From Natural Phenomena to Disaster
The Increasing Flood Risks to Built Heritage in the Modern World

Randolph Langenbach

Vom Naturphänomen zur Katastrophe. Steigende Hochwasserrisiken für das bauliche Erbe in der modernen Welt
Die Hochwasserschäden im Indus-Tal, im Kaschmir-Tal und in anderen Schwemmlandebenen der Erde zeigen, dass menschliche Siedlungstätigkeit seit Jahrtausenden sich notwendigerweise in diesen fruchtbaren Flussgebieten entwickelt hat. Bemühungen zur Risikovorsorge müssen diese Tatsache anerkennen, um Alternativen zu Umsiedlungsprogrammen zu entwickeln, die die Bevölkerung vom Land und der Lebensweise ihrer Vorfahren trennen. In diesem Prozess sollten historische Baustrukturen und Siedlungen (und im Falle des Indus-Tals archäologische Stätten der Bronzezeit) als Bestandteile lebendiger Kulturen aufgefasst und bewahrt werden. Angesichts zunehmender Hochwassergefahren stellt diese Situation besondere Herausforderungen an die Vorsorge.

Der folgende Beitrag geht einigen Erkenntnissen nach, die von der intuitiven Einschätzung abweichen und für die Bewahrung des historischen Erbes von Bedeutung sein können. So zeigte sich etwa bei Überschwemmungen im Mittleren Westen der USA im Jahr 1993, als einige Gegenden bis zu zwei Monate unter Wasser standen, dass die historischen Bauwerke viel weniger schadensanfällig waren als jüngere Häuser, die seit der Einführung moderner Sperrholz- und Verbundbaustoffe errichtet wurden. Auch das Beispiel von Venedig, wo wertvolle Baudenkmale ständig im Wasser stehen und häufig den Überschwemmungen des aqua alta ausgesetzt sind, liefert uns wertvolle Lehren zur Resilienz. Der Aufsatz konzentriert sich auf unterschiedliche Konzepte zur vorbeugenden Schadensreduzierung: einerseits für Bereiche, die dem Angriff der Wellen an Küsten oder in schnell durchströmten Überschwemmungsgebieten ausgesetzt sind, andererseits für Überschwemmungsgebiete ohne Strömungsangriffe, mit Beispielen von den Küsten Mississippis und New Orleans, und schließlich für die großen indonesischen und japanischen Tsunamis.

Introduction

In recent years, there has been an increasing interest in the role of culture and cultural heritage in disaster response and recovery. This comes at a time when a number of recent disasters have demonstrated that the promised benefits of modern technologies and construction systems have failed to deliver the resilience that had been expected of them. This has been true for many types of risks, including floods. Yet, heritage structures and traditional cultures can teach today's scientists and artists alike a great deal about resilience and disaster recovery.

Over the past half-century, culture and hazard mitigation and disaster recovery have primarily been understood as the protection and restoration of heritage properties. The conventional wisdom has been that historic buildings – by comparison to contemporary construction – are vulnerable and need to be upgraded and protected. However, observations of recent disasters increasingly have shaken this presumption. People have begun to realize that in the modern era there is a lot we have forgotten, alongside of what we have learned.

There are certain hazards that we can design structures to resist, and others where saving lives is simply a matter of getting out of the way. For example, we design ordinary buildings for wind and, to some extent, for earthquakes, but rarely specifically for tornados or tsunamis. For these, the only effective life-saving strategy is an early warning system, and a chance for people to find a refuge or get out of harm's way.

Andaman Islands 2004

The difference between the handing down of knowledge in a traditional culture and conventional modern-day classroom education was tragically demonstrated in the Indian Ocean Tsunami of 2004. While almost a quarter of a million people on both sides of the ocean drowned, the indigenous people on the Andaman Islands off the coast of India, who continue to this day to live a life similar to that in the Stone Age, all survived the tsunami's onslaught of the sea which inundated their homes and wiped out their villages.

"They can smell the wind. They can gauge the depth of the sea with the sound of their oars. They have a sixth sense which we don't possess," said Ashish Roy, a local environmentalist and lawyer. NBC News reported that "government officials and anthropologists believe that their ancient knowledge of the movement of wind, sea and birds may have saved the five indigenous tribes." Ashish Roy has called on the courts to protect the tribes by working to reduce their contact with the outside world, so as to avoid the

Fig. 1: Mohenjo-Daro

destruction of their culture. It was this deep cultural heritage and tribal communication that so effectively protected their very existence.[1] A simple message had been handed down from parents to sons and daughters: "if the sea retreats, you do too". They took refuge by quickly climbing up the nearby hills on foot. It was this basic lifesaving message that was missing from the formal teachings found in modern schools in the countries around the Indian Ocean.[2]

Part of the reason for the need to focus on culture is a growing recognition that over the past several decades, an increasing number of well-intended disaster recovery and mitigation projects have ultimately failed because social and cultural elements were ignored. Ironically, this has most often occurred because external professional personnel involved in the recovery efforts were ignorant of the local culture – or failed to consider it as within the scope of their primary responsibilities.

Pakistan 2010

In August 2010, unusually heavy rains in northern Pakistan caused severe flooding along the Indus River that runs through the heart of Pakistan to the coast south of Karachi (See also the paper by F. Ubaid in this publication). The Indus Valley is a wide and relatively flat area, which historically had been subject to flooding on almost an annual basis – a phenomenon which was responsible for the fertility of this important agricultural plain – and thus a feature that resulted in human settlements dating back to the Bronze Age. In addition to the archeological excavations of the modern era, levees and dams have been constructed to control the floods, but the consequences of these actions have not all been positive, as the annual flooding had brought fertile soil into the fields, renewing their agricultural productivity.

People historically have settled in flood-prone areas, once mankind established agriculture, because the alluvial plains are an important source of food. In Pakistan's Indus Valley, the ancient heritage sites provide evidence of human settlements dating back thousands of years. In Makli, there are ancient Islamic monuments of extraordinary quality. These are located on a hill above the valley, and so were not flooded. The much more ancient site of nearby Mohenjo-Daro is one of the most famous pre-historic archeological sites in the world (Fig. 1). It is a Bronze Age settlement with evidence of an extraordinary population density – even reminiscent of a part of ancient Rome or modern-day London or Paris. It is believed to have been settled during historical time, between a very wet period and an oncoming dry period.

The archeological reconstructions show the scale of what had been there. One can see in Figure 1 that it was like a modern metropolis, yet the recent floods have also provided a warning of the modern vulnerability of such a site, particularly because the ancient construction was not of stone, which was not available near such a site in such a broad alluvial plane, but of mud, which, of course, was abundant.

Thus, the archeological excavations of the site have removed the time-honored protection of the overburden of soil that was deposited over the past four millennia, making the site vulnerable not so much to inundation itself, but to the consequences of nearby inundation. The original settlers knew best where to settle, so they picked a higher location within the broad valley, rather than on its edge, but the water from the flooding carries with it naturally occurring soluble salts from the ground into the earthen structures with the rising damp. These salts then crystallize on the now newly-exposed surfaces of the ruins, and this crystallization, known as efflorescence, can destroy the unfired or low-fired clay masonry that is now exposed to the atmosphere. (Fig. 1, right).

Fig. 2: Balhreji Village, adjacent to Mohenjo-Daro World Heritage site

Nearby, there are threats of a different kind, but which nevertheless have the potential of diminishing the heritage value of the archeological site, even while they directly affect the modern-era settlements that surround the heritage site. While on the UNESCO mission to report on the flood disaster's effects on cultural heritage, we visited several settlements outside of the designated historical zone. This is where modern changes to the level of floods may be a product of changes to the levees and barrages in the floodplain, which in the more usual high water seasons serve to prevent flooding, but when there is extraordinary rainfall, can accentuate the inundations.

While it is unknown how ancient these surrounding settlement locations are, the very nature of their mud and timber construction suggests that the buildings themselves are renewed and rebuilt frequently as a normal cultural process, while the lifestyle of these settlements nevertheless had a deeply historic quality. In addition to farmers, there were a number of pottery-producing shops and craftsmen. Interestingly, the pots being produced in the present on these modern potters' wheels were nearly identical to the ancient pottery in the nearby Mohenjo-Daro Museum (Fig. 2). It was this cultural continuity that provided evidence of the ancient heritage of these settlements – and also of their value as a seamless part of the UNESCO World Heritage site, in spite of the fact that they were not included in the designated protected area.

At the same time, the challenge of protection from floods while meeting the need for water for agriculture was demonstrated by the fact that holes had been cut through some of the levees that surrounded Mohenjo-Daro. These holes were made to irrigate the fields, but no gates had been built to prevent flood-waters from entering.

The 2010 floods, although historic in scale, did not inundate the central archeological site. However, this situation demonstrated one factor that is perhaps unique to flooding: mitigation against floods is not simply effective or ineffective, but may even be counter-effective. This contrasts with structural improvements to counteract wind damage or earthquake damage, where even a partial retrofit can often save lives. This phenomenon can be frustrating. For example, when a property is upgraded against earthquakes or hurricanes, it may suffer less damage without making it more likely that another nearby property would suffer more consequential damage. However, in a flood, a levee around one village can result in a rise in the level of the water, which can overtop other older levees. Thus the consequence of the building of levees can result in all the nearby levees being overtopped. It can then take weeks or months to drain the water from behind the levees.

This situation can also be affected by discretionary decisions – such as when barrages are opened or closed to protect settlements under their control, releasing or impounding water onto other towns or villages. What is interesting in the Mohenjo-Daro situation is that the levees around the heritage site, and those that were being proposed to add to improve the protection, in some cases were likely to put some of these actively occupied villages – with their deeply historical pottery-making crafts – at greater risk. These kinds of issues in flood management were pertinent also in the Mississippi River Valley flooding in 1993 in the USA Midwest, and even more dramatically twelve years later in New Orleans from Hurricane Katrina.

It is not always easy to determine what is best for the local residents in such situations, as not only their livelihoods, but also their autonomy, self-respect, and identity are connected to the land. The urge has often been to move them to safer ground, something that has been done in Pakistan and in the United States. One problem that has often not been adequately recognized or dealt with in a constructive way is the psychological and sociological impact of moving a population miles from their ancient settlements and the rich agricultural fields from which they gain their sustenance. This can strip them not only of their livelihoods, but also of the connection to the crafts from which they gain their independence and self-respect.

Flood control measures also can cause deterioration of the agriculture from a rise in saline concentrations in the soil, in addition to the loss of the annual new alluvium which rejuvenates the soils.

USA Midwest Floods 1993

Halfway around the world from Pakistan, in the American Midwest, as mentioned above, an unusual season of flooding occurred in 1993, with floods in some areas along the length of the great Mississippi River leaving parts of many cities and towns under water for as long as two months.

One such town, Ste. Genevieve, Missouri, a National Historic Site with houses dating back more than two centuries, was threatened with flood waters that rose 12 feet above normal flood stage. Ste. Genevieve is one of the French settlements, as the French settled this area of the continent all the way down to New Orleans. The town had become accustomed to periodic flooding, yet it did not have a complete system of protective levees. One woman interviewed in Ste. Genevieve who had been flooded out of her home six times was quoted in the news as saying "I'll go back to my house again. You put up new wallpaper, and get that smell of a new rug, and it's not so bad."[3]

In this case, the townspeople and the National Guard, with help from the Army Corps of Engineers, set to work, and over a million sandbags were filled and placed, as can be seen in Figure 3. It is interesting to compare this with similar actions undertaken in Serbia in 2014, which were still holding floodwaters back at the same time as the Dresden conference. In Ste. Genevieve, this was done along with other measures, as the waters slowly rose with the prediction that the floods would reach historic heights. This extraordinary emergency levee came within only inches of being overtopped, but it held, preventing the town center from being flooded. However, a number of houses were left outside of it, as they were too low and close to the river for the emergency wall to protect them. These included the historic buildings visible in Figure 3.

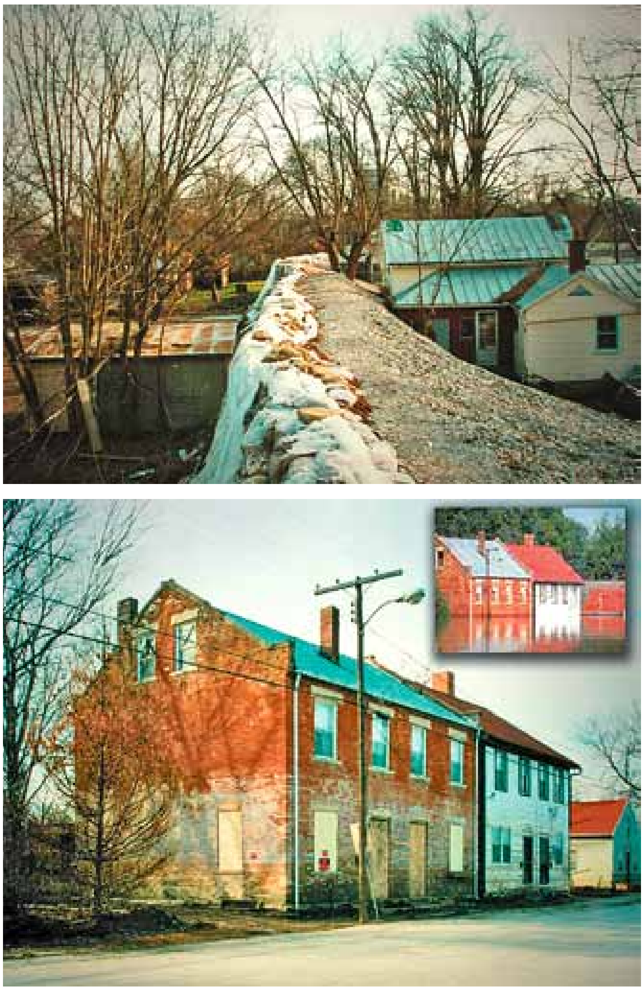

Fig. 3: Ste. Genevieve, Missouri, USA after the Great Midwest Floods of 1993. Above: emergency levee. Below: flooded historic houses outside of temporary levee

The story of Ste. Genevieve is interesting, as it provides evidence of a developed-world solution where large expenditures of funds are possible. A buyout plan was enacted to remove the houses that were on the lower floodplain outside of the levees, but the list of properties to be removed included 46 heritage houses. Interestingly, there was opposition to the buyout plan because people feared it would jeopardize the town getting a new levee at Federal Government expense. It turned out that the existence of recognized historic houses provided an opportunity to gain political support for the costly levee project. The opposition to the buyout ultimately prevailed, and the levee was constructed.

The Indus River in Pakistan and the Mississippi River in the United States have similar geographic characteris-

Fig. 4: Left and Centre: Historic church in Mississippi swept off foundations by Hurricane Katrina, right: A balloon frame wood house after the Johnstown Flood of 1889

tics. Both nourish and traverse two of the most important agricultural valleys in the world. Thus, the settlements in harm's way in both of these valleys were not only historically significant, but they continue to be necessary, in spite of modern motorized transportation. In the case of the Indus, archeological sites of early settlements date back to the Bronze Age, sites which have experienced periodic flooding now for four thousand years; and yet, the remains of these prehistoric settlements are still there.

From the standpoint of heritage structures in the American example, a potentially significant finding is that the historic houses have proven to be more resilient than the modern ones. This is for a simple reason: the modern era has introduced many building materials containing glues and products that are fabricated from wood chips, clad with paper, or otherwise subject to total destruction from sustained inundation. Traditional materials, which locally are primarily sawn timber but which also include masonry, can survive intact even though damaged. Interior plaster and electrical wiring have to be removed and replaced and mold often must be eradicated, but the building structures can be restored, with much of their heritage value preserved, at least on the exterior.

In Pakistan, where the Indus Valley agricultural village houses are largely constructed of unfired clay, the buildings are effectively recycled back into the ground by the water. Thus, the challenge is to determine how to reduce the risk of inundation, at least to lessen its frequency, so that multiple repeated rebuilding is not forced on populations over their lifespan. As mentioned above, the building of levees in one area can have the unfortunate consequence of causing the waters to rise higher in other areas. A balance is needed. This balance must include an acceptance of a certain amount of risk, as well as the government's acceptance of the need to provide assistance to allow people to rebuild their houses should they be destroyed in a flood that overtops the prior flood-mitigation efforts. As people around the world are confronted with global warming, the prediction of future flood levels from past events is fraught with uncertainty. FEMA (Federal Emergency Management Agency, an agency of the United States Department of Homeland Security) has approached this issue in some areas of identified elevated risk, by allowing a "one hit" approach to government assistance: insurance payouts are allowed once in an area, but not a second time.

One of the provisions under FEMA is that the areas under risk have to join FEMA's risk mitigation program in order to avail themselves of publicly available flood insurance. When they do, they have to go through mitigation procedures, which include raising the houses up to a level that is determined to be the flood elevation**.** More recently, after Hurricane Sandy struck the urbanized eastern seaboard area of the United States including New York City, the flood insurance program was reconceived. Hurricane Sandy (together with Hurricane Katrina) completely drained the program of its funding, and its ability to pay the claims, such that the Federal Government's General Fund had to be tapped. And, once U.S. Congress had to deal with the problem, they raised the premium costs for the insured. For many if not most of the insured, the premiums soared. The resulting political reaction forced Congress to reduce the rise in premiums, but the costs nevertheless are now considerably higher for the subsidized program.

One advantage in North America is that most of the population lives in wooden dwellings, which can be quite portable and capable of being moved. Of course, if the flood itself does the moving, the buildings are usually wrecked, and the advantage that wooden buildings provide in a relocation program becomes a disadvantage during a flood – particularly one with a strong current, because wooden buildings can float. The church in Figure 4 ended up a quarter mile down the road without a single pane of glass broken on the still-standing left side wall. It was interesting to see that "Do Not Destroy – Historical Building" was painted on it by advocates for its preservation, despite the condition it is in. I do not know if it was preserved and restored, but wooden stud-frame buildings, as this one is, demonstrate a remarkable resilience, as can be seen by this much earlier example washed downriver by a dam break in the famous Johnstown, Pennsylvania Flood of 1889 (Fig. 4).

From a loss-mitigation standpoint, buildings can also be constructed in ways to mitigate the effects of flooding, even where dry flood-proofing is impractical or too costly. "Wet flood proofing" is defined by the construction of the lower stories of structures out of materials that the flood does not destroy, which can be simply washed once the flood retreats. Candidates for this kind of mitigation are structures that are subject only to partial flooding by still, rather than rapidly moving, water. Wet flood proofing requires that the electrical, heating, kitchen or plumbing equipment of the house, (except for branch circuits) must all be kept above the flood level in the upper floors to avoid destruction. Also, the fabric of the structure is such that it is not degraded by water and can be cleaned, and is heavy and strong enough both to resist some hydrostatic pressure, even though the water is allowed to come into the structure, and to prevent the house from simply floating off of its foundation.

One may wonder then: why not design the buildings with water-tight doors and windows on the ground floor? However, if the structures are exposed to any significant rise in water level, the engineering requirements to resist the weight of such an amount of water on the exterior walls are large and thus impractical in terms of cost. This is why the concept of engineered wet flood proofing where flood waters are allowed into the building can prove to be practical.

Here then is a good opportunity to turn to the question of reinforced concrete – a construction type that has increasingly proven to be more vulnerable than originally expected in seismic zones. And yet, one cannot help but be impressed when looking across the landscape left by the 2004 Indian Ocean tsunami in Banda Aceh, Indonesia, with only a reinforced concrete frame mosque still standing amidst what is otherwise total devastation, having survived both the earthquake and the tsunami, despite being completely gutted by the inundation which swept away all the other structures (Fig. 5).[4]

Fig. 5: Banda Aceh Mosque, still standing after 2004 Tsunami

New Orleans 2005

Apropos to the discussion of waves, tsunamis and rapidly moving flood waters, Hurricane Katrina in 2005 and Hurricane Sandy in 2012 are the two most recent events in the United States that come most to mind. The 1993 Midwest Floods in the United States covered a vast area, but in many ways the coastal Hurricane Katrina was far more devastating because it affected larger urban areas and caused the displacement of a larger number of people.

Hurricane Katrina killed at least 1,833 people, damaged almost a quarter of a million homes, and caused the displacement of over one million people. This was the largest forced migration of people in the history of the country, except for the 1861–65 American Civil War – larger even than the approximately half a million that were displaced from over a much larger area and longer time period from the Dust Bowl of the 1930s. Tens of thousands of these people have never returned to New Orleans or the Louisiana coast.[5]

Katrina essentially came ashore over New Orleans, a city the size of Dresden, and flooded 80 % of it. The aftermath of this event was so large that there are now no fewer than three feature-length films on the human tragedy, as well as on the mistakes that were made in the management of the city's flood protection system.

Katrina was the anvil which really tested FEMA, and early on it became an embarrassment because both the State and Federal Governments were both ill prepared and overwhelmed by the scale of this disaster – while at the same time there were additional disaster management problems that stemmed from political differences. On top of this was overlaid the racial tensions that continue to brew just beneath the surface in the Southern states of the US, particularly in New Orleans. At the time of Katrina, New Orleans had an African American mayor.[6]

New Orleans is blessed with one of the most extensive and well-preserved collections of heritage properties and historic districts of any city in North America. All of this stems from the French rather than the English colonial heritage of the city, and of the whole Mississippi Valley. The central part of the North American continent originally had been settled by the French, but then ceded to Spain in 1762. France took it back in 1800, but then agreed to sell it for 15 million dollars to the United States following negotiations between

Fig. 6: New Orleans, extent of flooding after failures of the levees over the course of several days following the hurricane. The high-rise buildings in the city center can be seen way in the distance

Fig. 7: New Orleans Lower 9th Ward after levee break

Napoleon Bonaparte and Thomas Jefferson. With what then became known as the Louisiana Purchase, the size of the United States was doubled.

The French heritage is most conspicuous in what is still known as the French Quarter, which is the most famous neighborhood in New Orleans. Interestingly, the French Quarter did not flood. Again, like in Mohenjo-Daro, or Makli in Pakistan, people built the first settlement on high ground. Despite the subsidence of the ground under much of New Orleans from fresh water extraction, the French Quarter remains above sea level today. The levee along the edge of the Mississippi River at the French Quarter riverfront was never overtopped. In fact, the flooding of the rest of the later settlement areas of New Orleans didn't come from an overflowing of the Mississippi River. They came from the opposite side of the city. The hurricane created a rising tide of water like a tsunami, which came in from the ocean into the lakes that were on the rear side of the city, away from the French Quarter and the city center. While some of the levees were overtopped, many failed before the water had reached their crests. This happened, as will be explained more below, because of engineering shortcomings resulting from subsoil conditions that had not been properly accounted for in their construction.

The ironic lesson of the flooding both in New Orleans and in the Mid-West in 1993 along the Mississippi Valley is that a failure of flooding defenses can result in a worse situation than if there had been no levees at all. That is because the water is trapped behind the levee for days or weeks long after the flood stage of the river or the flood tide from the ocean have receded (Fig. 6). During this extended time in New Orleans, the people who sought refuge in the Superdome enclosed stadium couldn't leave, and it quickly became a health and sanitary disaster. Many others simply drowned. Some of those who sought to escape the flood by climbing into their attics had to knock holes through their roofs to escape as the water continued its rise, inundating their entire houses. If they did not have the tools or strength to do so, they drowned. Clearly the residents were unprepared for this, as the levees had been thought to be protective, and training for the possibility of their failure was conspicuously absent. This was not a situation of slowly rising water, but of a wave of water not unlike that caught on captivating home-made videos during the 2011 Tōhoku earthquake-caused tsunami in Japan.

The overtopping of an earthen levee is more dangerous than it may seem, particularly when an emergency spillway that can protect the rear side of the levee is missing. Any significant volume of water rushing over the top of a levee, which will happen at its lowest point, can quickly wash away the levee entirely to its foundation at that point, leading to a flooding of a neighborhood that is so fast that the houses are carried away and smashed. Many of the people who did not heed the warnings to leave drowned before they could escape.

In New Orleans, the protection against such a consequential levee breach is difficult because of the changing elevations that have resulted from the slow subsidence and differential settlement that had occurred over the whole area. Thus, the engineering and maintenance of these levees is extraordinarily important, particularly in the city where they are subsiding over time, such that the height of the levee gradually gets lower, and thus less effective against flooding, even if it was effective when it was first built (Fig. 7).

Even more profound than the differential settlement was the fact that the substrata on which the levees were built turned out to be unstable. After the water rose, but before it reached the top of the levee that protected the now infamous Lower 9th Ward, the whole levee slid on a natural layer of peat and sand. The resulting breach was so sudden that the wave of water carried the houses away, crushing them to kindling at the edges of the flooded area. On the historic preservation front, this even affected the house lived in by the famous jazz musician Fats Domino, who had to be helicoptered out as he was still in his house, with all of his now valued and historic collections when it was flooded to its roof.

On the macro scale, human action has stopped the natural alluvial recharging of this estuary, which had occurred on the alluvial fan at the intersection of the great Mississippi River with the Gulf of Mexico. Thus, the ground gradually subsided further and further below sea level. The biggest losses are of the bayous that had historically protected New Orleans and the smaller villages and towns from the sea. These have been destroyed by development, and also from the incursion of the salt water into the fresh water that had nourished the mangroves.

In addition, one of the features built in the 1960s that particularly aggravated this situation was an industrial shipping channel, dug so the ships didn't have to go around all of the switchbacks in the natural course of the Mississippi River as it traversed its alluvial fan at the entrance to the Gulf. This new shipping channel proved to be the undoing of New Orleans, simply because the flood waters could enter into the city without being arrested in their course by the ecologically important natural bayous. So severe was the continued destructive threat from this that after Hurricane Katrina, the decision was made to permanently block this channel.

A number of independent investigations have been carried out after the hurricane. Both FEMA and, in particular, the Army Corps of Engineers were criticized, and efforts were made to improve their future performance, sometimes by giving them more authority rather than less. What may be the most important lesson in dealing with future floods in Europe and other parts of the world is the need for an integrated single authority for all flood protection services. This is because of the unique feature of flood risks, where a weak link can destroy everything – even leading to a worse result than if there were no mitigation efforts at all. With multiple authorities and one independent project after another, the overall objective can be "lost in the forest because it is hidden by the trees". One may even say in this case, "where is Communism when you really need it?" This kind of "command and control governmental action" is not often embraced in the United States, but for flood control measures it may be exactly what is needed.

In closing, I return to describe two pre-industrial world examples of dealing with periodic flooding and living in a water-borne environment, illustrative of the influence of water and floods on the design of structures.

Mostar 2014

First, in Bosnia and Herzegovina in the City of Mostar, there is a famous bridge known as the *Stari Most*, or "Old Bridge," celebrated for its distinctive high 28-meter-wide load-bearing masonry arch design. At the time of its completion, it is believed to have been the widest span stone arch bridge in the world. This majestic bridge designed by Mimar Hayruddin, a student and apprentice of the famous Ottoman architect Mimar Sinan, had survived centuries of floods after its construction in the 16th century. Sadly, it fell as the result of human conflict in the Croatian-Bosnian war in 1993. It was subsequently rebuilt using its traditional load-bearing masonry construction with salvaged and newly quarried stone. The reconstruction was completed in 2004.

I had long known of this bridge, but had not thought of its design as having been shaped in part by the flood risk, until the 2014 floods in the Balkans flooded parts of Bosnia and Herzegovina, Serbia, and Croatia at the very time of the

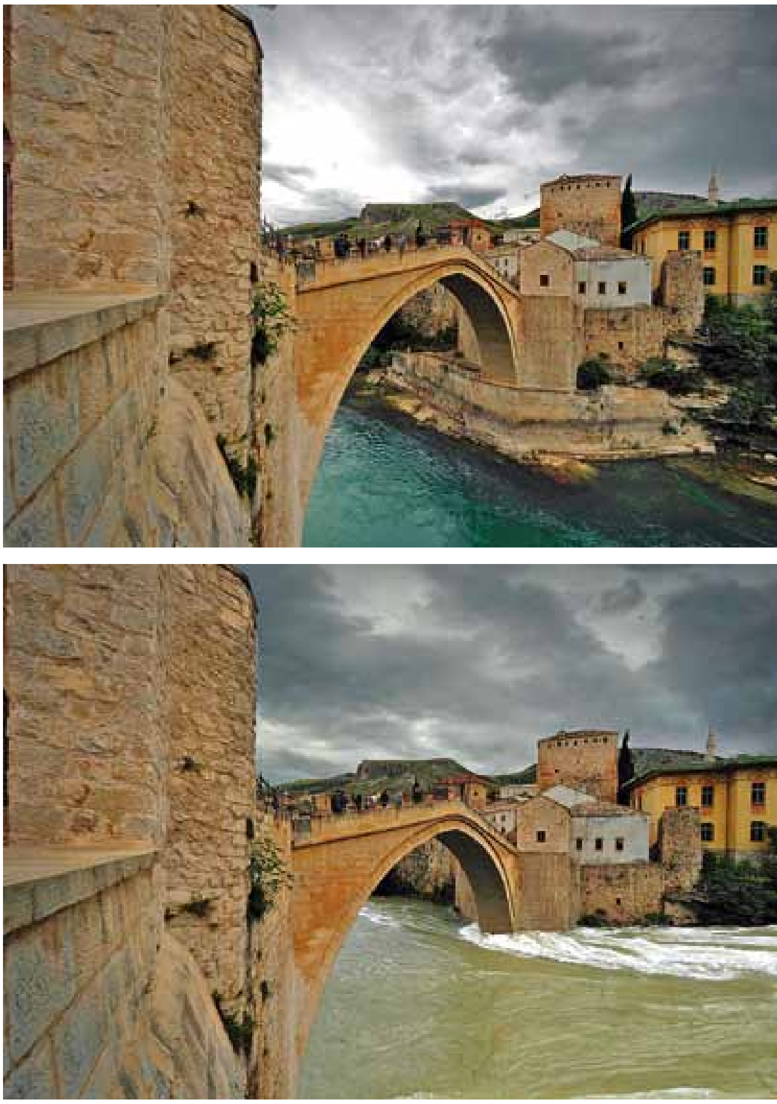

Fig. 8: Stari Most, Mostar, Bosnia and Herzegovina
Above: Photo taken July 2009. Below: CNN news photo composite with author's photo to show height of 2014 flood

Fig. 9: Hotel lobby in Venice during acqua alta, October 2002

Dresden Conference. The photograph in Figure 8 (above) gave me an insight I had not had before – that the principle shaping influence on this now iconic bridge was most likely the threat of it being carried away by a raging torrent of floodwaters passing through the narrow gap in the rock outcroppings that border the river at Mostar. When I compared the news images with the photograph I had taken five years before in Figure 8 (below), I realized that the original designers had experienced flooding at this location, and the technology at their disposal for the construction of a bridge to cross this river was masonry, but the bridge had to be both high enough and robust enough in its footings and piers to resist being washed away.

In the Andes, the Inca Indians have been documented as having built remarkable suspension bridges out of grass ropes over unbelievably deep gorges, but this bridge had to be rigid to be suitable for animals, carts and crowds of people in the urban center. The 2014 floods, which were near record height, made it clear that the flood level for which the bridge had to be designed was known by its masons and engineers presumably by the memory of past floods passing through that gap. This is because the 2014 flood is shown to have reached exactly to the spring of the arch. This means that the piers founded upon the natural rock on either side were below the rushing water, but they were able to conduit the water harmlessly through the gap without any water or debris striking the vertical sides of the arched bridge itself. By spanning the river with such a high single arch, there was no central pier in the river to catch debris or interfere with the floodwaters. With the spring of the arch elevated above the established flood elevation, the arched curvature of the bridge had to rise well above the ground level on either side, which gave the bridge its distinctive appearance – and also gave it the considerable strength it demonstrated by surviving for 450 years, and when, during the war in 1993, it took many rounds of shells to destroy it.

Venice 2002

The next example, Venice, is well known by all, yet much of the technology that makes it habitable is still partly a mystery. Here the daily normal situation would seem like a catastrophic flood anywhere else. The ancient masonry buildings stand in salt water – and have done so for centuries. The underlying ground would seem an inauspicious place to locate an encampment, let alone a city which has lasted for millennia. Throughout Europe, the plague of rising damp and the salt attack on masonry from efflorescence has been a widespread conservation problem, but there seems very little of it in Venice, considering its waterborne location, and people there do not remark or complain about it.

The technology that makes all of this possible is not the subject of this paper, but it is worth closing with these observations and image of a recent *acqua alta* – the high tides that now increasingly enter the city bringing its foot traffic to a halt, except on the elaborate temporary walkways that appear almost out of nowhere and cross the broad puddles and deep ponds of water that overtake the piazzas and passageways. This particular *acqua alta* coincided with a major UNESCO meeting held there in 2002. It was also one of the highest ever – yet another indicator of global warming, the phenomenon that has made the potential for floods, as well as the incidence of droughts, more common.

We were having our meeting right in the midst of a flood event. This was a "still water" event, so being swept away was not an issue. The only waves were those from the motorboats, but how often in a flood have you seen people boating around and having a good time? How different this is from the floating dead bodies and people yelling from the top of their houses in New Orleans, after having broken through their roofs upon being trapped inside. Here, people were simply taking it in stride – with the locals splashing by in their waders almost as if nothing was unusual. All the lights in the ground floor shops and hotel lobbies were lit, having been wired from above the flood elevation. Boots specifically made to distribute to tourists for a one-time use were for sale.

The most memorable experience was walking into a hotel and being greeted by the front desk staff and manager: "*Good day sir, what can we do for you*". They were looking at me as if nothing had changed; nothing was out of the ordinary. Only then did I see that there was a little metal shutter at the opening between the counters – the sort of thing that can be stored in a closet. Behind it, their feet were dry. In front of it, my feet were wet (Fig. 9).

Perhaps there, in witnessing such an event, one is looking as much at the future as at the past. There is still much in Venice that is worthy of study.

Credits
Figs. 1, 2, 3, 4 (left and center), 7, 8 (left), 9: R. Langenbach
Fig. 3: Inset Photograph FEMA (Andrea Booher)
Fig. 4 right: http://historicalphotosdaily.blogspot.com/2011/04/great-floods-johnstown-pennsylvania.html
Fig. 5: Agence France-Presse (AFP)
Fig. 6: Lieutenant Commander Mark Moran, National Oceanic and Atmospheric Administration (NOAA) Corps
Fig. 8 right: CNN iReport (AmnaMo) news photo to show water level from composite with 2009 Photograph by R. Langenbach

1 Neelesh MISRA, "Stone Age Cultures Survive Tsunami Waves, Indian islanders apparently heeded ancient lore." Associated Press, 4 January 2005, available at: http://www.nbcnews.com/id/6786476/ns/world_news-tsunami_a_year_later/t/stone-age-cultures-survive-tsunami-waves/#.Uz8m1_ldV8E

2 Mariana BUDJERYN, "… Indigenous peoples' survival demonstrated … relevance of indigenous traditional knowledge." Cultural Survival, available at: http://www.culturalsurvival.org/publications/voices/mariana-budjeryn/survivors-tsunami

3 David HOLMSTROM, "A View From Atop a Levee," Christian Science Monitor, July 21, 1993

4 Randolph LANGENBACH, "Rescuing the Baby from the Bathwater: Traditional Masonry as Earthquake-Resistant Construction," 8th Int'l Masonry Conference 2010, Dresden, Technische Universität Dresden, 2010. Also see: "The Great Counterintuitive: Re-evaluating Historic and Contemporary Building Construction for Earthquake Collapse Prevention." International Conference on Structures and Architecture, Guimarães, Portugal, July, 2013, both available at: http://www.conservationtech.com/RL's%20resume&%20pub's/RL-publications/1-EQ-const2.htm.

5 Chris CROMM and Sue STURGIS, Hurricane Katrina and the Guiding Principles on Internal Displacement, A Global Human Rights Perspective on a National Disaster, Institute for Southern Studies, 2008. Available at: http://www.brookings.edu/~/media/events/2008/1/14%20disasters/0114_isskatrina.pdf. Also, for statistics see https://en.wikipedia.org/wiki/Hurricane_Katrina.

6 Randolph LANGENBACH, Alberto DUSI, "The Victims' Dilemma: When Doing Good may be Doing Wrong," Proceedings of the 2006 International Disaster Reduction Conference (IDRC), Davos, Switzerland, ICCROM Workshop on the Integration of traditional knowledge systems and cultural heritage into risk management, Davos, Switzerland, August, 2006, available at: http://www.conservationtech.com/RL's%20resume&%20pub's/RL-publications/1-EQ-const2.htm.