# RESILIENT STORMWATER FUTURES FOR COASTAL CITIES

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**ABSTRACT**

With the majority of New Zealand's population living along the coastal fringe and a large proportion of these located in no more than five urban areas, the risks of stormwater management in coastal cities is an important issue that New Zealand must look to face sooner rather than later. The paper will look globally at what other communities are doing both reactively and now proactively to face the uncertainty associated with climate change, population growth, sea level rise and creating liveable cities in the coastal margins.

Much can be learnt from on-going work overseas across the US, Europe and Asia-Pacific Regions following on from major events such as Cloudbursts (Copenhagen), Hurricanes (i.e. Katrina, Sandy), Tropical Storms (Nock-ten) as well as other specific catchment approaches to protect communities.

The paper will draw specific examples from recent projects such as New York's Rebuild by Design Competition, the 100 Resilient Cities Programme, The Copenhagen Cloudburst Management plan and New Orlean's response to Hurricane Katrina as well identify how decentralized approaches to stormwater management including smaller scale catchment solutions (such as programmes of Water Sensitive Urban Design, Natural Flood Management) can yield multiple benefits for creating places where people want to live and work.

The author will then draw all of these examples, back down to New Zealand and identify emerging approaches to building resilience across New Zealand's Coastal Communities and signpost where further effort may be required.

**KEYWORDS**

**Flood Resilience, Extreme Events, Climate Change, Sea Level Rise, Coastal Communities, Risk Management, Infrastructure.**

**PRESENTER PROFILE**

Liam Foster is a Chartered Water and Environmental Manager (C.WEM) and Principal Environmental Consultant with over 16 years of experience across New Zealand, Holland, the Middle East and the United Kingdom. He has a background in hydraulic modelling, water sensitive urban design, hydrology and flood risk management, including how spatial planning and designing for exceedance can assist in avoiding putting more communities at risk unnecessarily.

## 1 INTRODUCTION

The natural attraction of settling adjacent to rivers and coasts for both trade and access to water has resulted in significant proportions of the world's major cities being located along coastlines and deltas, covering many of the world's most populous cities and substantial volumes of private and public assets.

The coastline has historically drawn populations to live in cities, such that the population densities in coastal regions is about three times higher than the global average. The World Bank (2010) has identified that more than a third of the world's people live within 100 miles of a shoreline. Additionally, McGranahan (2007) has identified that low-lying coastal areas represent 2 percent of the world's land area, but contain 13 percent of the urban population.

Coastal cities are facing into tremendous shocks and challenges in future year and are particularly at risk of natural hazards. The potential risks include accelerated sea level rise, extreme waves and storm surges, altered precipitation and runoff, amongst others (Nicholls et al. 2007).

Rapid urbanisation over the past few decades is partially causing an increase in this risk profile, however it can also be argued that the impact of human activities on the natural processes such as the degradation of coastal ecosystems (Scavia et al., 2002) is a further contributory factor.

Sea level change is a natural phenomenon that has affected coastlines based on interdecadal climatic trends such as El Nino and longer term warming of the seas since the last Ice Age. Irrespective of any continued debate over whether human actions are accelerating sea level changes, it would be prudent for coastal cities to prepare for a range of scenarios that could occur relating to sea level (in particular) and climate change impacts, including the effect a higher sea level has on the frequency and severity of extreme weather events.

The extreme weather events have an impact on the social, environmental and economic fabric of any community, but these consequences are exacerbated amongst coastal cities and it is clear that adaptive and spatial planning can help improve the resiliency to such events, before during and after.

# 2 THE NEW ZEALAND CONTEXT

A recent report, entitled 'Preparing New Zealand for Rising Seas' released by the Parliamentary Commissioner for the Environment in 2015, identifies that:

> *'Nowhere in our island nation is far from the sea, and most of us live within a few kilometres of the coast. Houses, roads, wastewater systems, and other infrastructure have been built in coastal areas with an understanding of the reach of the tides and the recognition that storms will occasionally combine with high tides to cause flooding.*
>
> *However, with rising seas, tides, waves and storm surges will reach further inland than before, resulting in more frequent and extensive flooding.*
>
> *Like other countries, New Zealand needs to prepare for rising seas. Under New Zealand law, the enormously challenging task of planning for sea level rise is the responsibility of local government. It is challenging on many levels. For a start, it is technically complex, and the size and timing of impacts are uncertain.*
>
> *Perhaps the most difficult aspect is the impact on people's homes, which for many are not just their homes, but also their financial security.' (PCE, 2015)*

The statement is such that failure to prepare will have a severe impact on the financial wellbeing of not only individuals of NZ Inc as a whole. This is demonstrated in the scientific reports supporting the PCE's report. For instance NIWA (2015) shows that even allowing for the limited information, currently available, across New Zealand on the national risk picture, articulated through the limited coverage of high quality topographical datasets (shown in Figure 1)), that the consequences would be severe for New Zealand (shown in Figure 2), with Critical Infrastructure (hospitals, electrical power stations and sub-stations and rescue services) and large proportions of buildings at risk from even marginal increases in the current mean sea level.

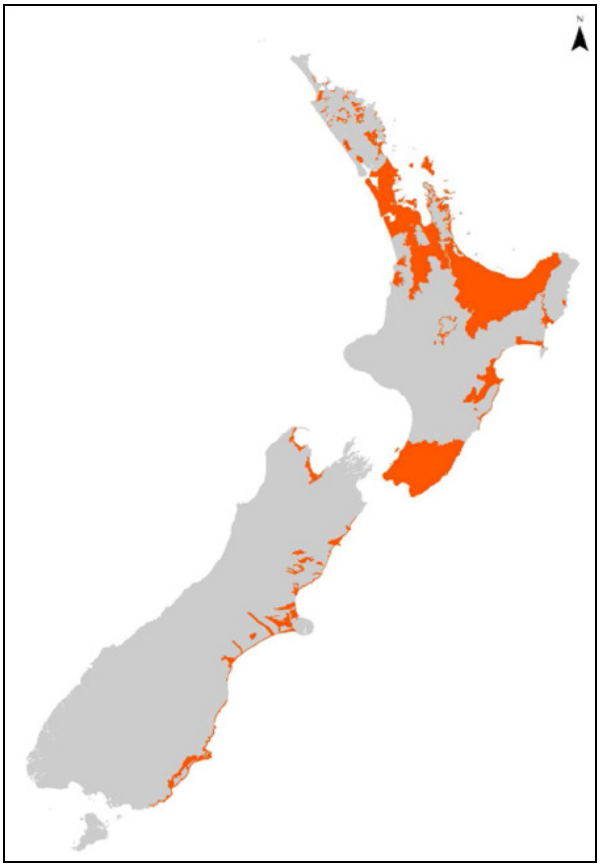


Figure 1: Coverage of LiDAR DEMs (NIWA 2015)

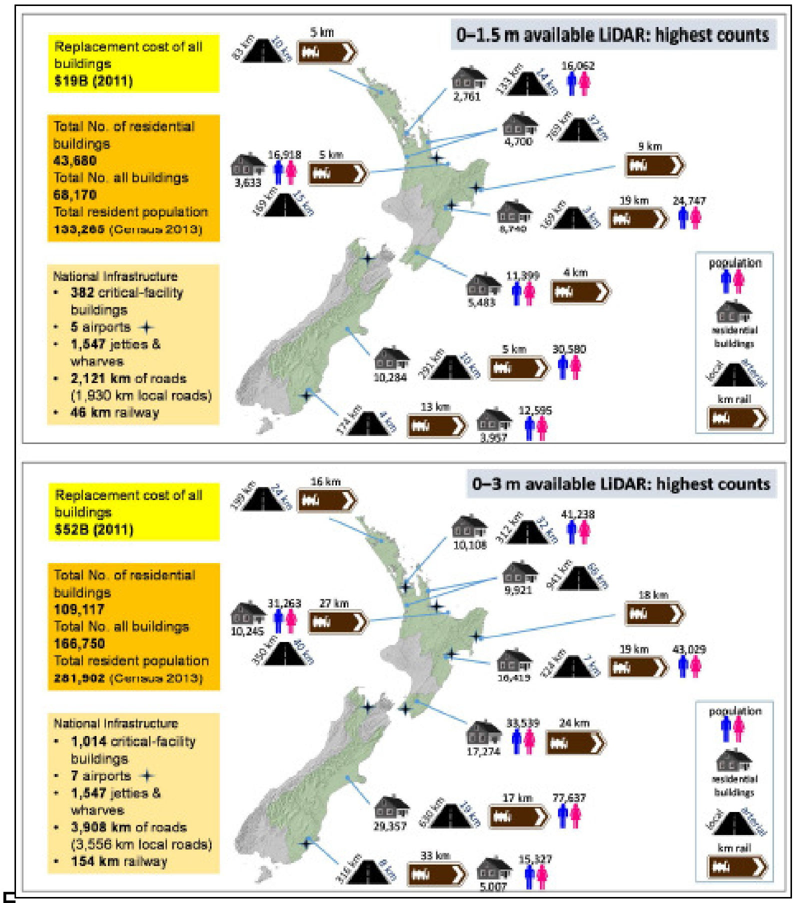



Figure 2: Regions with the highest counts for assets or population and the national summary for coastal risk exposure in areas with LiDAR available: (top) 0–1.5 m elevation zone; (bottom) 0–3 m elevation zone (NIWA 2015)

NIWA (2015) identifies that several authors cite credible projections for sea-level rise by 2100 to range from 0.5 to 1 m through to possible rises greater than 1m by 2100 are still possible. NIWA (2015) also identify that whilst sea-level rise in simplistic terms would only act to simply raise the levels of the key tidal markers, such as the Mean High Water Springs, it is the combined threat of how the higher sea level would exacerbate the impacts of natural coastal hazard events (e.g., storm-tide, river floods, tsunami, waves, coastal erosion) that is truly concerning. This is postulated to cause an increasing frequency of damaging events in the coming decades across NZ Inc.

# 3 HISTORIC STORMWATER MANAGEMENT IN COASTAL CITIES

## 3.1 NATURAL HYDROLOGICAL CYCLE

As with any development, the impacts of urbanisation of coastal margins can have a significant impact on the natural hydrological cycle. In 'natural' areas, the water balance or natural hydrology is altered only by rainfall and associated fluctuations in infiltration, evaporation and transpiration from plant growth. But urbanisation results in this natural hydrology being heavily modified, because land has been cleared of vegetation and capped with 'hard' or impervious surfaces, as shown in Figure 3 below.

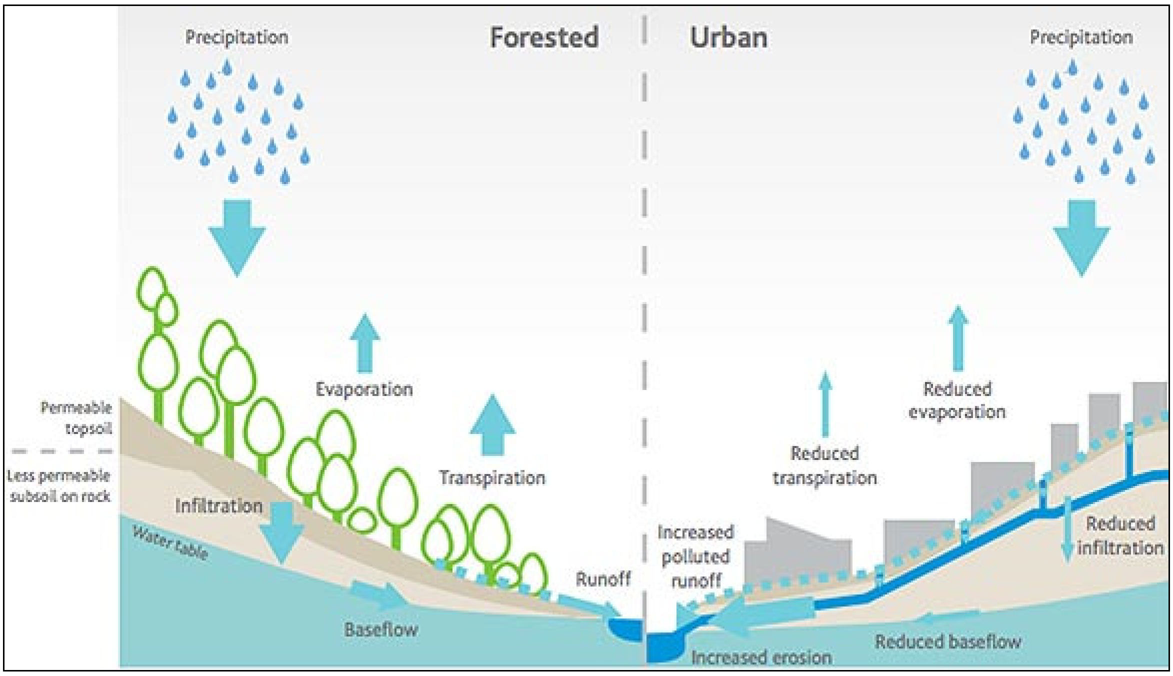



Figure 3: Impacts of urbanisation (taken from Melbourne Water website).

## 3.2 IMPACT OF URBANISATION

The approaches to deliver urban environments has, until recent moves for Water Sensitive Urban Design, resulted in paving, piping and pumping, resulting in a hard landscape that changes the water balance and timing of flows, including sudden surges in water volume and velocity, causing an impact on our communities, the urban waterways and ultimately the discharges to the marine environment. The impacts of urbanisation are well understood on the ecology, habitat, environment and urban communities. Some of the effects may be to:

- Increase the speed and volume of run off, impacting communities now living in these urbanised areas
- alter natural flooding regimes
- change the structure, variety and suitability of habitat for aquatic life such as fish and macro invertebrates
- disturb animals and plants living in the waterway, and affect animal breeding habits
- erode stream banks
- increase turbidity and pollution, affecting water quality
- increase volumes of litter and oils

Overall these changes tend to reduce our ability to use waterways and, more significantly, threaten the overall health of the waterways and the dependent aquatic species. This approach has had an enormous cost on communities around the world through poor development decisions, resulting in flooding, subsidence, high energy uses and the loss of natural ecosystem services.

## 3.3 COASTAL STORMWATER MANAGEMENT INFRASTRUCTURE

The development of cities within coastal environments largely mirrored the development of cities across the world, in that the key focus for encouraging settlement was the aspiration to control the water through the urban environment, resulting in the changes to the natural hydrological cycle. The consequence of this was to effectively encourage systems to be designed to remove stormwater from urban areas as fast as possible.

This by and large resulted in stormwater being buried away from sight and therefore the value associated with this potential resource has historically been very low, further leading to degradation of the quality of the stormwater itself and the receiving water environments into which they ultimately discharge (as shown in Figure 4).

Figure 4: Examples of existing approaches to draining our cities (Waggoner & Ball 2013).

Common with all urban areas stormwater drainage, in coastal cities, is effected through the provision of gravity or pumped systems. These systems are usually designed with a quasi-static level in mind in relation to the downstream boundary condition within the fluvial or coastal waters that the discharges enter.

The designs of these systems would be more than suitable if we lived in a stationary world where the flux in sea level was not present. Several communities around New Zealand and even significant portions of countries across the World are sited below current MHSW levels posing greater challenges on how to manage the rainfall that falls within the catchment, let alone the potential for higher sea levels and increased frequency and severity of extreme events.

Pumping is therefore, required to maintain the levels of service as gravity systems are unable to serve these urbanised areas (particularly low lying coastal areas where current and future sea levels are greater than the urban infrastructure). The current management approach in these areas is such that every drop of water that falls must be pumped out.

These forced drainage systems are relied upon to keep the communities and cities in low-lying areas dry. This approach is both resource intensive and often beaten as design guidance for stormwater management in these areas is often focused on the more frequent events and the investment required to achieve better levels of protection, against more extreme events, are often hard to justify alone.

It is clear that this pumped stormwater management approach has significant associated impacts, such that land subsidence in these areas is prevalent, for example Leake (2013) identified that many basins in Southwestern United States have sunk between 1 to 29 feet from 1945 to 1997. Waggonner & Ball (2013) have identified that for the Greater New Orleans urban area, the:

> *"existing single-purpose drainage systems are the primary cause of subsidence in the region. The current drainage regime has developed into a destructive cycle in which pumping and low water levels cause the land to sink, which then necessitates increased pumping capacity in order to keep dry, which then leads to further subsidence. Subsidence will cost the region an estimated $2.2 billion in damages to structures over the next 50 years….*
>
> *Climate change threatens to raise the frequency of the extreme weather events, placing further pressure on current undersized and ageing infrastructure such that these communities will 'occupy a precarious place where pumping stormwater and keeping floodwaters out both become more difficult over time'*

# 4 THE PARADIGM SHIFT – EVOLVING COASTAL CITIES

These stormwater, and associated challenges, in coastal cities require a shift in focus such that the stormwater and even groundwater are treated as being a valuable resource as opposed to a nuisance. Unfortunately, it has taken a series of catastrophic events across the world to determine that there is a more comprehensive way to enable a more sustainable future for continuing the inhabitation of these environments.

The approach relies on the integration of infrastructure planning and urban design across the hydrological context. Effectively, resulting in water in all forms (groundwater, storm and surface waters) being integrated and managed to be a resource that permits the revitalisation of communities, through the delivery of enhanced public space, opportunities for economic growth, whilst allowing ecosystems to be enhanced and add the non-tangible benefits to accrue and further evolve a virtuous circle of growth.

## 4.1 HURICANE KATRINA AND NEW ORLEANS

Figure 5: Hurricane Katrina at it's peak (August 28th, 2005) and its impacts on New Orleans (photo credits – NASA & Kyle Niemi).

Katrina caused severe devastation along the Gulf coast from central Florida through to Texas, due to storm surge and levee failures. Damage estimates reached US$125 billion in economic losses on the Gulf Coast, and US$30 billion in the city of New Orleans alone. More than 160,000 homes were destroyed or heavily damaged, 1,500 lives were lost and the event forced the evacuation of over 1.35 million people. The suburban developments on former back swamp areas suffered most, and subsidence of six to seven feet below sea level in some places worsened the effects.

Out of this event, a new direction has emerged, one that has been driven by a groundswell movement looking to deliver a paradigm change to the way their communities' are formed and live with water. The Greater New Orleans Urban Water Plan (Waggoner & Ball 2013), sets out to achieve this through developing a framework and action plan to address New Orleans's significant water challenges (see Figure 6), exacerbated by the devastating impact that Hurricane Katrina had on the communities in 2005 (See Figure 5).

The urban water plan builds upon the existing flood protection systems by developing the city's regeneration along the lines of 'multiple lines of defence' and follows the key principles to guide long range planning and strategic investments for the next 50 years:

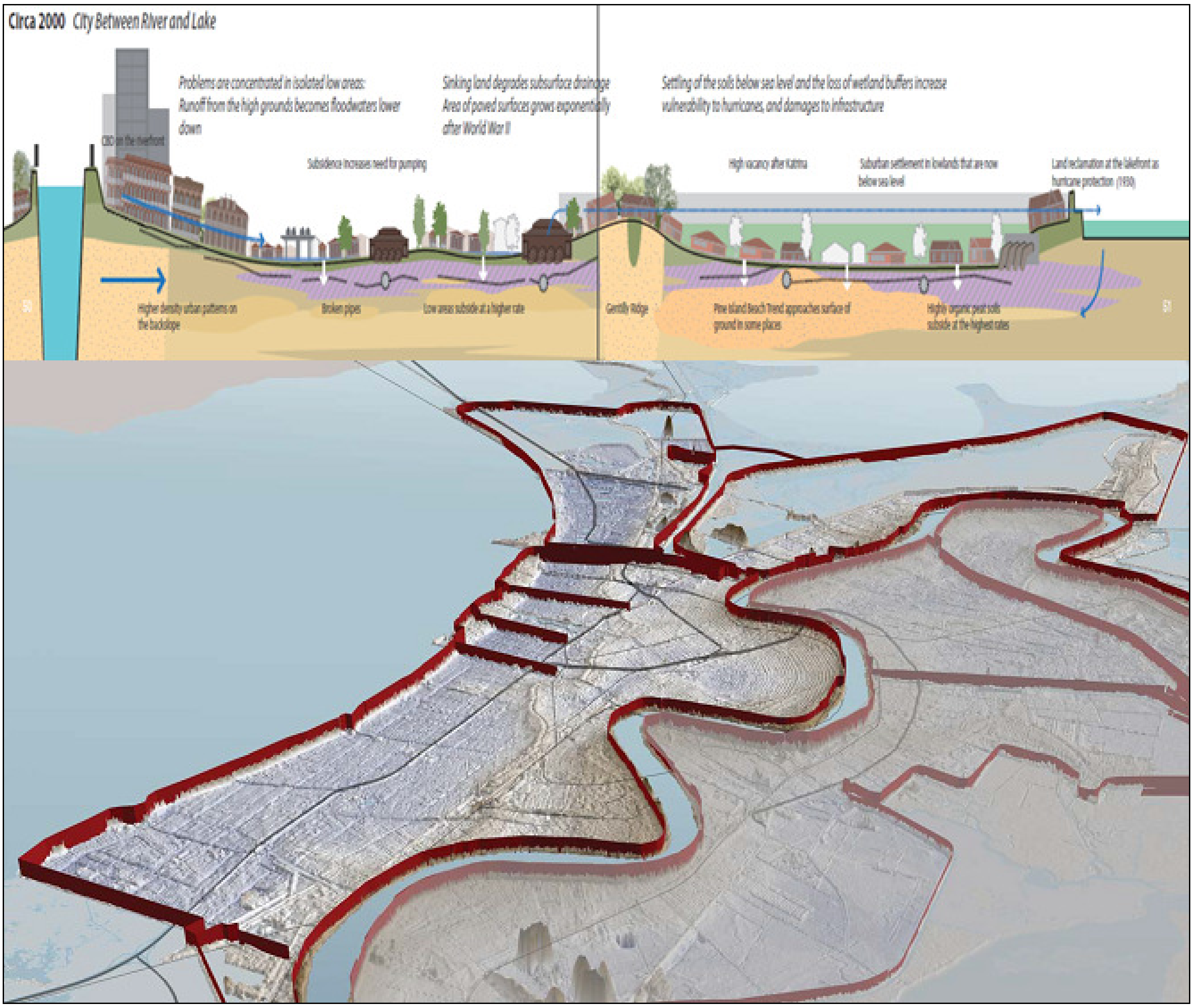



Figure 6: New Orleans Water challenges (Waggoner & Ball 2013).

- *Live with Water* - making space for water and allowing it to be an asset for the region;
- *Slow and Store* – Slowing the flow across the catchment and storing large volumes for infiltration. Pumps are used when necessary rather than as a default every time it rains;
- *Circulate and Recharge* – Incorporating surface water flows and higher water levels into everyday water management improves groundwater balance, water quality, and the region's ecological health;
- *Work with Nature* – Using nature to enhance our mechanical systems enhancing the function and resilience of the water infrastructure and landscape.
- *Design for Adaptation* – designing for dynamic conditions to support diverse uses, economic development and environmental recovery maximises the value of necessary water infrastructure improvements.
- *Work Together* - water has no respect for boundaries or social status, the collaboration across the community to develop solutions across all scales from property level to regional networks are essential to building a stronger future.

## 4.2 SUPERSTORM SANDY AND NEW YORK

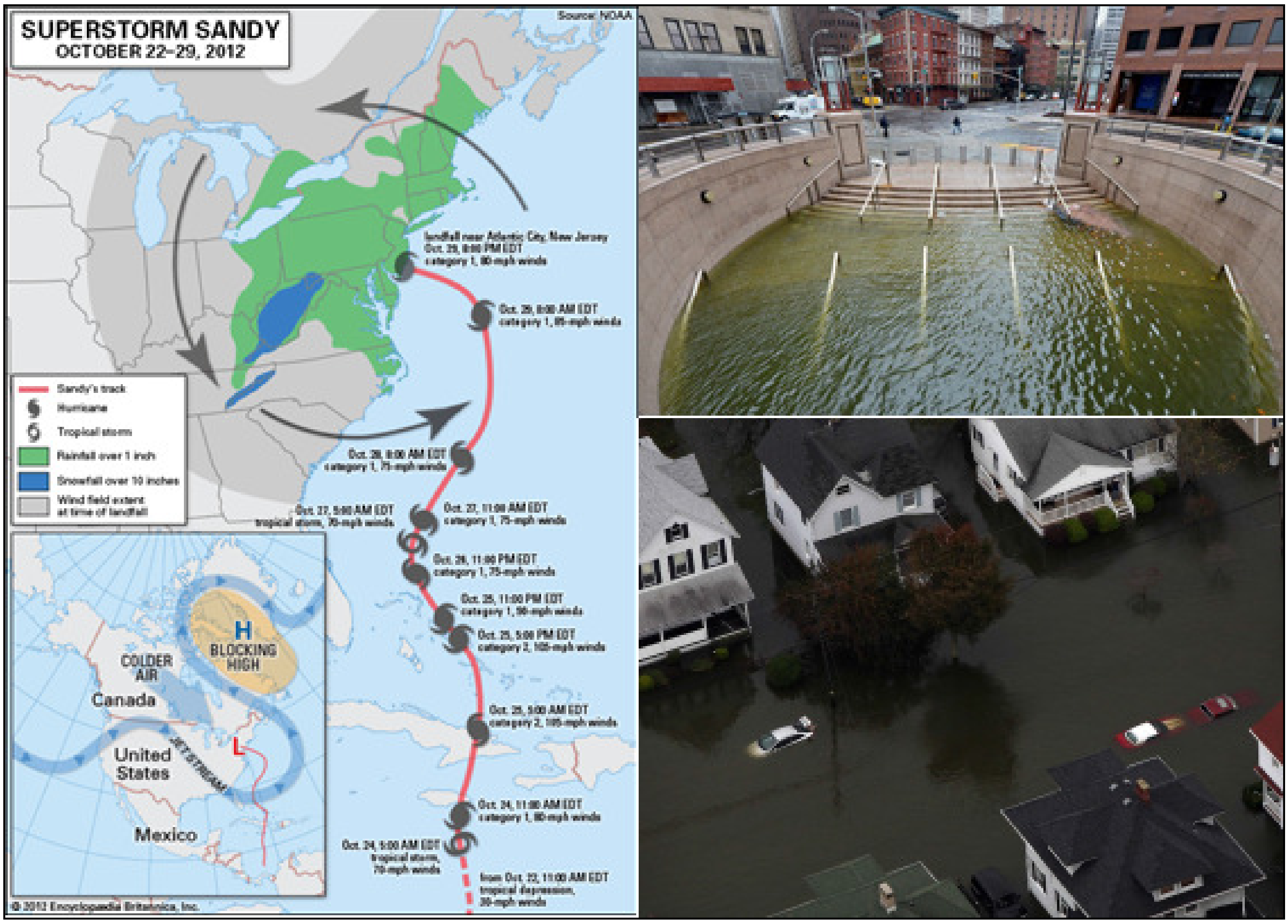


Figure 7: Hurricane Sandy's path (October 2012) and its impacts on New York (Image credits – Encyclopedia Brittanica, Tim Larsen & Justin Lane).

During October 2012, Hurricane Sandy had a severe impact along the Caribbean and Eastern Seaboard of the United States, leaving a trail of devastation with approximately 250 people losing their lives, over 600,000 houses damaged or destroyed. Several cities and towns along the Atlantic coast of New Jersey and New York were devastated, and air, rail, and road transportation ground to a halt. Heavy winds and rain or snow occurred throughout the Northeast and the Mid-Atlantic states. It has been estimated that damage is in the order of $80 billion for the event.

In New York City, a storm surge measured nearly 14 feet (about 4.3 meters). Along with heavy rains, the surge caused the Hudson River, New York Harbour, and the East River to flood the streets and tunnels of Lower Manhattan, including parts of subway lines. Flooding and power outages occurred near the New York Stock Exchange, forcing its closure for two days, the longest weather-related closure of the exchange since 1888.

In response to Hurricane Sandy's devastation, the United States Department of Housing and Urban Design, launched ***Rebuild by Design***, with supporting organisations in June 2013. A new approach to encouraging the recovery post disaster, effectively responding to a design competition that would develop innovative and implementable solutions.

The staged design competition was a research led, cross sector collaborative platform of professionals and communities to deliver outputs showcasing the best knowledge and talent that would ultimately be replicable, regional, and implementable.

Rebuild by Design will produce twenty-first century designs for coastal communities, high-density urban ecosystems, and ecological networks and waterways. The purpose of the recovery would be to enhance regional resilience to disaster risks, to support its ongoing economic development, ecological health, and the well-being of its citizens. The process involved generating innovative ideas from planners, designers and engineers that take into account the changing nature of the coastal environment.

The key difference with this approach is that there was up front commitment of resources to help develop and build winning projects that focus on implementation with local support, with nearly US $1 Billion allocated to the Local Authorities responsible to begin the implementation of the six winning proposals alongside their broader Disaster Recovery Implementation Plans.

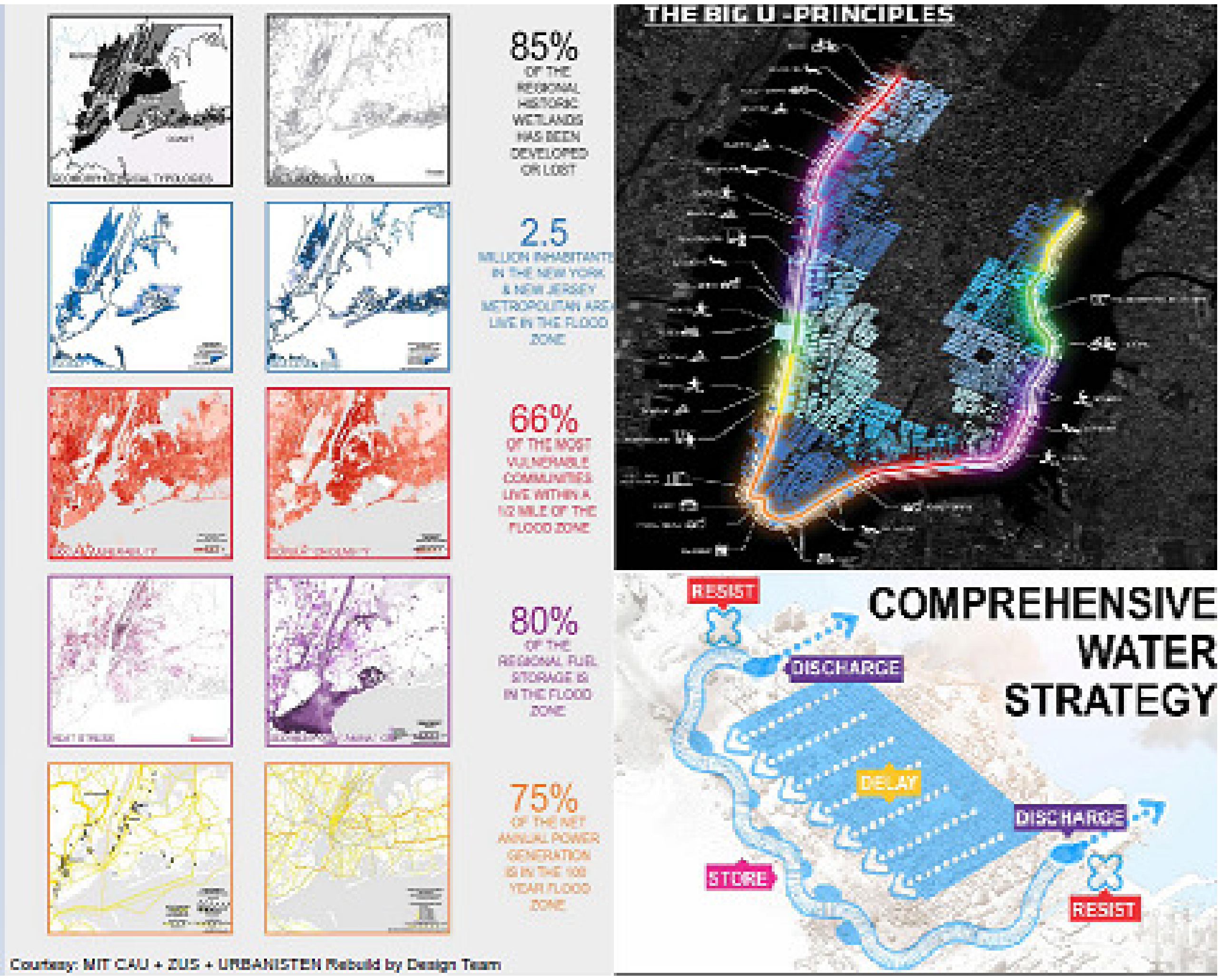



Figure 8: Examples outputs - Regional Hazards analysis across New York and New Jersey plus some examples of winning designs (OMA & the Big U).

## 4.3 COMMON THEMES

The two case studies presented along with many other examples across the world identify several key lessons. First of all, there is a great need to incorporate the concepts of both scenario planning and widespread engagement to deliver a more proactive approach to managing the changing climate and rising seas.

The key elements emerging from these approaches to deliver resilience across these communities, is that:

1. They are Multi-Disciplinary and Collaborative,
2. They take a Regional Systems Approach,
3. They allow for huge widespread participatory process and iterative in nature
4. They cross several hazards and deliver multiple benefits, and
5. Look to deliver integrate solutions

It is clear that there needs to be a long-term strategic vision embedded into the current planning regime. This is essential especially in relation to on-going and current land-use decisions. Local planning needs to look beyond the usual short term planning horizons.

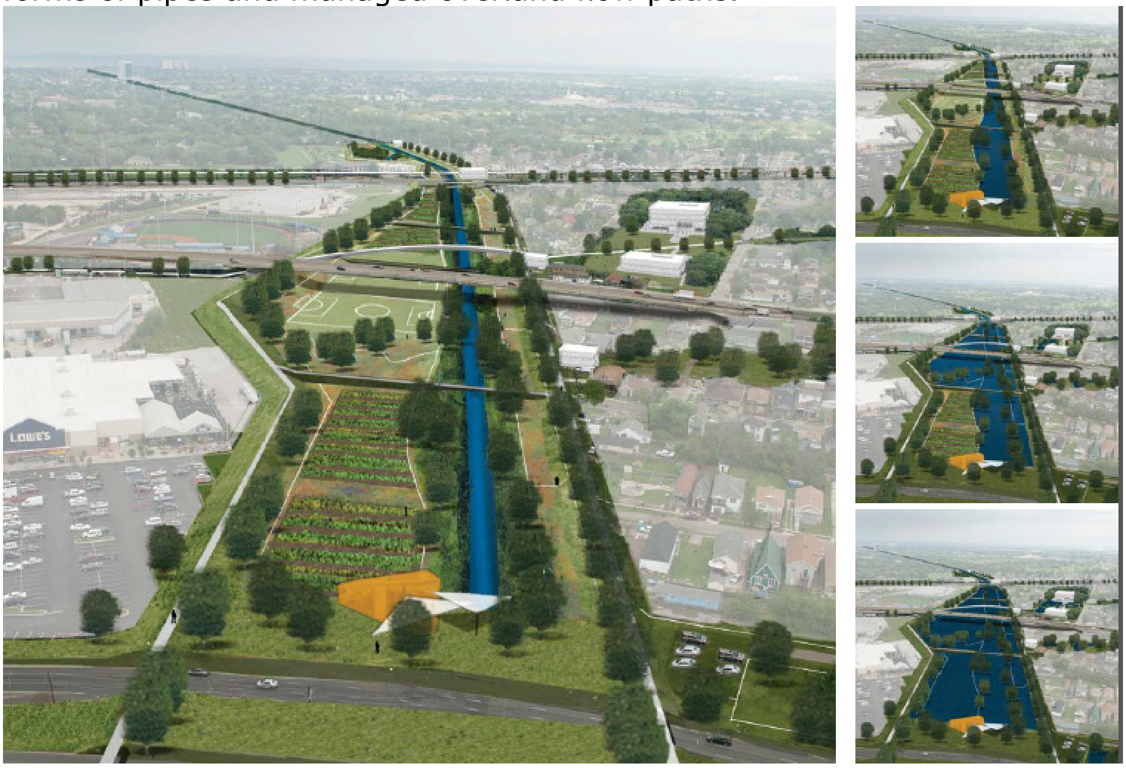
This requires strong leadership from both Local and Central Government to make the tough calls required to allow coastal cities to thrive and survive an increasing frequency and severity of storms against the backdrop of the rising sea levels. The scale of planning interventions will need to be as large as the problem.

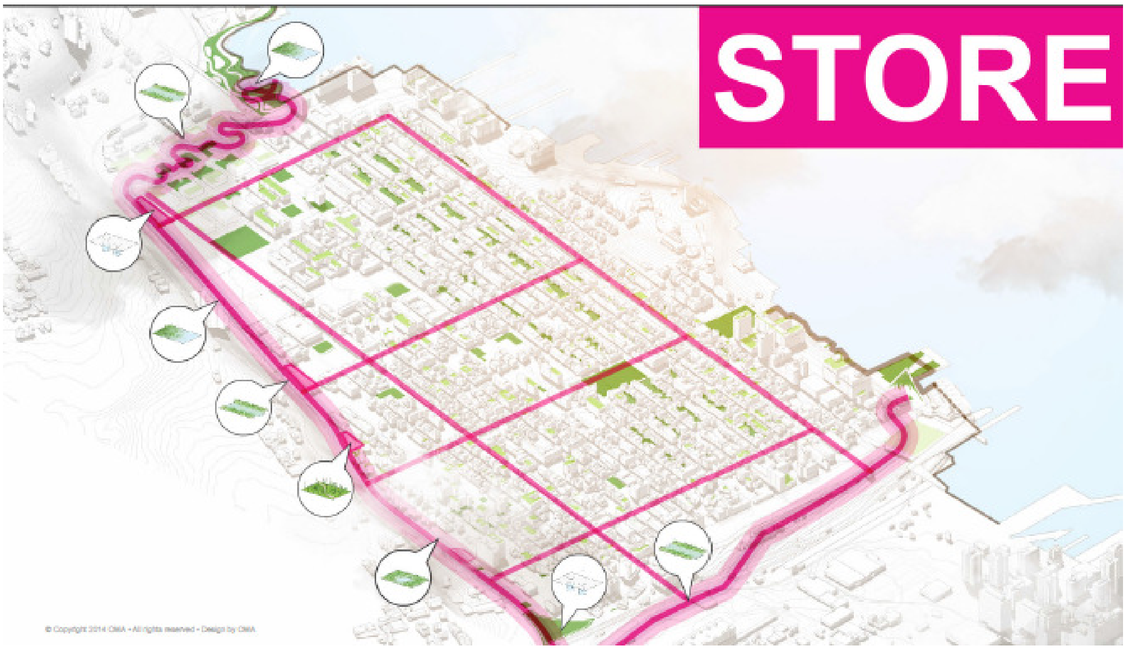
Events around the world, such as the 'cloudburst' that affected Copenhagen in 2011, when 150mm of rainfall fell in just two hours onto an urbanised coastal city, show us that the consequences are severe for cities (Figure 10) and these could be further exacerbated should the current sea levels rise.

Figure 10: Hazardous impacts of Copenhagen's cloudburst event in 2011 (City of Copenhagen, 2012).

The approach to divide cities into hydrological catchments is not unique, however the response within these catchments is such that there is no one solution for each catchment and that a whole series of hard and soft elements are required to help alleviate the impact of these catastrophic events as is common among all three case study examples (Figure 11).

Instead of taking a conventional approach that sees storm water as being an issue to be addressed with greater channelisation and burying it underground in pipes, the Management Plan looks instead to develop a holistic and integrated response using blue-green solutions wherever possible, supported by designated exceedance routes in both forms of pipes and managed overland flow paths.



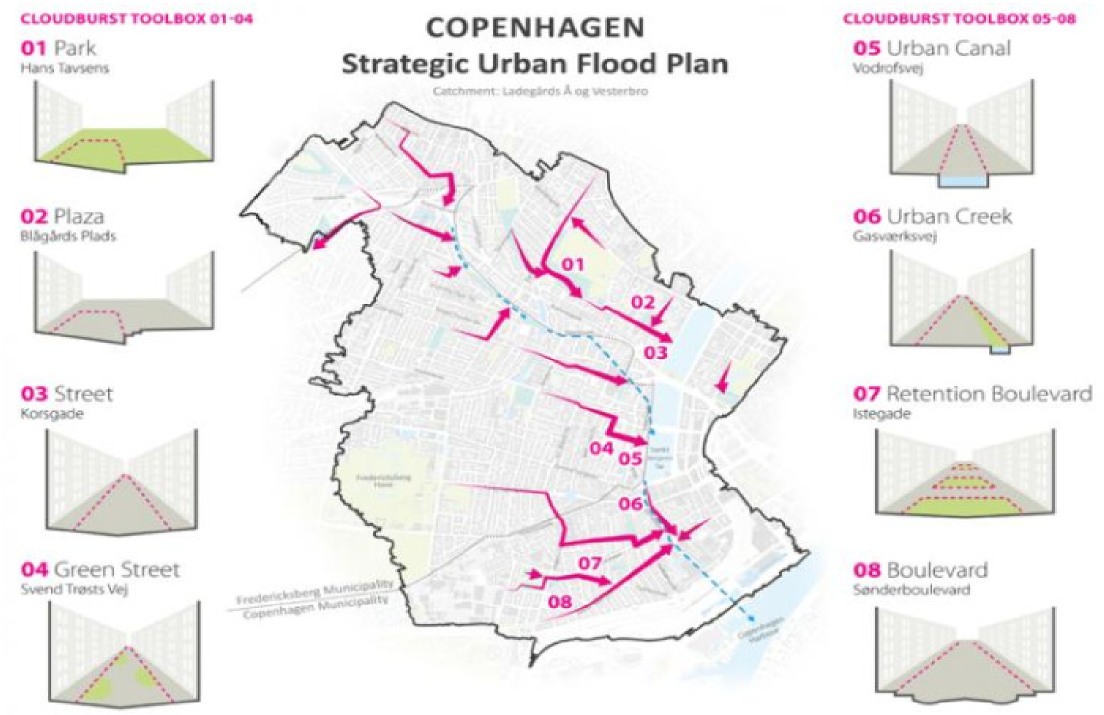



Figure 11: Potential Solutions to help manage extreme events across the three case studies. Top – Hollygrove District, New Orleans (GNO Urban Water Vision), Middle – Hoboken Town options for interconnected stormwater storage, New Jersey (OMA, 2014) and Bottom - Fredricksburg East and Vesterbro districts, Copenhagen (Ramboll, 2016).

The Cloudburst Management Plan looks to deliver much more socio-economic benefits, and aligns itself to deliver multi-use transport routes that double up as stormwater channels for more extreme events.

A common feature of this Plan (and the approaches being taken for New York and New Orleans) also looks to deliver open swales and other green open spaces to act as temporary storage and slow the flow (Figure 12). This provides places where people want to live and works in allowing them to benefit from the aesthetic improvements as a side benefit of the adaptation measures progressed, which also deliver greater urban biodiversity through the creation of greater density of connected habitats.

The Cloudburst Management plan report highlights that its it far cheaper and easier to implement these sort of surface/near surface improvements than developing harder, deeper grey infrastructure solutions but points to limitations in the denser areas of the city where these solutions are physically difficult to develop and far harder to combine with amenity and recreational advantages.

The fundamental message is that effectively integration of the whole water cycle and other key services is required to enable cities to thrive and deliver a more resilient future in the face of the changing environments. Depending on the risk profiles, associated with the coastal city, the approaches to achieve resilience should look to decide which of the three broad coastal management approaches to living alongside the risk, being retreat, defend or event attack.

Figure 12: Potential Cloudburst avenue solution along Sonderboulevard (Ramboll, 2016).

Depending on the overall strategy chosen on this front it is clear that there would be the need for coastal cities to plan to:

- Defend - A programme of soft landscape and hard infrastructure to defend against the coastal projections for sea level;
- Delay – change the current stormwater management mantra via policy recommendations, guidelines, and urban infrastructure to slow rainwater runoff
- Store - through natural processes and Water Sensitive Urban Design management approaches. Creating interconnected green infrastructure routes to store and direct excess stormwater;
- Discharge – deliver additional layers of protection for the communities through alternative designed and planned exceedance routes and, where appropriate or required, suitable pumping strategies.

These require a strong focus on delivering innovative and collaborative approaches to retrofitting the urban fabric to face the changing rainfall patterns and rising sea levels. These are best delivered through joined up, coordinated thinking and action across the communities involved and wide range of professionals (architects, urban planners and engineers for example) and delivering multiple outcomes to achieve additional funding across the whole plethora of interested parties and sectors that can benefit.

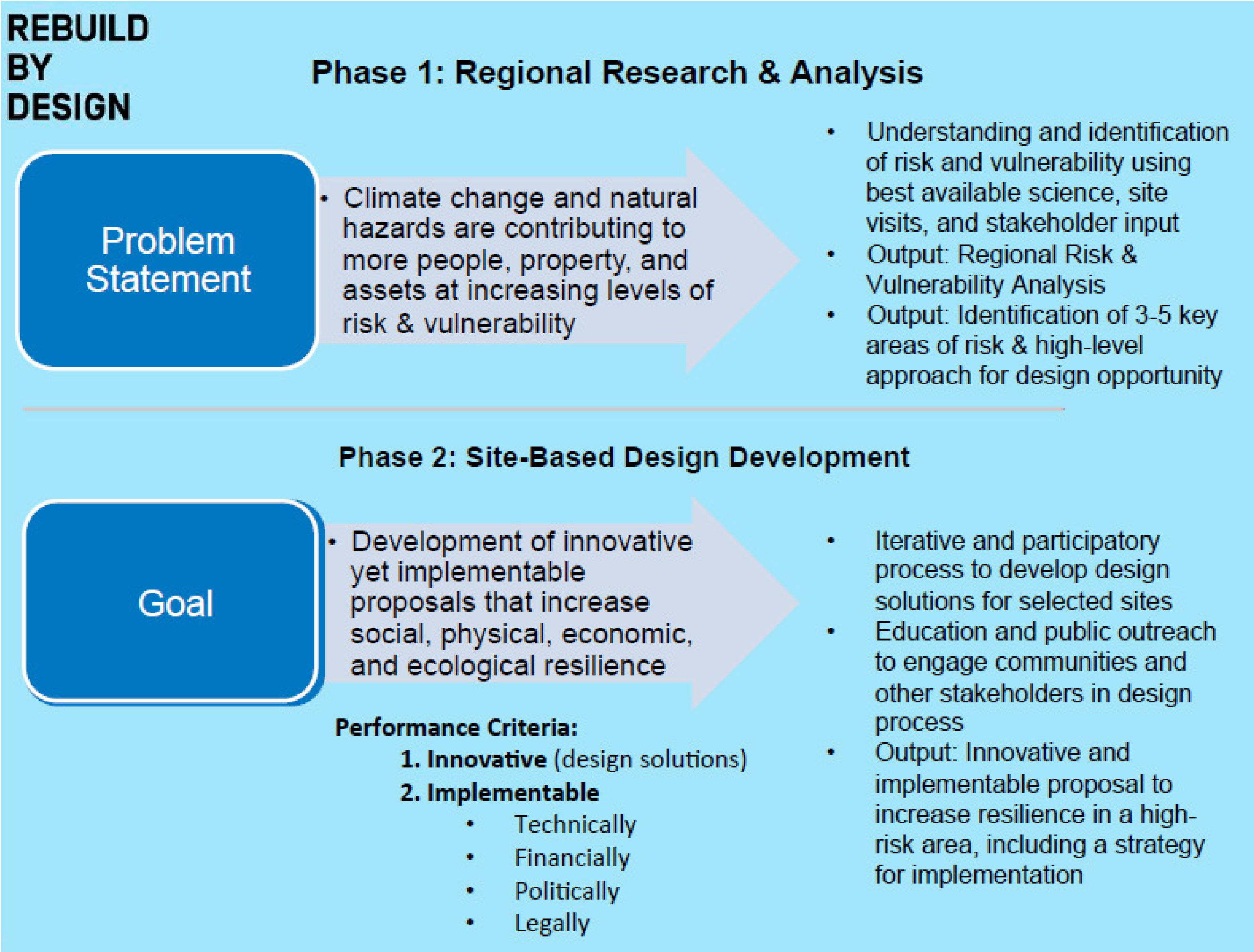



Figure 9: Rebuild By Design approach to delivering beneficial changes for communities at risk.

The net benefits are considerable. A robust coastal and flood risk management system for coastal cities, will help to avoid incurring losses to assets and disrupting activities (preserving communities). This will assist with helping to minimise the potential investment required in ad-hoc un-planned approaches to stormwater management in coastal cities.

The implementation of public investment into the infrastructure required to achieve the multi-layered defenses will in turn act as catalyst for inward investment and provision of community infrastructure and confidence which effectively provides for a sound basis for additional growth of these important communities who provide substantial levels of GDP for the national purse.

# 5 CONCLUSIONS AND WHAT DOES THIS MEAN FOR NEW ZEALAND

If these issues are ignored the likely consequences are serious, including hazardous fast-flowing floods, potential loss of human life, residents displaced from homes, enduring psychological damage, loss of critical coastal habitats, abandonment of cities, billions of dollars in damage and local/regional economic collapse.

Taking a long-term view of the future of our cities across New Zealand, we should look to adapt our thinking and approaches to help alleviate the likely consequences of sea-level rise and the future stormwater issues associated with:

- Coastal city flood prone areas will increase without a change of approach.
- Continuing intensification of coastal cities is further exacerbating the risk of flooding through climate change and sea level rise.
- Other factors such as land subsidence in low-lying areas exacerbate the risk profile.
- Costs of damages are likely to be substantial.

It is clear that National Government leadership is required to identify that New Zealand should plan for the long term and that following the advice of the PCE report in 2015, all future city plans must plan for accommodating higher sea levels to deliver sustainable communities across New Zealand and take the opportunity to decide across each community the appetite to adapt to the future risks, which may include retreat from areas of risk or continuing to defend as well as look to understand how the communities can best work with stormwater rather than remove it as quickly as possible.

The financial, social and environmental benefits of proactively delivering climate change adaptation are huge in comparison to the potential costs associated with future damaging events, both in terms of event management, recovery and rebuild on both the public and private funds.

Communities around coastal New Zealand need to learn the lessons from other geographies quickly to avoid having to repeat the recovery process and needing to derive our own approaches (Recovery Plans, such as Rebuild by Design) to significant natural hazard events.

We have the opportunity to choose our overall management strategy for delivering resilient stormwater futures now and adapt our cities to thrive in the face of these challenges, bringing multiple beneficial outcomes through to the delivery of integrated blue/green and hard stormwater management systems.

A philosophical change in our psyche to earn to live with water and view it as a valuable resource or commodity rather than a nuisance is key to our ability to deliver sustainable and successful coastal cities long into the uncertain future.

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