Arup UrbanLife

Water resilience for cities

Helping cities build water resilience today, to mitigate the risks of climate change tomorrow

ARUP

The effects of global warming on water supply represent one of the greatest challenges for cities in the 21st century. City administrations are seeking ways to meet demand for water from growing populations while grappling with the issues presented by climate change - extreme rainfall and drought, rising sea levels and flooding. Arup's global water, climate change and planning experts offer practical recommendations and case studies to help cities build water resilience as part of a programme of climate change mitigation.

Mumbai, India: Commuters walk through floodwaters after torrential rains paralysed the city of Mumbai, 27 July 2005. The city's weather bureau said that the western city had received 944.2 millimeters (37.1 inches) of rainfall in the past 24 hours, the heaviest rainfall ever in a single day in Indian history.

Top Liuzhou, China: A view of the city zone along the Liujiang River on 6 July 2009 in Liuzhou of Guangxi Zhuang Autonomous Region, China. The water level of the Liujiang River rose to 89.28 meters, exceeding the warning level by 6.78 meters. **Bottom** Nanjing, China: Stranded bus passengers help push the bus to higher grounds, along a flooded street in Nanjing, capital of eastern China's Jiangsu province on 6 July 2003, where the heaviest rains in 20 years deposited some 194.5 millimetres (7.65 inches) of water. Officials in the neighbouring province of Anhui blew up a dike and urged 760,000 inhabitants along the Huaihe river, a tributary of the mighty Yangtze, to maintain vigilance as its water levels reached a record high.

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990m gallons per day

water demand in Delhi

75%

of people estimated to live in cities by 2050

50%

of the world's population lives in cities today

1,083km²

of annual flooding in HCMC

1/3

of London's water supply lost to leakage

50%

Beijing's target for increased utilisation of recycled water in the city centre

$100bn

per year economic impact of sea level rise by 2030

$65bn

economic impact of sea level rise in 2010

5%

of Thailand's GDP: estimated recovery cost for a severe flood event in Bangkok in 2050

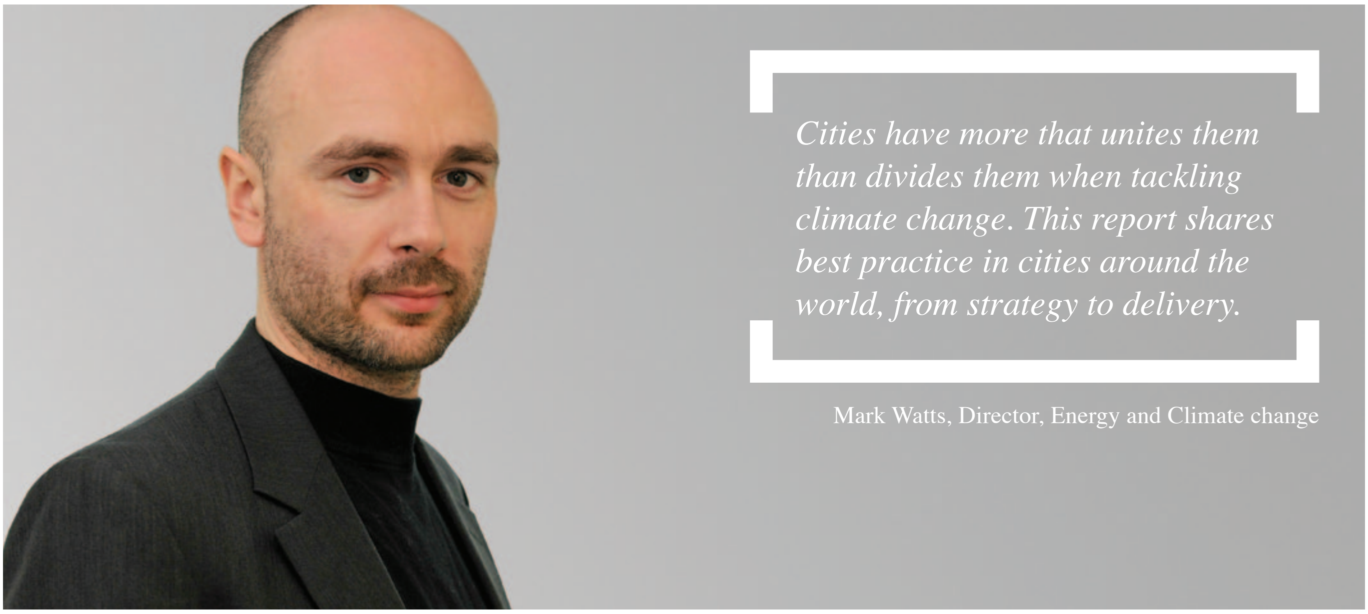
300,000

people displaced by flooding in Manila in 2009

3.3mm

per year sea level rise 1993-2010

The urban climate challenge



50% of the world's population lives in cities and they are responsible for 75% of the world's carbon emissions. Both of these figures are increasing. City administrations across the world face the challenge of building new, or more commonly adapting existing infrastructure, buildings and systems to meet the challenges of changing weather patterns, increased demand for resources, shifting demographics and increased pressure to reduce emissions.

This report, the first in a series, presents a high level approach to urban water management and practical case studies for mayors and city administrations to consider as they put climate change adaptation policies into action.

These recommendations were developed and refined at a C40 UrbanLife workshop, held in Ho Chi Minh City in May 2010, which brought together Arup's global water, climate change and master planning specialists together with the city administrations in order to recommend strategic measures for helping the Vietnamese city build water resilience against climate change.

Each city has its own context and no single approach can help all cities adapt to water. However, the measures can form a starting point for considering an effective response by the political and private organisations involved in keeping cities running.

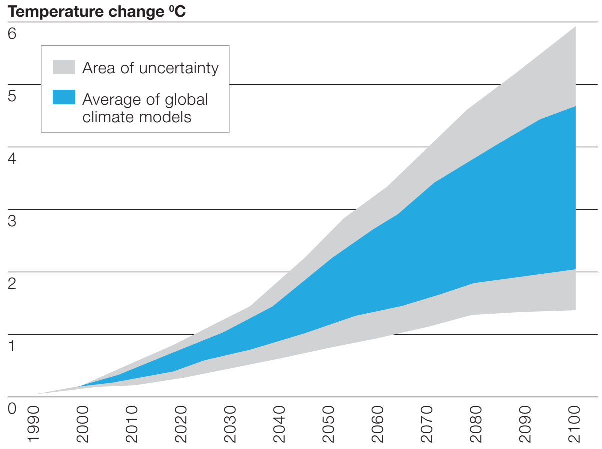
Director, Energy
and Climate Change

Urban water resources: the challenges

Around the world, city leaders are searching for ways to meet growing demand for water while grappling with water issues associated with unexpected new patterns in global temperature changes.

The problems for cities are complex and pressing: Growing and more affluent populations and changing climate are putting pressure on cities' demand for water, and, as sea levels rise, on their ability to handle flooding. Increased demand for water is resulting in groundwater depletion. Meanwhile, saline water intrusion runs the risk of making groundwater supplies unusable.

Projected warming



Increase in average global temperatures 1990 – 2100, shown in degrees Celsius (Source: Dow and Downing, 2006).

Sea levels on the rise

The latest International Panel on Climate Change (IPCC) projections from climate change models predict that sea levels could see a mean rise of 480 millimetres by the year 2100 – and some sources, that account for dynamic changes in the ice sheets, make this figure four times higher.

Flooding will increase, affecting the hundreds of millions of people who live in cities situated close to vulnerable coastlines, river flood plains and river deltas. Many non-coastal cities, located besides rivers or in the foothills of mountains, will also face the problem of flooding as a result of more intense rainfall or snowmelt.

Extreme weather events

Extreme weather events, such as tropical storms, are expected to become more frequent while rainfall is predicted to become more intense, even as some areas receive less rainfall than usual. Many cities can expect greater rainfall while others will experience droughts more severe than they have had in the past.

Reductions in fresh water stores

Where there are higher rates of evaporation, prompted by increased temperatures, drier soils will soak up more water, reducing the recharge of underground aquifers and the flow of fresh water springs. Higher temperatures will reduce the amount of water stored in mountain snowfields. As fresh water reserves found in glaciers and snow fields diminish, cities will be pressed to find new ways to store water to meet growing demand throughout the year.

Although the global supply of water remains relatively stable, regional differences in seasonal and annual precipitation will be significant. Estimates suggest that climate change will account for about 20% of the increase in global water scarcity.

Water scarcity

Water scarcity affects hundreds of millions of urban dwellers worldwide. Climate change will exacerbate this, as prolonged droughts and spreading destertification will increase the stress on already-stretched water resources. Cities that rely on glacial melt water may be impacted as glaciers recede and dry season water sources are not replenished. The result could be reductions in available water for drinking, household use and industry.

Water quality issues

The quality of existing water, moreover, will become a further concern for some urban areas. Changes in the amounts or patterns of precipitation may change the route and residence of water in the watershed, in gturn affecting its quality. Regardless of water quantity, water could become unsuitable for use.

Salination

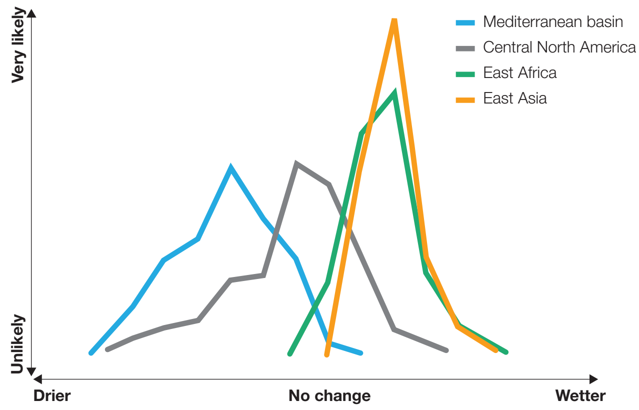
For coastal cities, water quality is likely to be affected by salinisation, or increased quantities of salt in water supplies. This will result from a rise in sea levels, which can increase salt concentrations in groundwater and estuarine rivers. At times of low rainfall, city water managers will find it more difficult to release fresh water from reservoirs when needed for salinity control. The problem becomes even worse in regions where the dry season extends.

Higher sea levels due to climate change are more likely to breach existing coastal/river defenses. The result can be greater inundation of salt water which runs the risk of overloading water treatment systems. More intense rainfall may cause overloading of drainage systems, increasing cities' vulnerability to flooding and reducing the level of flood protection.

Reduced food security

Climate change, finally, could threaten food security as agricultural activity in the tropics and sub-tropics is forecast to slow because of rising temperatures and drought. As demand for water intensifies under the climate change, effective methods for managing water resources and demand will become essential.

Precipitation



Likelihood of wetter or drier June to August with a doubling of CO_2 equivalents in atmosphere, at approximately 2100 (Source: Dow and Downing, 2006).

Water resource management

Ensuring a resilient water supply as climate patterns change and populations grow requires cities to introduce active water resource management measures. Arup recommends that city administrations consider a combination of increasing raw water storage capacity, combating salination, implementing demand management and improving river basin management.

Increasing raw water storage capacity
Recommendation

Cities will increasingly face the challenge of how to store water during times of water plenty so that sufficient water resources are available during times of need.

With ever increasing demands for water, many cities face the real possibility that in drier years water basins experience a seasonal deficit.

An investment in urban water security

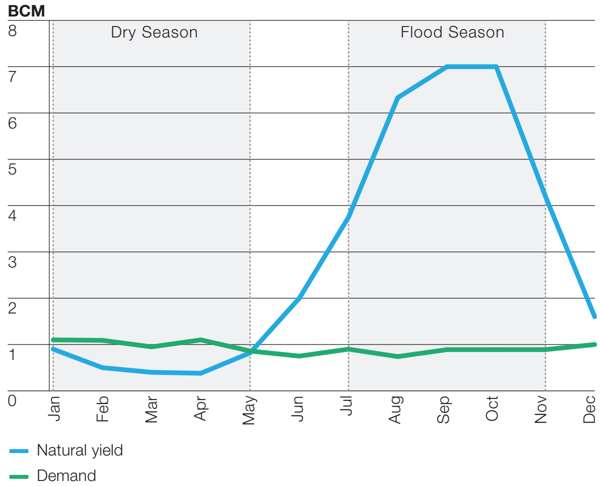
Climate change for some urban areas may cause more frequent and more severe storms and longer, drier periods of drought.To combat the impacts of drier dry seasons and wetter wet seasons, cities need to ensure that they have sufficient water storage capacity. Storage of water in reservoirs or in underground aquifers helps to ensure that water collected in the wet season will be available to boost river flows in the dry season.

Greater storage will be needed to capture peak flows and supplement low water flows. Increasing water storage capacity can be regarded as an investment in greater urban water security and reliability New groundwater and surface water storage will ensure a reliable water supply, and provide vital flood protection by managing more variable precipitation and runoff.

Alternative storage solutions

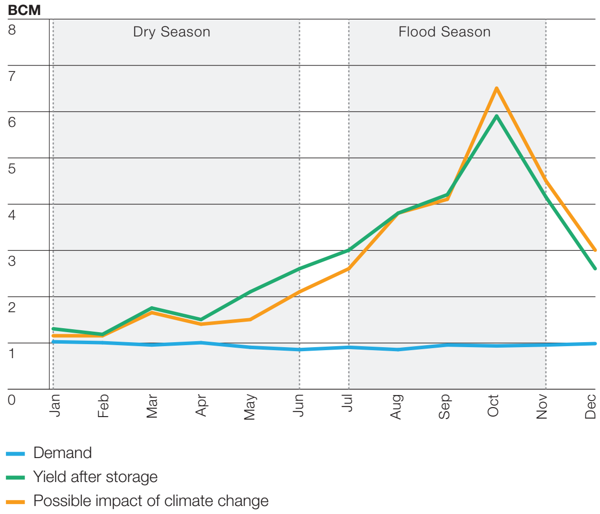
Climate change will impact not only the amount of water storage that cities need, but also the method of storage. While water storage strategies tend to focus on large-scale man made dams, there exists a wide range of alternative storage solutions, including natural storage, such as groundwater storage, wetlands and lakes, community tanks, and smaller scale reservoirs.

Water Resources in Ho Chi Minh's River Basin



Water supply in Ho Chi Minh City's Dong Nai river basin illustrates the issue of seasonal supply in a typical year.

Impact of climate change on water resources



Owner
Southern Water

Location
Southampton, UK

Consultants
Arup

Completion date
2002

Testwood Lakes scheme, UK
Case study

The Testwood Lakes Scheme uses river bank storage facilities to provide security of water supply to meet peak water demands during low river flows and it ensures against short term river pollution events. It consists of lakes formed in three disused gravel pits, just 800m away from the river and near to an existing water treatment facility. The scheme converted one to a reservoir and two to nature conservation areas.

Before the commissioning of the storage reservoir, raw water was pumped to the water treatment works directly from the nearby River Test. However, during seasonal drought conditions low river flows made operation of the works questionable given the requirement to maintain environmental flows in the river downstream.

The scheme provides the UK's Southern Water with a valuable water storage asset and benefits the local community through the provision of a major amenity and leisure facility. River bank storage solutions are one way that water authorities are combating the impacts of climate change such as increasingly longer dry seasons while protecting against pollution risks.

270m
litres storage capacity

A valuable water storage asset and a major environmental and leisure facility

Top Little Testwood Lake, one of three disused gravel pits, is now a reservoir with a storage capacity of 270m litres. **Left** Two of the lakes have been converted in to nature conservation areas, benefitting the 200,000 inhabitants in and around Southampton. **Right** Little Testwood Lake is 800m away from the River Test, the previous source of raw water.

Combating salination
Recommendation

As sea level rises, there is the risk that salty seawater will intrude up estuaries, into the lower portions of rivers and into groundwater aquifers. In flat lands, even a minor sea level rise can result in salinity intruding miles up-river during dry periods. Furthermore, with simultaneous changes in river flow in climates with reduced precipitation and more water extracted from upstream reservoirs, and in ocean winds and waves, seawater may intrude even further – changing critical habitats and threatening freshwater supplies to cities located close to coastlines.

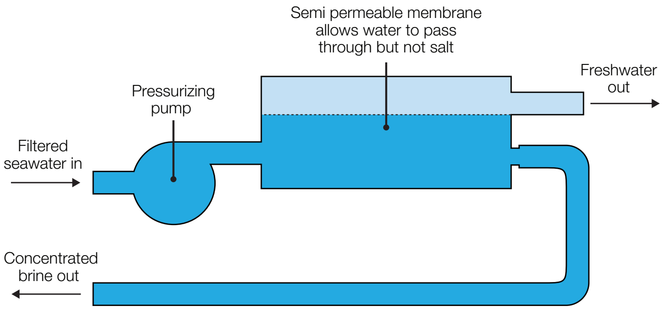
Raw water storage

The first method of combating salination is to develop raw water storage that is protected from the effects of salination and can allow continued production of water at treatment plants when water becomes temporarily too saline.

Desalinating brackish water

The second approach is to improve water treatment by introducing a desalination process for brackish water that operates alongside the conventional treatment of surface water. Ocean water and brackish groundwater are desalinated so they can be converted to drinking-quality water. Conventional treatment processes such as coagulation, flocculation, sedimentation and filtration cannot remove dissolved salts from water.

Desalination of brackish water by reverse osmosis



The RO treatment process works by forcing water under pressure through a membrane. The membrane is specifically designed so that the salt fraction and other impurities in the water stream do not pass through and the concentrated brine solution is held and discharged to waste from the upstream side of the membrane. In hotter climates the brine waste is evaporated in ponds so that the residue with value can be disposed of more readily.

Owner
Shanghai Municipal Government

Location
Shanghai, China

Consultants
N/A

Completion date
2011

Shanghai Qing Cao Sha reservoir, China
Case study

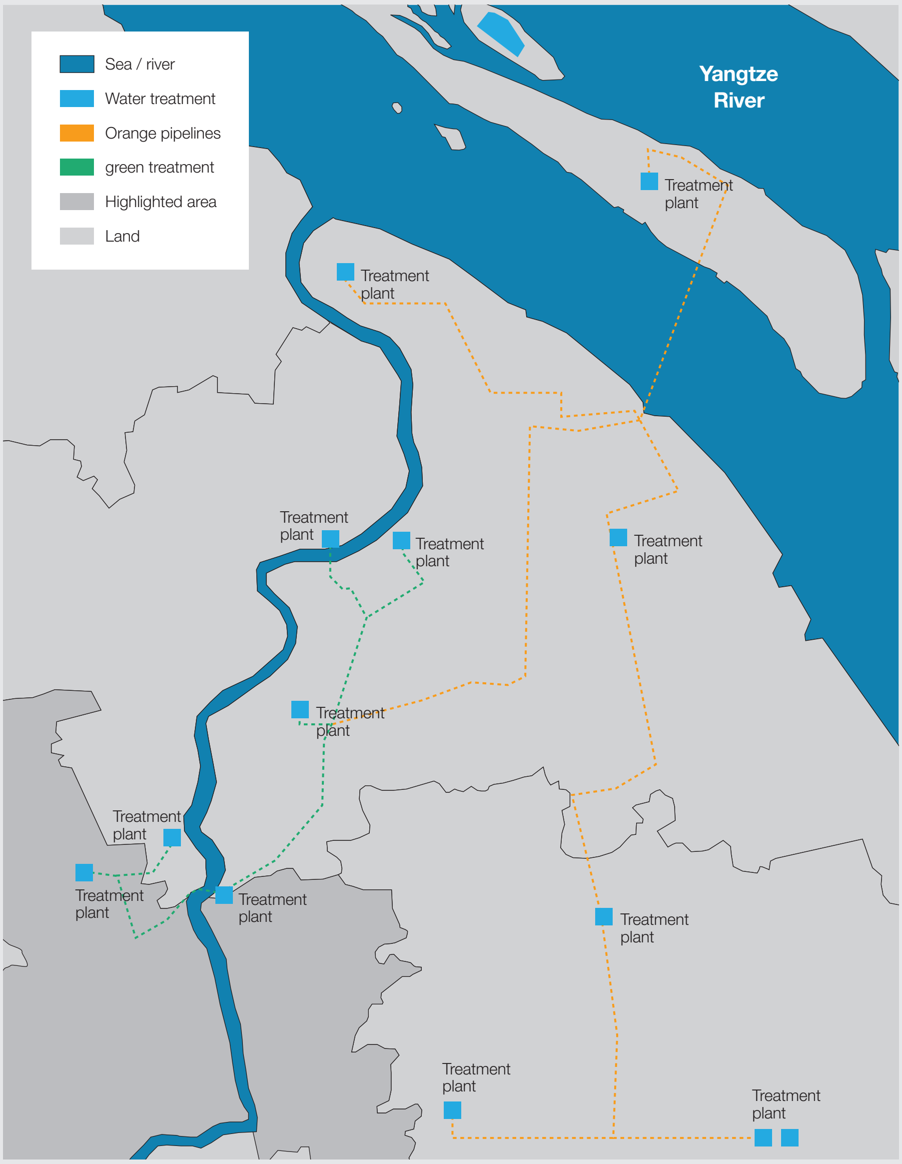
To cope with the challenges of existing water source pollution and seasonal salination, the city of Shanghai opted to invest in a bulk water storage reservoir in the middle of the Yangtze River.

In November/December high tides and diminishing river flow can create temporary salinity problems as far as 80km inland for Shanghai, a city of more than 20 million. The situation could grow worse due to upstream dam construction, over-use of groundwater and water transfer to the north of China.

Expected to be complete soon, The Qing Cao Sha Reservoir will have a footprint of 70 sq km with a capacity of 435MCM, which is estimated to equate to 68 days worth of water demand. To link this new source of water to various treatment facilities, Shanghai is building-out its water grid to optimise the delivery of fresh water in the years ahead.

20m
population of Shanghai

68 days
equivalent water demand of Qing Cao Sha Reservoir



Implementing water demand management
Recommendation

Demand management and conservation play an important part in the development of a robust and resilient water resource strategy for any city. Importantly, cities that apply non-supply based approaches will be positioned to make the most of what could be diminishing water resources as a result of drier climatic conditions in the years ahead.

The need for demand management policies

The impacts of climate change makes development of water management demand management policies even more important for city administrations responsible for managing water. Growing water scarcity, problems with deteriorating water quality, and the effects of more severe and frequent extreme climatic events, such as storms, floods and droughts increase the need for water demand management measures.

Water conservation measures

Key water conservation and efficiency measures – also called demand-side measures –will be of critical importance for groundwater resources that suffer from over-use and should therefore be given priority. These measures include:

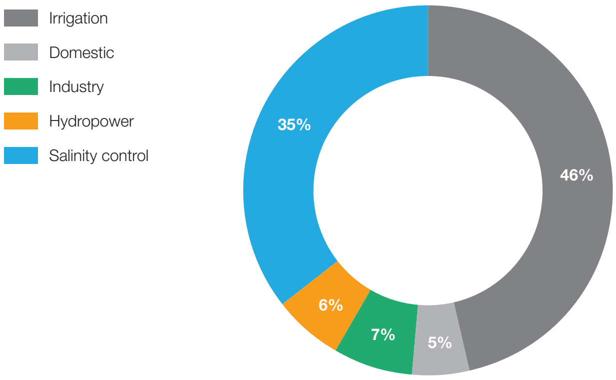
- Reducing waste from water transmission systems and networks
- Recycling water
- Using water-efficient or water-saving devices
- Fiscal measures to ensure that water goes to the highest socio-economic value users, such as domestic and industrial users
- Ensuring that rivers remain healthy and beneficial as ecosystems

Social and economic benefits

Improved demand management can generate important social and economic benefits. In a delta city such as Ho Chi Minh City, reducing agricultural irrigation demand upstream means more water can be made available to high value users such as domestic and industrial use downstream, and, in turn, more effective salinity control can be achieved by higher downstream water flows.

At the same time, by reducing industrial demand for water, cities are better able to conserve groundwater, a common water resource for industry. Finally, by decreasing domestic demand and pipe network waste, this high value water can service a larger population in the future.

Gross water demand in the Dong Nai basin, Vietnam



The Dong Nai river basin supplies Ho Chi Minh City. The majority of the water usage is for agriculture and for salinity control, largely associated with agriculture. Water demand management allows more water for important higher value uses such as domestic and industrial use downstream and more effective salinity control may result due to higher river flows.

Owner
Ministry of Water and Irrigation

Location
Jordan

Consultants
USAID / DAI

Completion date
Ongoing

IDARA programme, Jordan
Case study

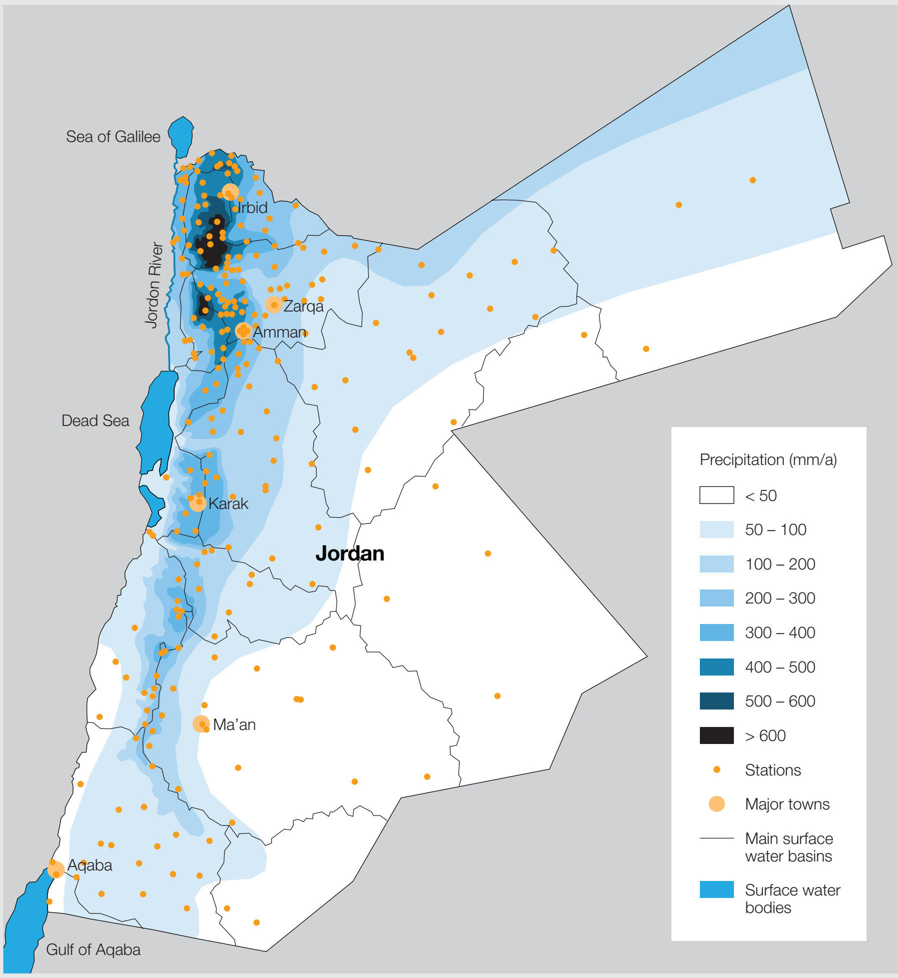
One of the driest places on earth, Jordan suffers from absolute water scarcity. In response, the Instituting Water Demand Management in Jordan (IDARA) programme is engaging citizens in water conservation efforts. The programme uses water policy change, new regulations, institutional support, modern technology, best management practices and education and outreach to affect change.

IDARA's achievements to date are impressive: water demand from new high rise developments in the capital city Amman is down 40% as a result of a new building advisory code, while the city has witnessed a 15%-20% demand reduction in residential areas involved in the IDARA outreach programme.

Meanwhile, new measures to reduce demand from the agricultural sector, Jordan's largest water consumer, include reusing treated wastewater, modern irrigation techniques and technologies, switching to less water intensive crops and imposing higher tariffs on agricultural water consumption.

20%
reduction in water demand from residential areas

40%
reduction in water demand from new developments



Improving river basin management
Recommendation

Basins need to be managed for the benefit of all stakeholders and the ecosystems that depend on healthy river systems. To do this effectively requires investment in time and resources by national governments.

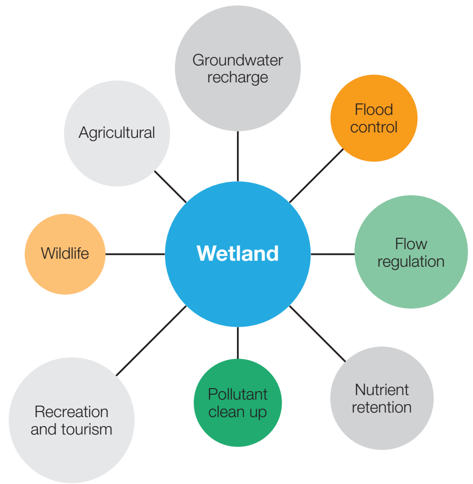
National assets on international boundaries
River basins are valuable national assets and the management of their water resources should not remain in the hands of marginal interests, such as hydropower or agriculture. At the same time, a large number of river basins are located on regional or international boundaries. Many of them are not governed by cooperative management agreements.

Water does not stop at administrative or political boundaries, so the best way to protect and manage water is by close international co-operation between all the countries within the natural geographical and hydrological unit of the river basin – bringing together all interests upstream and downstream.

Transboundary agreements
Transboundary water management arrangements and legal agreements must be developed to provide an effective framework to share the water resources equitably. It is particularly important that mechanisms are put in place to stimulate greater cooperation between transboundary countries on adaptation measures. This may be done under existing international frameworks such as the UN Watercourses Convention, which already encourages such cooperation.

Flood management
Basin management should not only be concerned with the best use of water resources. Effective management of flooding due to discharges from reservoirs and the inflows from catchment downstream also need to be considered.

The benefits of wetlands



Wetlands are an important part of river basins and a national asset, as well as being a mechanism for harvesting stormwater (see page 22)

Owner
MDBA

Location
South Australia

Consultants
N/A

Completion date
Ongoing

Murray-Darling Basin, Australia
Case study

For years, inadequate cooperation among the individual states of Queensland, New South Wales, Victoria and South Australia hampered integrated management of the Murray-Darling Basin.

The Basin suffered due to severe drought and over-allocation of water for agriculture. A single, independent agency, The Murray-Darling Basin Authority (MDBA), backed by a $12 billion Australian government investment program, is now responsible for planning integrated management of the water resources of the Murray-Darling Basin.

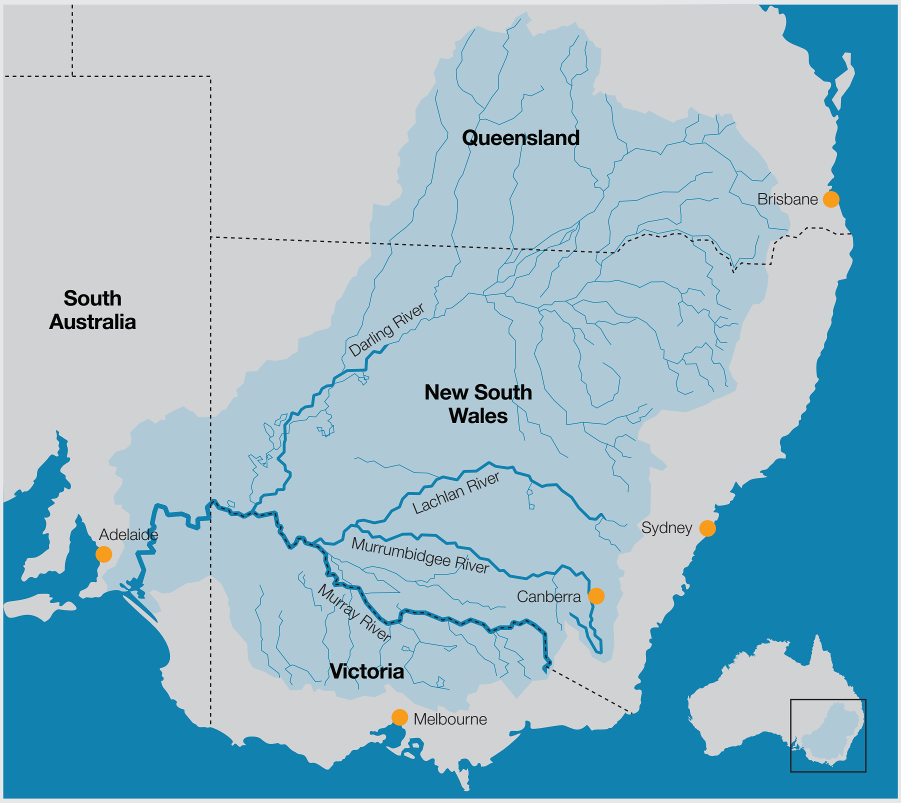
The Authority is preparing a Basin Plan that will, for the first time, set a long-term sustainable limit on the use of both surface and groundwater in the Murray-Darling Basin, while strengthening the role of the Australian Competition and Consumer Commission (ACCC) in regulating the water market.

Additional programs undertaken by the MDBA include the:

- Stakeholder engagement: a critical component in developing the Basin Plan. Helping people understand the plan development process, the content, potential implications and providing opportunities for people to input into the plan.
- The Sustainable Rivers Audit: monitoring Basin health.
- The River Murray Water Quality Monitoring Program: the primary objective of which is to collect physicochemical parameters at 36 sites along the River Murray and the lower reaches of its tributaries.

14%
of total area of Australia

39%
of Australia's national income derived from agriculture in the basin



The catchment area for the Murray and Darling rivers covers 1m km² and includes 23 river valleys. It produces 53% of Australia's grain crop and 28% of the nation's cattle herd.

Flood management and climate resilience

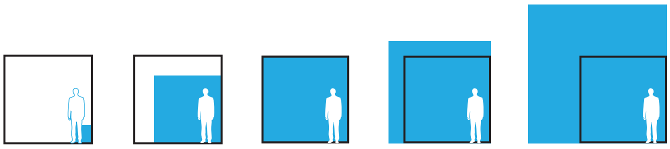
Flooding is becoming a reality for the many urban areas that for economic and historical reasons are situated in flood plains. Arup recommends the following measures to improve the resilience of cities and their ability to adapt to climate change relating to flood management: improve drainage networks, deploy Water Sensitive Urban Design (WSUD) into city planning, harvest rainwater and recharge groundwater.

Deploying WSUD into city planning
Recommendation

Water Sensitive Urban Design – or WSUD – is a widely promoted best management practice concept in America, Australia and Europe. It is an approach to urban planning and design that integrates land and surface water planning and management into urban design.

WSUD relates to all parts of the urban water cycle and involves improvements in town planning, engineering design, asset management, urban landscaping and urban water management.

Green space in urban areas



A comparison of available green space per person in some of the world's largest cities, compared with the World Health Organisation's recommendation.

The key objectives of WSUD

- Protect and enhance natural water systems within urban areas. Promoting and protecting natural water systems, and treating them as assets, allows them to function more effectively and supports the existing ecosystems that depend on them.
- Incorporate stormwater treatment methods into the natural landscape. Natural stormwater drainage systems can be employed by taking advantage of their natural aesthetic qualities.
- Protect water quality and improve the quality of water draining outward to the natural environment from urban areas. Through filtration and retention, water draining from urban developments can be treated to remove pollutants close to their source. This approach reduces the effect that polluted water can have upon the environment and protects the natural waterways.
- Reduce runoff and peak flows. Local detention storage enables effective land use for flood mitigation by utilising numerous storage points in contrast to the current practice of utilisation of large retarding basins. This approach subsequently reduces the infrastructure required downstream to effectively drain urban developments during rainfall events.
- Add value while minimising development costs. The reduction of downstream drainage infrastructure due to reduced peak flows and runoff minimises the development costs for drainage, whilst enhancing natural features such as rivers and lakes that add value to the properties of the area.

Owner
Bay Meadows Land Company

Location
San Mateo, California

Consultants
Arup
Cooper Robertson & Partners (architects)

Completion date
2011

Bay Meadows, San Francisco
Case study

Arup applied WSUD to a new storm water management system along one of the San Francisco Bay Area's busiest commuter rail corridors. Embracing a philosophy of 'doing more with less', Arup proposed the following key storm water strategies to alleviate longstanding flooding problems:

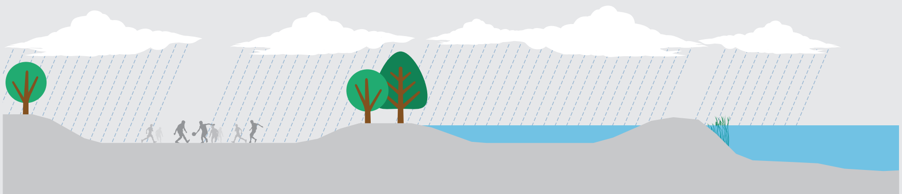
- Surface runoff from the development drains to a designated wet pond prior to discharge to the downstream drainage system. The pond retains and attenuates the peak surface runoff and also cleans the storm water. The pond also serves to provide 2,270m^3 of year-round water storage for firefighting water supplies.
- Floodable recreation fields behind the wet pond safely accept and detain floodwater during and after major storms.
- A suite of best management practices – such as rain gardens, curb-side biofiltration planters and bio-swales – are planned for street-level development to reduce peak flow and control pollution locally.

Developer Bay Meadows Land Company is transforming 33.8ha of impenetrable private property into a pedestrian friendly mixed use development driven by the approach 'environment, society and economy'.

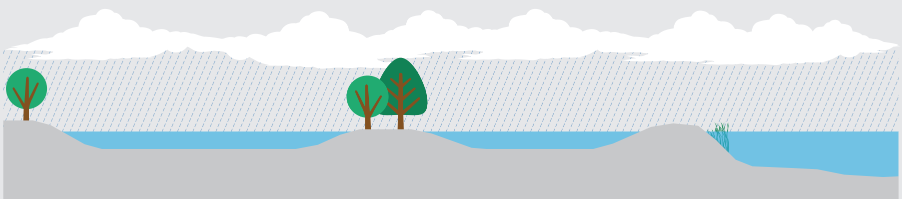
Wet and dry ponds

Case 1: <2 year rainfall

Case 2: 2 to 10 year rainfall



Case 3: 10 to 100 year rainfall



This conceptual design indicates how a community park can provide flood relief at times of heavy rainfall.

Harvesting rainwater and recharging groundwater
Recommendation

As water demands rise and surface water supplies become become further stressed by climate change, urban areas will grow increasingly dependant on ground water resources. Ground water resources need to be managed so that withdrawal is kept at pace with the aquifer recharge.

If ground water is used more than replenished, then the ground water present in the aquifer will be depleted and the ability of the aquifer to store water may eventually be diminished.

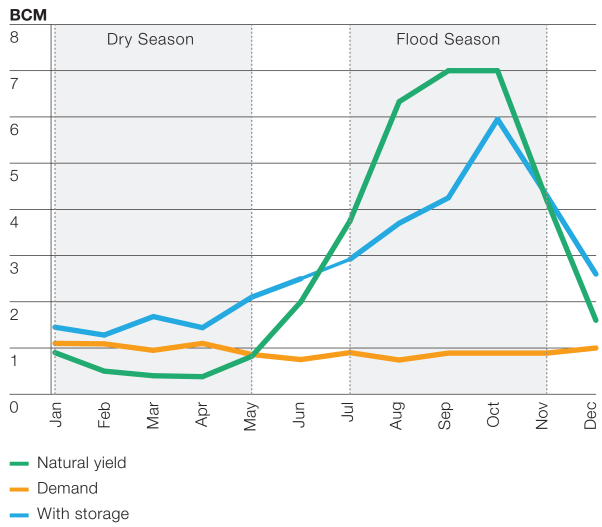
Artificial recharging of the aquifer

Artificial recharge by rain water harvesting is an important way of maintaining ground water resources.

Rainwater harvesting means "Catch the rain water where it falls". Collected rainwater can be stored for direct use or can be recharged into ground water for later use. Rain water may be collected and recharged into the ground water aquifers through the use of pits, trenches, dug wells, hand pumps, recharge wells and shafts, lateral shafts with well bores and spreading techniques.

Harvesting of rainwater and the recharge of groundwater provide cities with resilience to climate change. Rainwater harvesting reduces storm water discharge to the downstream drainage system and provides an alternative water supply at source. Recharging groundwater reduces or arrests ground settlement and safeguards groundwater as a resource for water supply.

Water demand and yield in Ho Chi Minh City



Demand can outstrip natural yield during the dry season, and the oversupply during the wet season can result in urban flooding. Introducing storage systems will mitigate these issues.

Owner
City of Salisbury

Location
Salisbury, South Australia

Consultants
CSIROS

Completion date
2002

Salisbury, South Australia
Case study

This is one of the world's first projects in which urban storm water, harvested from an urban catchment, is conveyed to an engineered wetland, stored underground in an aquifer and recovered as water suitable for a continuous and sustainable supply at potable water quality.

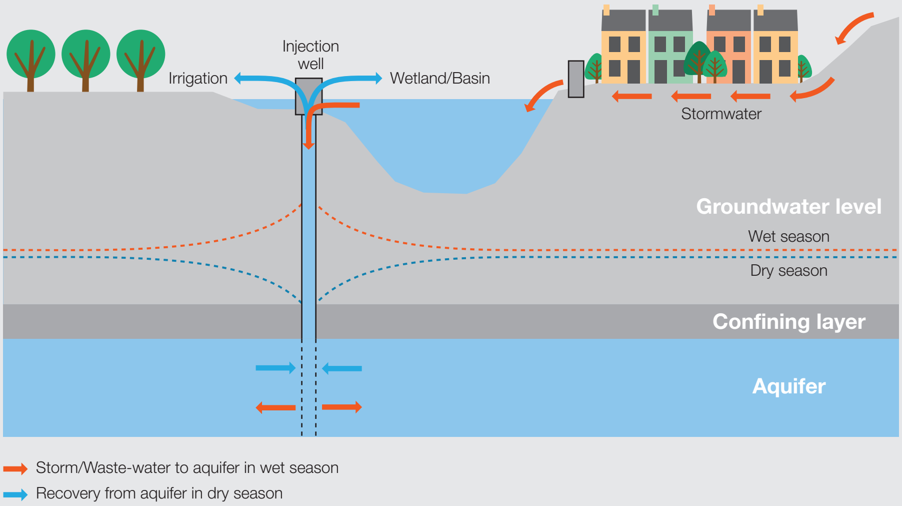
An average annual 450mm of rainfall lands on the 1,500 hectare residential and industrial catchment yielding a total runoff of some 1,300ML per year. This is stored, treated and eventually fed to the city's water grid. As well as eliminating the flow of polluted water into the marine environment of the Barker Inlet of Gulf St Vincent, the project provides landscape enhancement and creation of habitat diversity.

This project marks City of Salisbury as a world leader in the field of stormwater harvesting, wetland construction and implementing aquifer storage and recovery technology.

260ha
of wetlands created

The creation of wetlands to cleanse stormwater was Salisbury's key strategy to help the ecological rehabilitation of the Barker Inlet while providing water to local industry and other users.

Aquifer storage and recovery (ASR)



During the high rainfall period in winter, excess stormwater, filtered and cleaned by the wetlands, is pumped into the aquifer, 164 metres below the ground. During the dry summer, the water is recovered as needed to irrigate sports fields and turf areas. This eliminates the demand on mains water for irrigation, conserving water and reducing costs.

Improving drainage networks
Recommendation

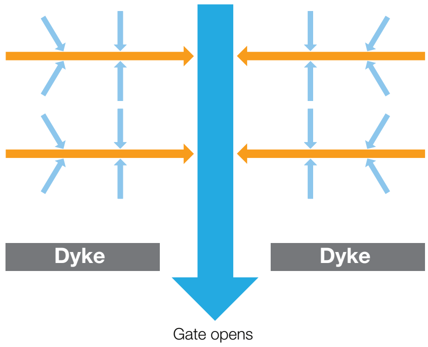
Urban drainage networks need improvement to cope with more intense rainfall. This is particularly so for coastal cities also affected by sea level rise, which include 13 of the world's megacities.

The measures recommended will vary according to topography and the prevailing natural drainage system. In some cases, diversions will be possible directing runoff from upstream away from vulnerable low lying areas. In others cases, storage of the peak runoff underground will be appropriate.

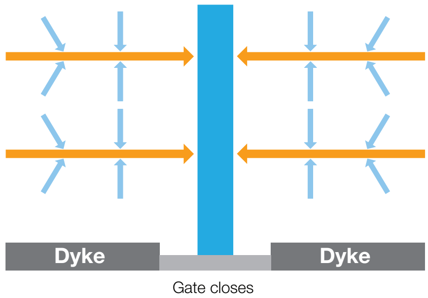
In all cases the best measures will be those that allow the maximum use of rainfall as a source for water supply, thereby making the best use of available resources.

Improving Ho Chi Minh City's drainage network

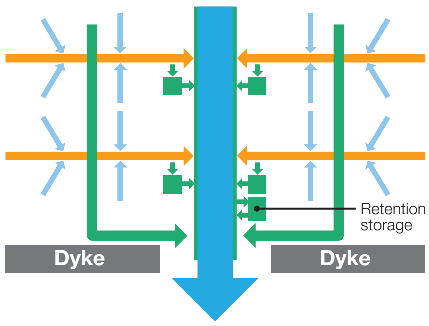
a) Operation mode 1: free discharge to Saigon and Dong Nai Rivers



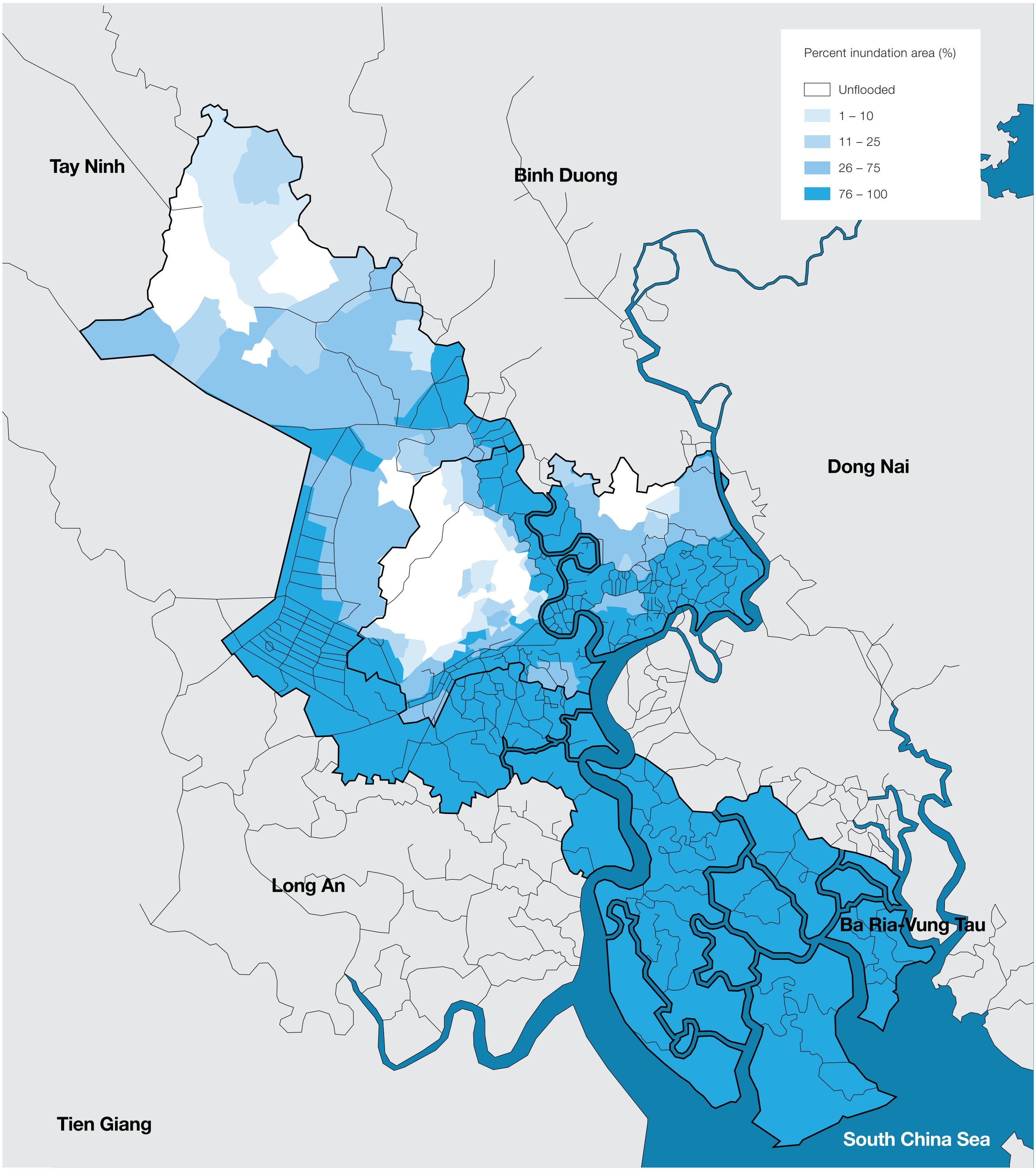
b) Operation mode 2: gates closed to isolate discharge to Saigon and Dong Nai Rivers



c) Implement diversion and increase Retention storage in drainage system



Ho Chi Minh City's drainage system has two different modes of operation requiring different improvement strategies: (a) divert discharge of stormwater in to the Saigon and Dong Nai Rivers and (b) at high tide or times of storm surge, gates closed to retain water within the catchment. Arup's recommendations were (c) adding retention storage along the canal system and a diversion system so that stormwater bypasses flood prone areas.



Ho Chi Minh City's vulnerability to urban flooding: the above map, extracted from the ICEM report 'Adaptation to Climate Change', shows the % area of HCMC that will be affected by flooding under combined heavy rainfall, high tides and wind and storm surge typical of a '30-year' storm, e.g. Tropical Storm Linda in 1997. Almost the entire city would be severely affected by flooding.

Owner
Tokyo Metropolitan Government

Location
Tokyo, Japan

Consultants
N/A

Completion date
2006

Tokyo, Japan
Case study

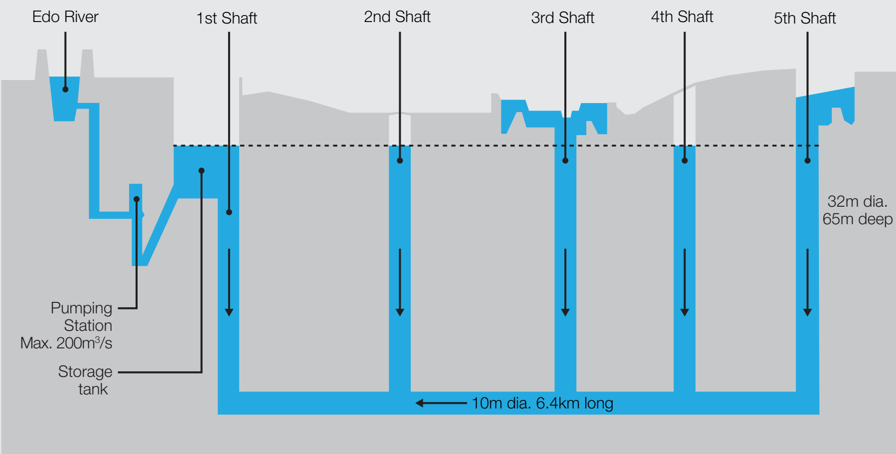
Flooding from heavy rainfall and typhoons was a recurrent event in Tokyo. Due to the city's heavy urban development and congestion, traditional 'above-ground' flood control measures – such as drainage improvement works, river training, channel-widening and dredging are not always possible. Tokyo therefore turned to 'below-ground' flood prevention measures.

- Metropolitan Area Outer Floodway: To reduce flooding of the Naka, Kuramatsu and Ohotoshi-no-furutone Rivers, five vertical intake shafts (32m in diameter and 65m deep), connected by a 6.3km long underground water tunnel (10m in diameter), divert floodwater from these rivers eastwards to the Edo River.
- Kanda River Diversion Channel: A box culvert was installed along under the carriageway adjacent to the Kanda River to provide additional flow capacity for the Kanda River.
- Meguro River Underground Reservoir: An underground storage reservoir temporarily stores floodwater from the Meguro River. When water flows in Meguro River reach a high level, water overflows via a side weir into an underground storage reservoir. Land above the underground storage reservoir has been designated for high-rise housing development

1,714mm
annual rainfall, twice the world's average

2,187km²
urban area

Cross section of the Metropolitan Area Outer Floodway



The hydraulic stormwater tunnel system discharges floodwater to the downstream underground storage tank. The pumping station which is located adjacent to the storage tank pumps floodwater at a maximum rate of 200m³/sec to the Edo River.

Arup has put forward a number of key measures for consideration that we believe will help cities mitigate the risks of climate change on water resilience. They relate to both water resource and flood management and indeed many of the measures should be seen as integrated solutions to manage both.

Measures founded on technical expertise, sustainable, integrated thinking and policy considerations pave the way for urban decision makers to respond effectively to the water-related issues arising from climate change. Such measures are designed to help cities build water resilience today, and mitigate the risks of climate change tomorrow.

Credits and further information

Bay Meadows
www.baymeadows.com

C40 Cities Group
www.c40cities.org

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www.cweb.salisbury.sa.gov.au

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Arup authorship team:
Roger Alley
Kenneth Kwok
Debra Lam
Wilfred Lau
Mark Watts
Fergal Whyte

With thanks to Ben McClure

www.arup.com/urbanlife

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