are also important wildlife landscapes. There are numerous small towns and villages along the Venice coast, making protection here even more vital.

Coastal defences include creating new beaches and widening existing ones. The ancient sea walls and jetties require maintenance, and new groynes are being built out from the beaches to dampen the effect of storm waves. Sand dunes also need to be conserved and preserved, with the added benefit of bringing wildlife back to the bay.

TIDAL INLETS

There has been much debate about how to alter the three tidal inlets, at Chioggia, Malamocco and the Lido, to restrict the amount of water entering the lagoon. Some scientists have supported proposals to narrow the inlets and where possible to reduce the depth and round the seabed there. This would create higher resistance against water flowing into the lagoon during a strong surge, resulting in a lower volume of incoming water over a given period of time and a lower peak water level. The effect of inlet modifications would be less for normal tides and almost negligible in a 1966 type event.

Other scientists argue whether this approach is useful as part of the overall safeguarding measures due to long-term impacts on the water flows and sediment processes. The Comitato agreed in 2003 that some changes to the inlets will occur as part of the so-called ‘complementary measures’ discussed in the next chapter.

A HUGE CHALLENGE

The task is a vastly challenging one, as each change made to the lagoon will ripple through the system. Many measures are experimental and what works ‘on paper’ may not work in practice in such a complex, multi-dimensional system. Detailed research and constant monitoring is needed to track the changes and measure their impact.

At the same time, scientists are still working to establish a sufficiently detailed baseline of information about the lagoon’s behaviour today. Without this, they cannot accurately judge the true impact of the changes.

IS IT ENOUGH?

Could the local and diffuse measures described in this chapter be sufficient to protect Venice from the floods?

While a few people argue that they will, the majority of scientific opinion is that, although they help limit the number of floods they are not sufficient – they cannot protect the lagoon from extreme events, like the storm of 1966. Nor can they offer protection from inevitable long-term global sea level rise. Studies aided by computer simulations suggest that neither the lagoon-wide restoration efforts nor the changes to the lagoon inlets (presently under construction) will be able to reduce high water levels in Venice by more than a few centimetres.

Measures in the city and across the lagoon would have to be far more drastic, and unacceptable in view of the world importance of its architectural heritage. And most people are certain that it is only a matter of time before another major disaster happens.

The consensus is that the only feasible way to stop the rising waters from overwhelming the city again is to provide a physical separation from the sea.

CHAPTER 4 SUMMARY

- All projects to restore the lagoon and protect the city must work in a symbiotic way
- There are two kinds of measures: ‘local’ measures within the city and the islands, and ‘diffuse’ measures across the entire lagoon environment
- Local measures offer vital opportunities to improve the city’s infrastructure and restore its buildings
- Some remedial measures are highly experimental and their effects will only be learned in the long-term
- Restoring the saltmarshes is key to the future health of the environment, its unique wildlife and the resilience of the entire lagoon system
- Most scientific authorities are in agreement that the most viable way to protect Venice from extreme flood events is to create a barrier
THE mobile flood barriers to be built at the three inlets to the Venice lagoon have a single purpose, to protect the city and lagoon islands from major storm surge flooding. They are being developed against a background of intense scientific and political debate about whether they should take priority over other measures, how viable they are, and what their likely impact will be on the life of the lagoon. The barrier design is radical and poses enormous engineering challenges. Research will continue as the gates are built and tested, as will research into their effects on the natural system of the lagoon. Lessons can be learned from other flood barriers across the world, but each barrier system and location is unique.

THIS CHAPTER EXPLORES

■ THE CONSTRUCTION OF THE BARRIERS
■ THEIR MECHANISM AND OPERATION
■ THE COMPLEMENTARY MEASURES AT THE COAST AND INLETS
■ OTHER BARRIER SYSTEMS
■ THEIR PREDICTED IMPACT ON THE LAGOON SYSTEM
■ DEBATES ABOUT THEIR ENVIRONMENTAL IMPACT

“Building barriers and flood defences against changing sea levels is an on-going process. Barriers buy you time”

Sarah Lavery, Thames Flood Defence Strategy 2100

left Malamocco inlet, where construction of the breakwaters associated with the barriers officially began in spring 2003
The mobile barriers

The barriers will consist of 78 hinged steel floodgates, stretching across the three inlets of the lagoon. The wider Lido inlet barrier (41 gates) will be in two parts, separated by an artificial island. The Malamocco (19 gates) and Chioggia (18 gates) inlets will each incorporate a navigational lock for shipping.

The huge gates are 20m wide, up to 5m thick and between 18 and 28m in length (depth). They will be anchored at one hinged end to concrete foundations sunk into the lagoon bed. They will lie unseen on the bed, filled with water, until a storm warning comes, when they will be pumped full of air and rise to form a wall against the sea. They will remain up for the duration of the surge tide, and will then refill with water and sink down again.

The construction of the barriers is a major engineering feat, not just to design a complex mechanism that will continue to work reliably for decades, but also to manoeuvre the huge panels into place without error or technical hitches. The materials used must withstand the harsh conditions of the saline waters.

The proposed mobile barrier. Design modifications, even during construction, are a common and expected part of sophisticated engineering work, and the final design is likely to vary slightly from this specification, first published in 1996.
THE idea of a system of gates between the lagoon and the Adriatic Sea is not new – a scheme was even proposed in the 17th century. But the need for protection came sharply into focus after the 1966 flood and in 1971, a ‘competition of ideas’ was held. The concept that won was for an underwater mobile barrier.

It took more than a decade for an institutional framework to design, assess and start to build the barrier to be put in place. The 1984 ‘Special Law for Venice’ led to the creation of the Consorzio Venezia Nuova (CVN), a consortium of large Italian engineering and construction companies, which was charged with implementing the solution to the ‘water problem’ (for details, see Appendix). Twenty years of planning, technical development and testing followed, amid intense scientific and political debate. The final go-ahead to plan and build the mobile barriers was given only in 2001, and work began in earnest in 2003 with the construction of an outer breakwater at Malamocco.

The first experimental prototype, called MOSE (MOdulo Sperimentale Elettromeccanico) was built and tested between 1988 and 1992. It has given its name to the larger scheme – the complete set of mobile barriers and ‘complementary measures’ at the inlets.

MOSE is being developed under a set of constraints imposed by the Comitato (see Appendix) deriving from environmental assessments in the late 1990s and pressure from the Port of Venice and industry concerned by the possibility of disruption to their transport links. The barriers must have little or no negative impact on navigation, nor on lagoon flushing and water quality, ecology and habitats, or on the ‘aesthetics’ of the lagoon. The latter is a key reason for the underwater design solution.

The project is being developed through detailed engineering studies, physical modelling and computer simulations to explore how the barriers will work in situ, how they should be managed, and to assess their impact on water flow in the lagoon. This work must be integrated with, and informed by, scientific studies on the lagoon’s physical and biological functioning, as well as research to improve weather forecasting. It is remarkable that an enormous amount of data collected by numerous institutions (but mainly the Venice Water Authority) has not been circulating or made readily accessible to the scientific community nor the public at large. This has obstructed the comparison of research results and findings from different modelling approaches and the development of a non-ideological, constructive, science-based debate on certain key issues.

PROPOSED MODIFICATIONS AT THE THREE INLETS

These diagrams show the positions of the barriers and navigation locks at the three inlets. The MOSE scheme is required to reduce the inflow of water from the Adriatic Sea by between 15 and 28 percent at the inlets. To achieve this, the complementary measures – moon-shaped (lunare) breakwaters will also be built beyond each inlet. The Malamocco outer sea wall is about 1,300m long and 3–4m above mean sea level; at Chioggia it will be about half as long and 2.5m high.

The Malamocco breakwaters will be complete by the end of 2004 and work is beginning at Chioggia. The Lido breakwaters are still at the design and approval stage. At the same time, the channels through the inlets will be reduced in depth and their profile will be changed. Some engineers believe that these changes will help increase resistance to the flow of water in and out of the lagoon, and so further reduce the volume of water entering the Adriatic Sea. Other hydraulic engineers expect the benefits to be slight, and the key issue is cost effectiveness. There is also concern about the long-term ecological and water quality impacts of these changes.

WILL THE BARRIERS WORK?

‘This type of project requires a high percentage of unusual work and advanced technology.’

Alberto Scotti, barrier design engineer

above Engineering interventions at the inlets were also considered 400 years ago

below A physical model of the lagoon is used to investigate the system and the barrier impacts

Will the barriers work?
FLOOD barriers protect many vulnerable cities in Europe. The three examples given here – from London, Rotterdam and St Petersburg – highlight some of the experience that Venice can benefit from, although the context and tidal systems differ markedly and every situation bears a certain uniqueness. Each project was set up to protect major cities and other areas of dense population from sea storm surges, and each scheme chose a completely different barrier system.

In two cases, there was serious conflict between environmental impact and the desire to protect the urban population. In all cases, major social and economic issues were at stake. A balance always has to be struck, a trade-off between protection, trade and environment. Everyone also has to recognise the scale and uncertainty of these grand schemes, where whole ecosystems are dramatically changed – indeed, in the Dutch case, altered beyond recognition from salt to freshwater. Research cannot stop when the barrier is built; the consequences of our actions need to be understood, so that we learn for the future.

In summary, the lessons to be learned are that:

- Flood disasters are commonly a trigger for action
- There needs to be a general public and political will to drive the project forward – often it is only crisis that focuses people’s attention
- Major engineering schemes are expensive, experimental and difficult
- Funding needs to be secure – half-completed schemes pose environmental hazards in themselves
- Barriers cost a lot of money to operate and maintain
- High-tech barriers need skilled people to run them, not just to build them
- Design modifications are normal as engineers learn more about how a barrier will perform once installed, and what impact it will have
- There will inevitably be a trade-off between safety and environment, the skill is to find a way of working together, rather than in opposition
- In a changing world, barriers are never a final solution – cities have to keep planning for the following 100 years
- Safeguarding against sea surges is the first step, but if sea levels rise more than expected, we must be prepared for future storms
- Experience shows that the consequences of a barrier are far-reaching, especially for the environment
- The Thames Barrier system is now also used for management of river flooding – an unforeseen application at the time of construction

The Thames Barrier

The River Thames runs through a densely populated and commercially sensitive floodplain, including the City of London, and flooding has the potential to cause economic and social disaster. Surge tides from the northern Atlantic are forced down into the North Sea, driving extra water up the river and occasionally flood defences are overtopped. Plans to protect the city were triggered by a disastrous flood in 1936, which killed 317 people in England and Scotland.

The chosen barrier scheme consists of a series of rotating (normally submerged) gates suspended between a series of towers. Construction started in 1974 and the barrier opened ten years later. London now has one of the best tidal defences in the world, designed to cope with storm surges and estimated sea level rise well beyond 2030. But climate change is predicted to bring higher seas and uncertain changes in storminess, and planning has already begun for the ‘next generation’ of protection up to 2100.
Learning from other schemes continued

ROTTERDAM AND THE EASTERN SCHELDT, HOLLAND

Holland is particularly vulnerable to flooding, some 60 percent of the land being below sea level, so flood defences are critical. Just as in England, the decision to embark on large-scale storm and flood defence systems to protect the area around Rotterdam was taken following the disastrous 1953 flood, in which 1,835 people died in Holland. This led to the ‘Delta Plan’ to reinforce the dikes and to close many of the existing estuaries with dams.

Only two of the estuaries were left open: the Western Scheldt estuary, which leads to the Port of Antwerp, and the New Waterway, which is the entrance for the Port of Rotterdam. For the New Waterway, a barrier project was started in 1991, and just six years later the Maeslant barrier was completed. This barrier is almost as wide as the Eiffel Tower is high. Giant swivel gates swing across the estuary to form an impenetrable wall protecting one million people.

During its construction, the engineering design had to be revised when the team realised that ‘seiches’, long waves with a period of 15–90 minutes and with amplitudes of over 2m, could create a negative head over the gates, which were initially not designed to resist them. Seiches are also a feature of the Adriatic, and the Venice gates will have to cope with them.

The Delta Plan brought about considerable changes in the tide and the ecosystems of the area. In some areas the decision was made to change the ecosystem completely from a saline to freshwater environment. At the Eastern Scheldt, there were furious protests culminating in a sea battle pitting environmentalists and fishermen against visiting politicians. A much more expensive system resulted, incorporating a storm surge/barrier.

The Maeslant barrier has now been operating for seven years, and has yet to be closed for a surge emergency. But it is tested yearly, just before the beginning of each storm season, to check it still works. Dutch experts stress the importance but difficulty of maintaining highly skilled teams, who are used to the demands and vulnerability of such a high-tech system.

Initial attempts to build the barrier suffered from poor public consultation

ST PETERSBURG, RUSSIA

Like Venice, St Petersburg is a major port, and one of Russia’s greatest architectural treasures. The city is in a low-lying coastal plain where the Neva river discharges into the Gulf of Finland. Much of the old city lies little more than 2.5m above the sea, and floods have been part of its history – the greatest in 1824 when waters rose nearly 4m above normal levels.

Plans to build a 24km flood barrier across the Neva Bay began in the 1960s. Construction started in 1980, but work halted in 1990. There was also huge local and international opposition to the scheme, based on the fear that the ecology of the bay and the Gulf of Finland would be seriously damaged by the system. The shallow waters are internationally important breeding grounds for fish and feeding grounds for migrant birds.

Extensive studies have since showed that the bay is already suffering serious environmental problems due to pollution from the city and industry. Large-scale field experiments have since demonstrated that the gates could be used to change the water flow in the bay, to help rather than damage the ecology. This has also been discussed in Venice.

In 2002, the scheme restarted when a consortium of international banks agreed to support completion of the flood defence project. A public consultation exercise on the environmental aspects of the scheme resulted in both an improved feasibility study and increased local support for the barrier. The barrier should be completed in five to seven years.
Debates about the barrier

The key debates around the barrier scheme concern the possible impacts on the water quality and ecology of the lagoon and the cost-effectiveness of the scheme. Some uncertainty prevails.

ONE of the most serious political challenges to the MOSE scheme has come from environmentalists and their scientific supporters, who believe that the gates will have a very damaging effect on the lagoon. MOSE is now underway, but the questions still come.

HOW OFTEN WILL THEY HAVE TO CLOSE?
At present, the barrier designers predict that the gates will operate an average of five times a year. As storms tend to occur in winter, most of these closures will be concentrated in a few months. The gates may stay closed for several tidal cycles when the storm surge is followed by echoing seiches.

ARE THESE ESTIMATES RELIABLE?
The opponents argue that predictions of how often the gates would operate are unrealistically optimistic, as global environmental change is expected to bring higher sea levels may increase future storminess.

HOW WILL THE LAGOON BE AFFECTED?
The basic argument of opponents is that, when the floodgates are closed, the lagoon will become a closed basin, cut off from the beneficial effects of tidal flushing. The lagoon will also be cut off from sediment exchange during a storm. Although we still do not know enough about the current role of storms in the net sediment transport for this system, it is possible that the barrier closure could have a positive effect on reducing sediment export from the lagoon.

WHAT ABOUT THE WATER QUALITY?
Without daily tidal flushing, ecologists fear that the water in the lagoon will stagnate and bottle up pollutants and nutrients. Fish and other species could suffer, and the algal blooms that plague the lagoon in the 1980s could return. The counter-argument is that flushing will occur very quickly once the gates re-open – recent studies have shown that much more water is exchanged between sea and lagoon on each tide than was previously thought.

COULD THE GATES ACTUALLY HELP WATER QUALITY?
Some scientists and engineers have even proposed that the barriers could be operated, when not needed for flood control, to simulate flushing in the lagoon. By opening and closing the gates in sequence, for example, favourable water circulation patterns could be generated within the lagoon to aid flushing. However, it is also recommended that a correct solution is, after all, to tackle the problems of water quality and pollution at source, such as providing a sewage treatment system for Venice, and not to look to the sea to solve them.

“What effect will the breakwaters have?
Some scientists claim that it is not the barriers that present the problem, but the lunate breakwaters – their effect on dissipating the inflow of the sea may be fairly marginal plus they could create additional sediment budget complications.

AREN’T THERE ANY OTHER SOLUTIONS?
Many other barrier concepts have been proposed over the years, with varying degrees of professional credibility and feasibility testing. They include placing a number of smaller flood barriers at the entrance to the main island canals; installing inflatable rubber tubes at the inlets; and parking old tankers filled with water at the bottom of inlets instead of the fixed gates. Other ideas involve a combination of engineering and socio-economic reorganisation, notably the proposal to move the passenger port to outside the Lido inlet, which would allow greater flexibility in re-dimensioning the inlets.

ISN’T THERE A BETTER WAY OF SPENDING ALL THIS MONEY?
Some opponents argue that the money spent on the barriers would be better spent on the other diffuse and restoration measures described in the last chapter, and that these ‘alternative’ measures will be enough to protect the city. However, careful analyses and computer simulations show that the diffuse measures would not have a significant effect on high waters, nor would their combined effect reduce levels by more than a few centimetres. They certainly could not provide the protection needed to cope with a storm surge like that of 1966.

While not all scientists are confident that the radical design chosen for the barriers is the right one, most are convinced that, if flood protection is the immediate priority, then flood barriers must be built now. For them, the barrier is the only way of protecting the city and lagoon from future floods. Alongside this, the lagoon will continue to become a bay despite the barriers – so other works are needed to combat the erosion and associated ecological problems.

Left A prototype single gate was tested near the Lido inlet – many people feared that these red towers were a permanent feature, and there were huge protests when the prototype was first seen in Venice
A summary of interventions

The scale of the projects underway to solve the ‘Venice problem’ is staggering. Their development needs careful coordination, as each will affect the other.

HIGH waters and tides, erosion and pollution, physical and socio-economic deterioration – the many risks and problems that face the Venice lagoon are intricately bound together. While each requires its own tailored solution, the problem can only be solved if it is tackled as a whole.

Scientists and engineers are dealing with many layers of uncertainty about the semi-natural system and the measures proposed to modify it. There is much that is not known, much to study, and each element of the chosen approach must remain flexible, ready to respond and adapt to new knowledge. Meanwhile, the mobile barrier and other interventions are proceeding, from feasibility to planning and final execution, always under constant review by all parties.

The success of the interventions will be measured not just in technical terms, but also in terms of the wishes of many others. These include people who live and work in the city, those who depend on the lagoon’s industry and port, those who visit the city and those who treasure the lagoon’s ecosystems. All have a stake in Venice’s future.

Few projects, least of all those that involve complex environmental systems, have the benefit of perfect certainty and complete knowledge, but decisions still need to be made and acted on. This is especially so for large-scale projects. But such projects do provide an opportunity to learn: from actual impacts as well as during construction, at different phases before the project is completed. Protecting the city from flooding is urgent. The barrier is not the final solution, but it buys the city time.

“If I had to choose between the Port or Venice, I would choose Venice”
Claudio Boniccioli, former President of the Venice Port Authority

CHAPTER 5 SUMMARY

- To protect against extreme flooding, construction has begun for the MOSE scheme of mobile barriers and breakwaters at the lagoon inlets
- Further measures are needed to reverse the degradation of the lagoon system, to complement and mitigate the negative impacts of the barrier system
- Venice can benefit from experience gained in reducing flood risk in other places, notably flexibility during implementation, institutional rigour and unexpected benefits/adaptations of the system
- This is a new phase for science in Venice, where some old questions are sharpened by implementation of the barriers and many new questions arise
- The long-term options for Venice will need to be considered in the context of uncertainty over future global environmental change
Futures

“A future that we would like to think has no end”

Bruno Dolcetta, President, Insula SpA

TO most people, a world without Venice is unthinkable, but as the previous chapters have shown, saving the city is a daunting task. It needs the concerted efforts of everyone – politicians, scientists and engineers, every citizen and the international community – to succeed. There are many possible futures for Venice, serving different interests and rival demands, which must be made explicit, prioritised and reconciled. Good science is the bedrock for any lasting solution, but in the end it is up to the people who live in Venice – and also all who love it – to answer the question, ‘what sort of Venice do we want?’

THIS FINAL CHAPTER LOOKS AT
■ THE UNCERTAINTIES THAT FACE THE DECISION-MAKERS
■ THE ROLE OF SCIENCE IN MOVING FORWARDS
■ WHAT THE WORLD CAN LEARN FROM VENICE
■ WHAT CHOICES ARE AVAILABLE

Left: St Mark’s Piazzetta, with the landmark statues of St Mark and St Theodore, flanks the open lagoon.
Venice and global warming

Climate change may pose the most serious threat to the long-term survival of Venice as sea level continues to rise.

There is substantial agreement among international scientists that human-induced climate change is a reality, and that it will lead to increases in average sea level and changing weather patterns. Currently available estimates of future changes are mainly global averages and, to date, there is little agreement on the rate and scale of sea-level rise on a regional or local level. In addition to sea level change, regional weather patterns are being affected and in Venice this could mean changes to the intensity and frequency of winds, surges, rainfall and indeed extreme events.

These uncertainties are bound to continue but may be reduced as we develop a better understanding of how the world’s climate systems work, based on detailed studies of present climate, analyses of past climate conditions and improved simulation of future scenarios. The association between observed, measured changes and human-induced factors is still tenuous – because climate and sea level are both inherently variable and because there is a time lag between cause and effect of climate processes. We have less than a hundred years of measurements since industrial activities and pollution levels reached a globally significant level.

Climate scientists liaising through the United Nations’ International Panel on Climate Change (IPCC) show that global sea level rise could be anywhere between eight and 88cm by 2100. The IPCC is now making a special effort to establish the likelihood of the various levels within that wide range of possibilities. Their predictions are based on data up to 1998, but more recent measurements of glacial melting already question some of the scientific assumptions used in the general models. Others challenge the economic assumptions about industrial development and the associated amount of atmospheric emissions. So the range of possibilities to plan for is very wide.

For Venice is in the region of 12.6–70cm by 2100, according to a broad literature review. Besides the general sea level rise and the continuing role of subsidence, it is imperative to better understand the local conditions that affect not only sea level rise but weather patterns. Changes in the frequency and magnitude of storm surges that cause flooding in Venice is an expected consequence of climate change – but in Venice no trend has emerged yet. Storms could become more frequent and/or stronger, or fewer but more intense.

Associated with this, Venice is constantly improving its ability to predict high waters with greater accuracy on timescales of hours and days. Two models are used – one based on a statistical approach, which means that the model tells its operator the likely water level in response to data from weather systems moving in the direction of the city, based on the historical correlation of certain winds and observed water levels in Venice. The other approach is deterministic – by setting up a model of what is known about the many parameters affecting tide levels, data for each of these is fed into the model, which then calculates the expected water level on the basis of known interrelationships between the parameters. These systems are crucial to the success of the barrier management scheme.

**LOCAL UNCERTAINTIES**

At a local level, uncertainty is even greater, although the positive link between average sea level and flooding frequency has already been made (see Chapter 3). The possible sea level rise for Venice is in the region of 12.6–70cm by 2100, according to a broad literature review. Besides the general sea level rise and the continuing role of subsidence, it is imperative to better understand the local conditions that affect not only sea level rise but weather patterns. Changes in the frequency and magnitude of storm surges that cause flooding in Venice is an expected consequence of climate change – but in Venice no trend has emerged yet. Storms could become more frequent and/or stronger, or fewer but more intense.

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**WIDER CONCERNS**

Mobile barriers may be able to protect Venice from extreme floods, but much of the northern Adriatic coastline is vulnerable to permanent flooding. Venice is enormously privileged – less famous places, lacking its high international profile, will probably not be helped.
Science and uncertainty

In predicting and adapting to the future of the lagoon we have to accept uncertainty as a reality that must be managed.

IT is unrealistic to expect science to provide simple, clear answers about such a complex, dynamic system as the Venice lagoon – partly because scientists do not know enough about how the lagoon system works. There is a huge amount of work to do to understand key physical dynamics, how various physical and biological components interact, let alone to predict how their relationships will change once the barrier and other restoration and defence elements are in place. Each change will ripple through the system, affecting all the other factors. Adaptation takes time.

The challenge is an exciting one, with implications well beyond Venice, and well beyond science. The Venice lagoon is a natural laboratory for studying the impacts of global, as well as local, changes on a coastal ecosystem and the lives of its people. Even after more than 35 years of intensive research, theoretical advances and implementation of extensive safeguarding measures, the open questions regarding the Venice lagoon system have changed little – as our knowledge deepens, so does the detail required.

THINKING BEYOND THE BARRIER

The barriers are designed to protect Venice from flood surges of more than 110cm above the reference water level. The calculated closure scenarios incorporate a sea level rise of 16–25cm, which would bring the expected number of annual closures from seven to 39 times. The barrier scheme’s Environmental Impact Study stated that a 50cm increase in sea level was not considered, as it would be catastrophic not just for Venice but for the entire world. The barrier designer’s cost-benefit analysis gives the project an expected lifetime of 100 years or less. Thus the mobile barriers are not a complete or final solution, but they could save Venice some more time. If all goes well, and the fears for the lagoon’s ecology are not realised, the barrier will not significantly alter the basic character of the lagoon during its operating years. But the city will continue to sink and water levels will continue to rise.

RADICAL IDEAS?

In the 1970s a project investigated the viability of raising Venice, building by building, out of harm’s way – by injecting materials underground to push it upwards. A trial on one of the small islands in the lagoon, Poveglia, revealed the heterogeneously distributed and highly variable ground layers beneath Venice and the instabilities that could be caused by differing responses to the injections within a single building or even adjacent ones. Recently the concept has re-emerged in a far more sophisticated and technologically advanced form.

The injection of sea water is being proposed at a depth of 300–500m via a series of wells placed in a 5-km radius around Venice. The aim, this time, is to uniformly raise a large area of the lagoon and the potential is a gain in height of 30cm relative to mean sea level. It will take a few more years to investigate the feasibility in greater detail – particularly as the geological composition below Venice and its lagoon and distribution of different types of soil down to nearly 1km from the surface has presently only been characterised in a couple of points. Even in the event of promising indications, the technique must first be tested in a pilot well. If it works, Venice could have several more decades in its fight against sea level rise and increasingly frequent ‘chronic’ flooding.

Alternatively, Venice could look to the Dutch example in the Eastern Scheldt, where an area was permanently closed off from the sea and transformed from a saline system to freshwater. Aside from the biodiversity implications of losing many plant, invertebrate, fish and bird species, pollution control would be a major issue – including a reduction in contaminating inputs from the watershed. Equally essential would be the implementation of a complete sewage collection and treatment system for the historical centre and other inhabited areas of the lagoon.

At the opposite extreme is the option to accept the forces of nature and let the lagoon develop naturally into a marine bay, creating other, different habitats, and essentially relinquishing the city to the waves.

“If there is one thing that researchers do agree on, it is that the gates are not the sole solution.”

The Economist, September 2003

Pierpaolo Campostrini, Director, CORILA

“The lagoon system and its dynamics represent the perfect laboratory to develop an approach in which scientific, technological and economic factors interact and influence each other. If we can find a solution to our problems in Venice then it might be possible to apply that solution elsewhere in the world”
What future does Venice want?

Tackling complex environmental problems is not only a matter of finding scientific and technical solutions. It is also important that people have the political will to solve them, and the financial means to do so.

IN nature, lagoons are ephemeral, but in the history of Venice, man has actively maintained the stability of the system and its ‘natural’ dynamics. The environment and culture of Venice and its lagoon have evolved and maintained each other for more than ten centuries, and they will always have to be managed in some way. The question is, how is it best managed, and for whom?

Venice excites huge emotions. Each interest group sees the city and lagoon in different ways, valuing some attributes above others. It is perfectly possible to make deliberate choices about the direction to go in – whether, at its most radical, to return the lagoon to the sea (or to land), letting nature finally take its course, or to take the necessary measures to maintain the precarious balance finally take its course, or to take the necessary measures to maintain the precarious balance.

The various institutional roles are outlined in the Appendix – the Venetian district is characterised by a large number of authorities with overlapping competences (many of which possess the power of veto) resulting in a substantially weak system with divided authority and restricted impact. Scientists therefore have an interest in making people aware of the threat and in working across disciplines, they can be called essential. Further work is necessary to properly assess the role of restoration projects as part of the final equation. But environmental problems exacerbated by market distortions caused by mass tourism – Venetians are deserting their city. How will they be persuaded to return? Rebuilding the city fabric, making it fit for the 21st century – the essential infrastructural world, restoring abandoned buildings – could all make it worthwhile. Policy measures are needed to stimulate traditional and promote traditional building techniques for the demonstration of the feasibility of traditional building techniques for the restoration of popular housing in Venice. Marghera, Venice: full of tourists right sea walls at the Lido.

FOR TRADE, INDUSTRY AND AGRICULTURE?

Each has been targeted as villains in Venice’s story, and there are increasingly tight restrictions on their waste, run-off and emissions. Time bombs from the past still rest in the sediments of the lagoon as well as the many hectares of abandoned industrial areas earmarked for remediation measures in Marghera. But the industries that cluster round the port are vital parts of the economy, bringing wealth to the region and employing thousands of people. To what extent must Venice learn to live alongside these economically indispensable sectors? How much can the lagoon absorb without further damage? Would an offshore oil terminal reduce the risk of tanker pollution? Can alterations be made to the burgeoning growth in passenger traffic aboard gigantic cruise liners that pass right through the heart of the city and deliver yet more ‘bite and run’ tourists, as they are now called?

VENETIANS!

With worsening flooding, structural decay and pollution, matched by increasing costs of living and buildings maintenance – problems exacerbated by market distortions caused by mass tourism – Venetians are deserting their city. How will they be persuaded to return? Rebuilding the city fabric, making it fit for the 21st century – the essential infrastructural world, restoring abandoned buildings – could all make it worthwhile. Policy measures are needed to stimulate traditional and promote traditional building techniques for the demonstration of the feasibility of traditional building techniques for the restoration of popular housing in Venice. Marghera, Venice: full of tourists right sea walls at the Lido.

FOR THE WORLD! Venice is a UNESCO World Heritage Site: people all over the world feel they have a stake in its future, too. But does that mean Venice is obliged to allow itself to be consumed by tourism, and are tourists merely supporting the preservation of a fossil? A review of the criteria that put Venice on the list of World Heritage Sites carries some important reminders – in addition to Venice’s unmatched artistic, architectural and cultural development and influence around the world, it is an outstanding example of wetland biodiversity and “symbolises the victorious struggle of mankind against the elements, and the mastery men and women have imposed on hostile nature”.

Venice has the potential to be a powerful case study in sustainable social and economic development, leading the world in learning to live with natural systems in more harmonious ways, rather than trying to dominate them. The scientific community recognises that the answers they can provide are only part of the final equation. But theirs remains a vital voice.

FOR NATURE?

Tackling complex environmental problems is not only a matter of finding scientific and technical solutions. It is also important that people have the political will to solve them, and the financial means to do so.

The Science of Saving Venice

Foreword

Dr Roberto Frassetto, founder
CNR Institute for the Study of Large Masses

Futures

San Giobbe housing project. A Venice in Peril Fund initiative to demonstrate the feasibility of traditional building techniques for the restoration of popular housing in Venice. Marghera, Venice: full of tourists right sea walls at the Lido.

“It is a delicate task to get people to work together at the bottom of the pyramid, where the real work gets done!”

For the Study of Large Masses

“Venice is one of the most consistent and continuous examples of permanent urban planning, affecting both settlement and environment known to humanity.”

CHAPTER 6 SUMMARY

- Human-induced climate change poses one of the biggest long-term threats to the survival of Venice – sea level could rise locally by at least 8cm and as much as 70cm by 2100.
- Predicting sea level rise is extremely complex and there is much uncertainty regarding the scale of impact it will have, also depending on adaptation and mitigation measures.
- Radical ideas for saving the city include raising the ground level by up to 30cm.
- The future health and survival of the city and lagoon depend on creating a balance between the needs of the environment, industry, agriculture, tourism and the Venetians.
- Scientists need to work better among themselves as well as to support greater stakeholder interaction if sustainable policies are to be developed.
The Science of Saving Venice

During Venice's time as a Republic (607–1797), there were carefully targeted and scientifically applied laws for the lagoon and mainland domains. This attention dwindled from the 19th century onwards and consequently the lagoon's defining features such as the dome of the lagoon began to diminish. Only following the 1968 Venice Centennial did the state make provision for the special characteristics of the lagoon and its inescapability from safeguarding measures for the unique city.

While ordinary laws set the duties of the State and local authorities, to regulate the management the Special Law of 1973 established a new institutional framework for the safeguarding and management of the lagoon ecosystem, against the backdrop of Venice's cucurrial administration, including the President of the Veneto-Water Authority (Secretary), the Minister for Infrastructure, the Minister for the Environment, the Minister of Cultural Heritage and Activities and Tourism, the Minister of Navigation, the Minister of Universities and Scientific and Technological Research, the President of the Veneto Region, the Mayor of Venice, the Mayor of Chioggia and two resident representatives from the Veneto regional authorities bordering the lagoon.

The first Special Law (1973) established responsibilities among the various administrations, including the President of the Veneto Regional administration and those of the Venice and Chioggia municipalities for safeguarding strategies and measures. Its main objectives and areas of intervention were:

- Reduction of pollution, especially from the drainage basin. The city councils of Venice and the town of Chioggia at the southern end of the lagoon are responsible for urban conservation and maintenance measures, as well as activities aimed at promoting socio-economic development.
- Coastsal defences; guarantees of the hydraulic and hydrogeological equilibrium;
- Protection of the hydraulic and hydrogeological equilibrium;
- Regulation of watercourses (natural and artificial); and
- Pollution protection works.

The second Special Law (1984) added further responsibilities for the safeguarding and restoration of the hydrogeological balance in the lagoon. The plan is two-pronged: The first prong relates to implementing measures designed to safeguard Venice's water quality, via theVeneto-Water Authority and the New Venice Consortium. The second prong aims at improving the environmental quality of the lagoon through a series of interventions that tackle the factors causing the deterioration of the lagoon's ecosystem and that also reconstruct and maintain the natural environment of the lagoon.

The Province of Venice is responsible for the abatement and control of the implementation of all measures to safeguard Venice and the lagoon, especially how to divide the budget. The committee is chaired by the President of the Council of Ministers and includes representatives from the Ministry of Environment, the Ministry of Cultural Heritage and Activities and Tourism, the Ministry of Navigation, the Ministry of Universities and Scientific and Technological Research, the President of the Veneto Region, the Mayor of Venice, the Mayor of Chioggia and two resident representatives from the Veneto regional authorities bordering the lagoon.

Magistrato alle Acque (MAV) – Venice Water Authority

The MAV is the Technical Authority and Transport with direct and primary responsibility for implementing the protection of a large area spread across a number of regions (Veneto, Friuli and Lagoon). It has established a project, not the date back to an origo of the Veneto Region of the same name founded in 1500. MAV duties cover five river catchments (Adige, Brenta, Bacchiglione, Piave, Livenza, Tagliamento), a small catchment area (Fiume), and the lagoons of Venice, Marano, and Grado. With regard to Venice's lagoon, MAV carries out systematic monitoring activities in order to ensure the running and execution of safeguarding measures via Consorzio Venezia Nuova (CVN). A few technical offices have remained with MAV, notably the Air Pollution Service, which monitors pollution in terms of air and water quality according to a series of physical-chemical characteristics as well as monitoring and controlling tourism to assisting young couples to set up a working group in 1999 to review the Environmental Impact Study of the Mestre and Marghera. (About nine other municipalities (Veneto municipality) is also part of the Provincial Administration does not participate in regional, national or supranational consultative bodies, although it oversees certain key elements of Veneto natural resources, along with about 40 other municipalities within its domain. It has some land use management, environmental protection and restoration, monitoring and controlling tourism to assisting young couples to set up a working group in 1999 to review the Environmental Impact Study of the Mangiarotti (pending approval of the Safeguarding Project) and for the integrated management of canal and estuary systems. MAV has a long-term role in the management of the Venice lagoon falls within the domain of the Venice Metropolitan Committee (www.comune.venezia.it) which is also part of the Provincial Administration does not participate in regional, national or supranational consultative bodies, although it oversees certain key elements of Veneto natural resources, along with about 40 other municipalities within its domain. 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The Science of Saving Venice

The principal thematic areas thereby provide decision support information to manage research on the Venice Lagoon and its environment. The Hydrographic Office has been operating in the area of tides and atmospheric conditions since 1946 as the National Centre of Climatology. It runs a programme to integrate tide gauge stations for the systematic evaluation of environmental damage.

* Weather forecasting, monitoring and statistical analysis; for instance, meteorological parameters: air pressure, humidity, wind velocity and direction, waves and air temperature.
* Environmental protection and monitoring; can be summarised as:
  * protection of water bodies, in particular the lagoon waterways, which are of strategic importance, in cooperation with water management, Enel.Hydro (electricity), Italgas (gas) and Telecom Italy (telephone), Inraco (water), local police (security) and along the Adriatic coast. All stations measure sea level and some also collect meteorological parameters: air pressure, temperature, humidity, wind velocity and waves; data availability for the public is not limited to the Italian territory, but also includes the Adriatic Sea and the lagoon system.

Concerning the Venetian Lagoon System, UNESCO’s Venice office is the focal point for architecture, history, design, and urban planning. It works as part of the international association of architectural and cultural heritage institutions and also partners with the Superintendencies of Antiquities and Fine Arts to provide a forum for discussion. It brought together experts from many countries to collect and channel contributions to preserve and restore Venice. Over the years, the International Scientific Committee (CSC) has remained closely with the Superintendencies of Monuments, and Galerie des Offices through UNESCO to identify and address priority needs. Since 1969, they have funded the restoration of more than 10 monuments and 1,000 works of art, provided laboratory equipment and scientific expertise, sponsored research and conferences, and awarded innumerable grants for craftsmen, restorers and conservators. In the past, UNESCO operated courses in Venice. Expenditure by the Private Fund for the Year 2000 was well in excess of 5 million (about £3 million).


The trigger for this project was Venice as the focus for discussion of state-of-the-art coastal, estuarine and near-shore processes, landforms and ecosystems. The Unit’s research is closely aligned with the Superintendencies of Antiquities and Fine Arts to provide a forum for discussion. It brought together outstanding figures from the humanities and the sciences, and the Unit also supports special research projects that concern Venice and the Venetian lagoon. The Cambridge Coastal Research Unit (CCRU) is a research centre at the University of Cambridge. It carries out research on the physics, biology and chemistry of coastal waters, and the ways in which they interact with the land. The Unit is part of the international association of coastal and marine scientists and also partners with the Superintendencies of Antiquities and Fine Arts. It works as part of the international association of architectural and cultural heritage institutions, UNESCO’s Venice office is the focal point for architecture, history, design, and urban planning. It works as part of the international association of architectural and cultural heritage institutions and also partners with the Superintendencies of Antiquities and Fine Arts to provide a forum for discussion. It brought together experts from many countries to collect and channel contributions to preserve and restore Venice. Over the years, the International Scientific Committee (CSC) has remained closely with the Superintendencies of Monuments, and Galerie des Offices through UNESCO to identify and address priority needs. Since 1969, they have funded the restoration of more than 10 monuments and 1,000 works of art, provided laboratory equipment and scientific expertise, sponsored research and conferences, and awarded innumerable grants for craftsmen, restorers and conservators. In the past, UNESCO operated courses in Venice. Expenditure by the Private Fund for the Year 2000 was well in excess of 5 million (about £3 million).

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The college was endowed by some of the first major work of modern architecture in the Cambridge, and is set in 40-acre grounds. As the multidisciplinary community for the study of the educational venture – Churchill College. The foundations and benefactors, which enabled Sir Wiston Churchill to launch his memorable educational venture – Churchill College. The college was created as an international multidisciplinary community for the sciences and the humanities in order to meet the national need for scientists and technologists, and to forge links with industry. It is one of 31 colleges of the University of Cambridge, and is set in 40-acre grounds. As the first modern work of modern architecture for Venice city and islands, usually during the winter months. It has been a feature of Venice for centuries but incidents of high water are becoming increasingly common as average sea level slowly drains into aquifers. To tap the soil and trees – refills the aquifer; flowing into recharge areas - land covered like) deposits or consolidated rocks. Water aquifers consist either of unconsolidated (soil-stores water, like a giant underground sponge. Water becomes starved of oxygen, producing Eutrophic algae bloom. These are synthetic chemicals, particularly pesticides and plastics, are suspected endocrine disruptors. They are typically persistent in the ecosystems and depend on each other, either directly or indirectly. Ecosystems are dynamic: their biodiversity and their characteristics change over time.

Endocrine disruptors are synthetic chemicals that when absorbed into the body displace normal hormones, and in the sea, disrupt the balance of the entire aquatic life. Other factors, including the moon, winds and temperatures, affect the amount of water that enters and leaves the lagoon. The wearing away of land, soil or built structure by wave action within the inner canals. Wave action, which is a key factor in defining the lagoon's physical form and structure, form, and the arrangement of rocks and landforms. In geology, the structure, form, and the arrangement of rocks and landforms. In the case of a lagoon, its physical form is influenced by the current or tide, in order to expand the duration of a flood episode. Nutrients Elements or compounds essential for animal and plant growth. Major plant nutrients are phosphorus and nitrogen. In areas with low nitrogen levels, there may be a nutrient imbalance and anoxia.

Sediment There are various classes of sediment. Sediment can be transported by wind, water, or ice. Sediment can also be transported by water, such as a river or a storm surge. The Sirocco's duration may be a half day or many days. Sirocco: A hot, dry dust-laden wind that blows from the Sahara Desert north or northwest across continents. In some parts of the world, it may bring as much as 100mm of rainfall. One meteorological theory states that the movement of motor boats creates the most destructive wave action within the inner canals.

Mussel beds These are the islets within the historical centre of Venice and the term is used to refer to a localised freshwater system strategy which involves raising the perimeter of individual islands and waterways. The key is to create open surfaces and valves on the interior. Small-scale modular barriers are deployed, and the entrances of the inner canals connected to the individual islet. This approach has been implemented at Malamocco where low-lying areas are protected from the floods. The San Marco islet and the island of Burano.

Jetty A protective structure of stone or concrete extending into the sea to protect harbours, shores and beaches. It provides protection for marinas, harbours, and coastal areas from the effects of wave action. It may be constructed as a breakwater to reduce wave energy at a location. It is used to protect harbours, and to create a sheltered area for boats. Jetty's are often used as a part of a coastal defence system.
In nature conservation terms, it refers to the use of a natural resource in a way that it can be restored and maintained in a natural state. Today, it applies to managing and conserving the environment’s natural qualities. To do this, man-made structures, such as polders, are sometimes necessary to protect the environment from natural processes. Today, it applies to managing and conserving the environment’s natural qualities.

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