

# Singapore

## **WATER MANAGEMENT CHALLENGES**

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# Flash Floods

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# Flood Protection: Information

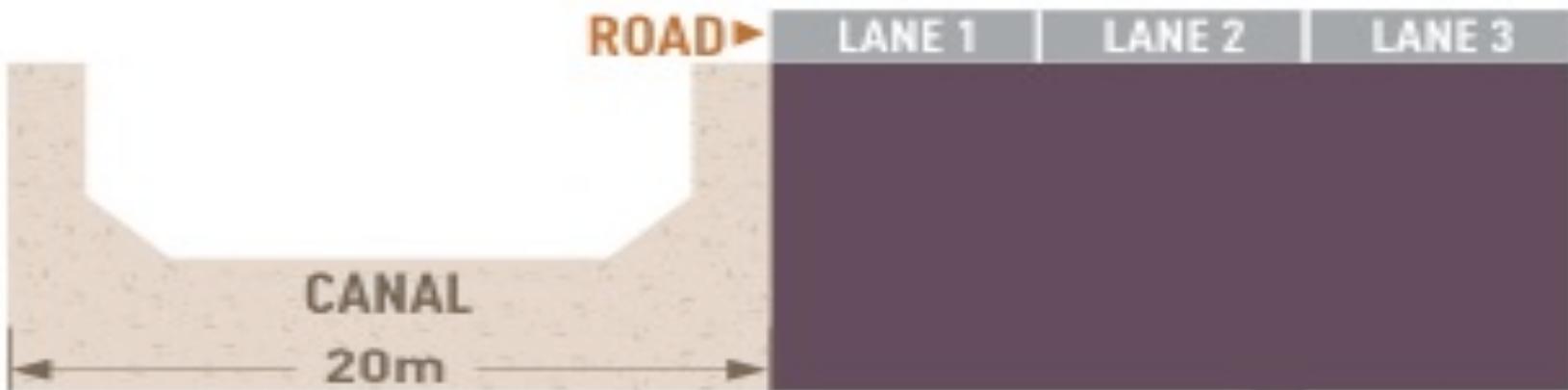
Traditional reduction of floods by storm water:

- Drainage
- Channelization
- Levee construction or improvement

Main disadvantage is that they merely pass the danger of flooding further downstream

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BEFORE



AFTER



A trade-off of widening the canal is a reduction in the number of road lanes

# Flood Protection: Singapore

Approach:

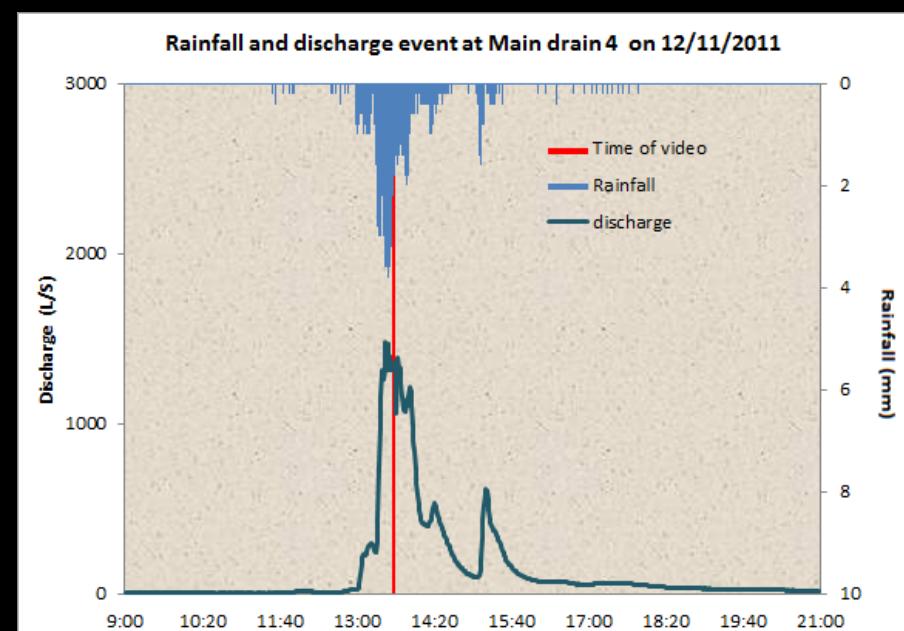
Provide adequate drainage ahead of new developments

Adopt flood protection measures

Continual drainage improvement



# The effect of a 90 mm storm at the outlet of KR catchment



# FLOOD RISK MANAGEMENT

PROBABILITY OF  
FLOODING  
DEPENDS ON  
RAINFALL

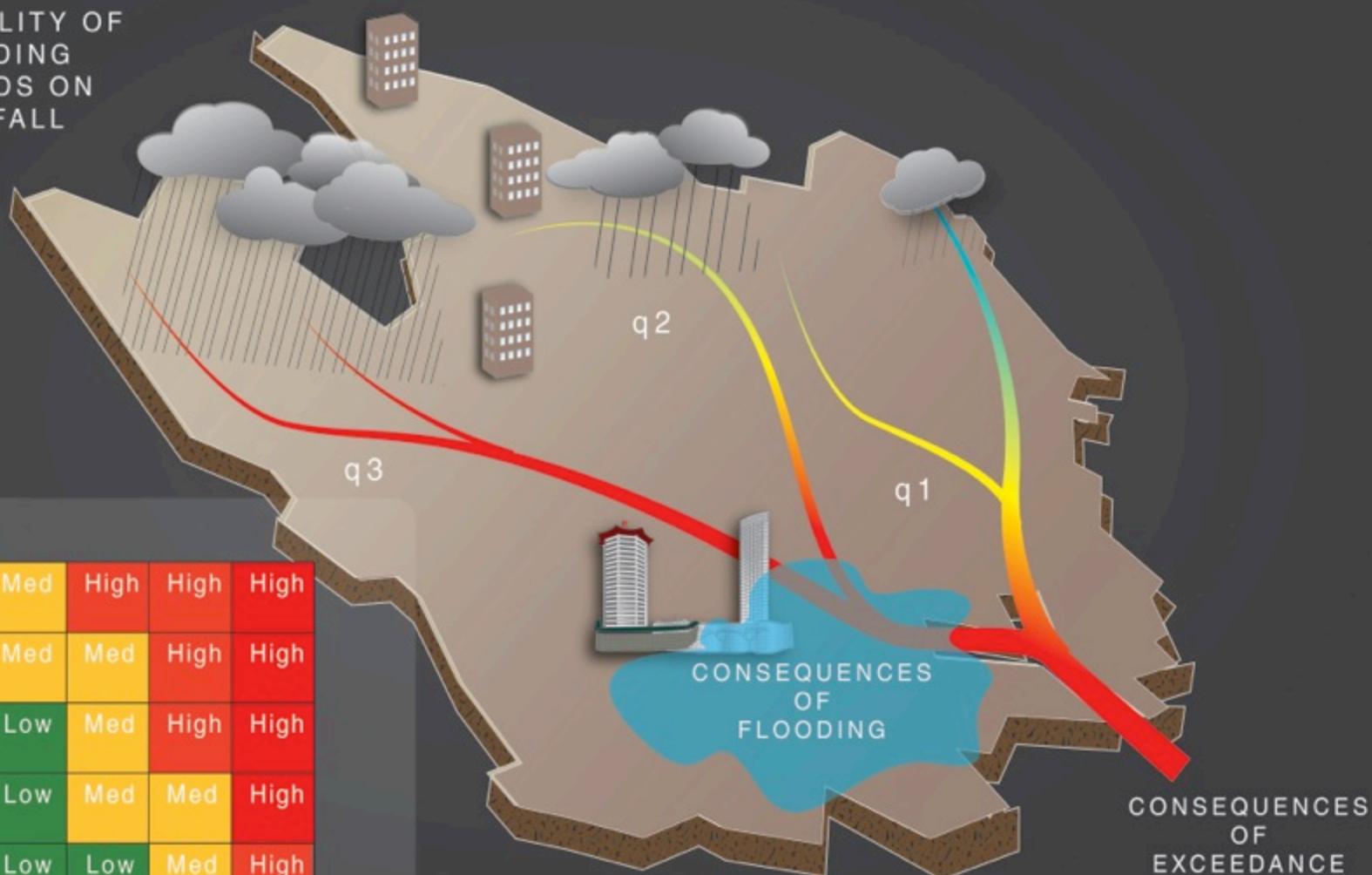
Probability	low	low	Med	High	High	High
high	Low	Med	High	High	High	High
Probability	Low	Med	Med	High	High	High
Probability	Low	Low	Med	High	High	High
Probability	Low	Low	Low	Med	Med	High
Consequence	low	low	low	Med	High	high

Consequence

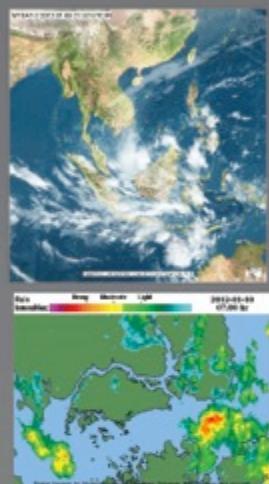
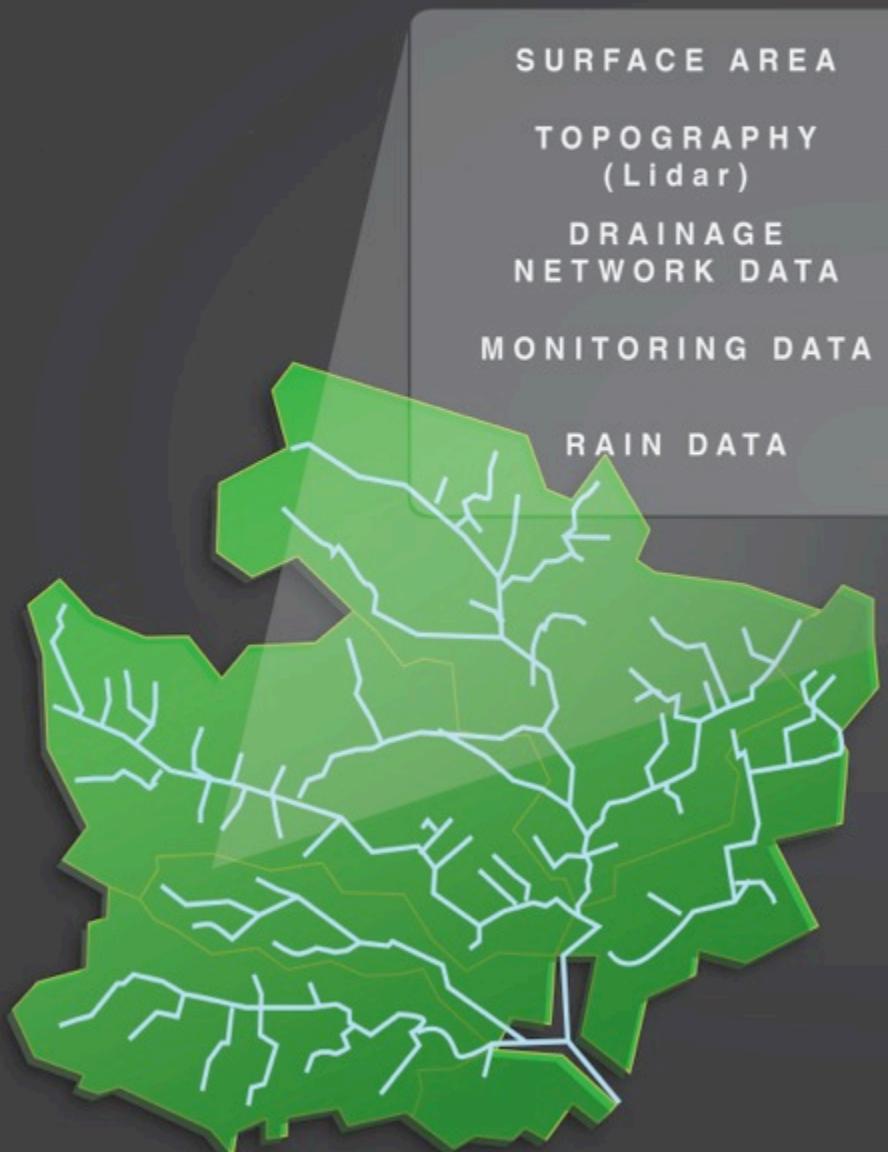
high

Consequence

$$Q = q_1 + q_2 + q_3 + \dots$$



# DYNAMIC MODELLING & MONITORING

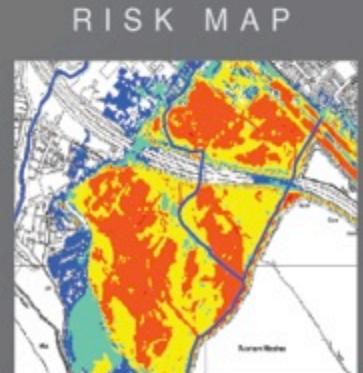


SENSING  
\* Weather Radar  
\* Water Level  
\* Water Flows

PREDICTION & FORECASTING SYSTEM  
\* Adaptive  
\* Self-Learning  
\* Robust /Climate Proof

REAL TIME CONTROL & INTERVENTION

BENEFITS  
\* understanding system performance  
\* evaluating different options  
\* selecting the best solution  
\* continues improvements of system



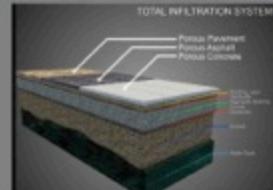
## SOURCE



Detention Pond



Rain Garden

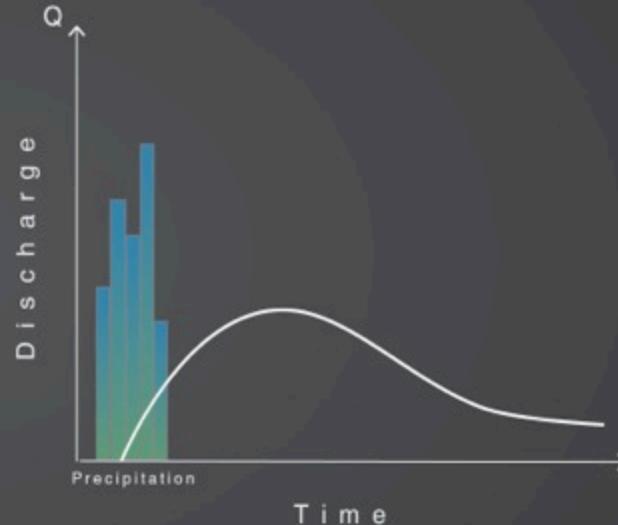
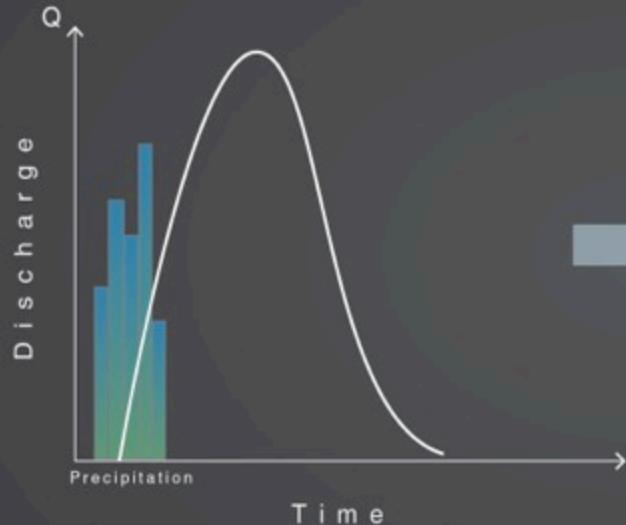


Porous Pavement



Roof-top Water Retention

## PATHWAY



## RECEPTOR



Underground Tunnel



Retention Pond



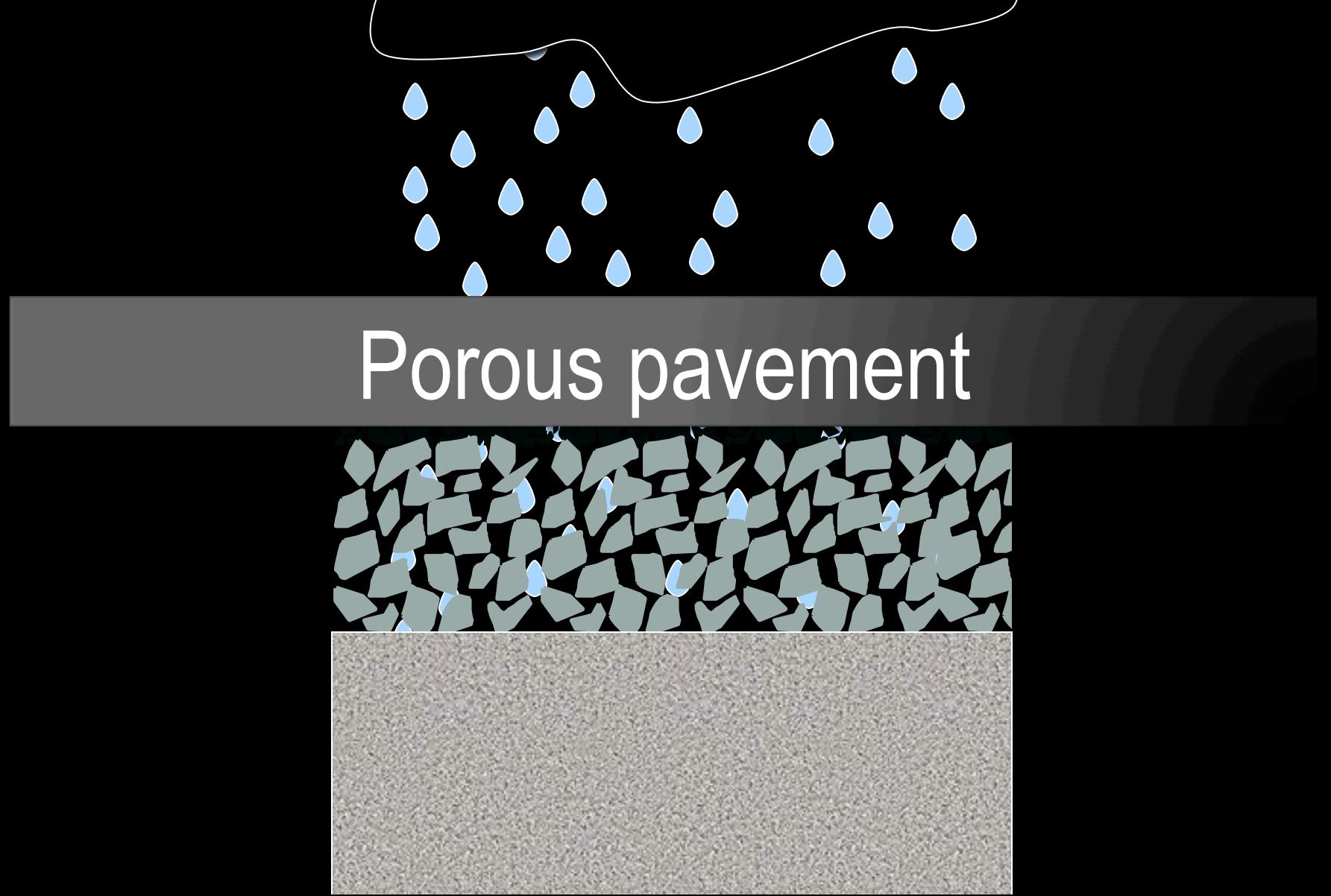
Parking Area Protection



Anti Flood Barrier



Urban Flood Plain



# Porous pavement

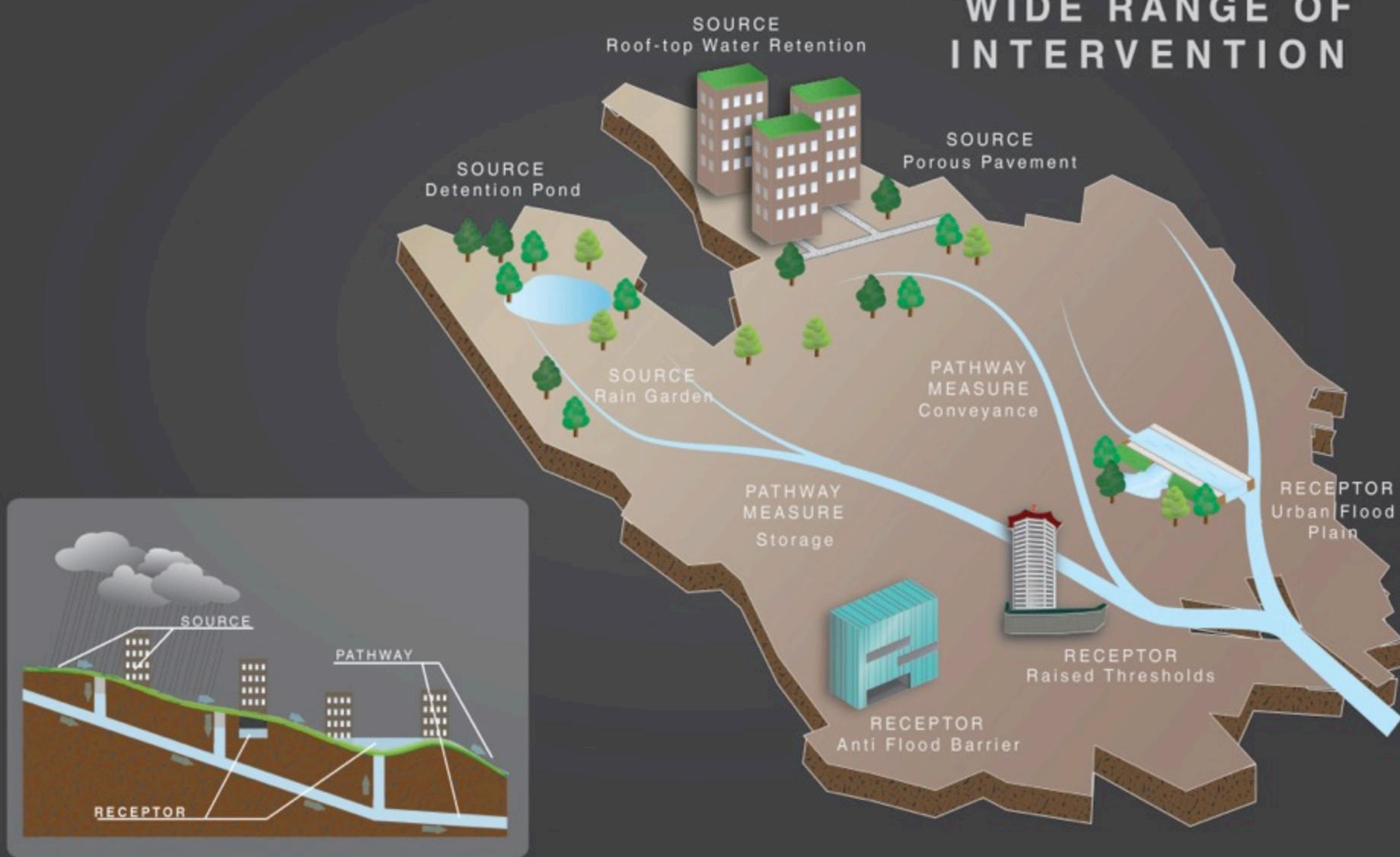
The diagram illustrates the infiltration process of porous pavement. At the top, blue water droplets fall from a wavy white line representing the sky. Below this, a dark grey rectangular area contains the text "Porous pavement". Below the text is a cross-section of the pavement. The top layer consists of grey, irregular stones or pavers. Between these stones, numerous small blue water droplets are shown filling the spaces, representing infiltrated rainwater. Below the stone layer is a thick, light grey textured layer, likely representing a permeable base or subgrade.

*Image courtesy of Kent Hansen, NAPA*



# FLOOD MITIGATION

WIDE RANGE OF  
INTERVENTION



# FLOOD MITIGATION

## Anti Flood Barrier



## WIDE RANGE OF INTERVENTION

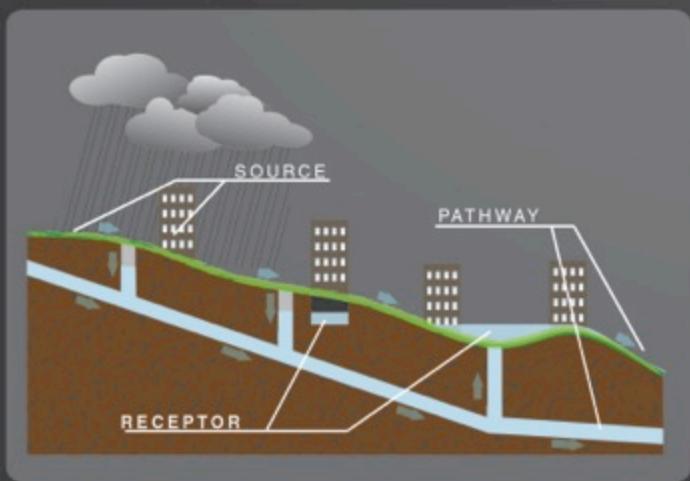


# FLOOD MITIGATION

Detention Pond



WIDE RANGE OF  
INTERVENTION

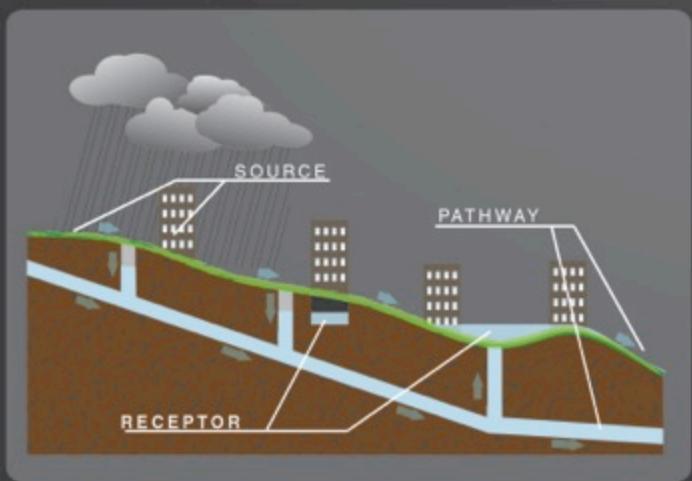


# FLOOD MITIGATION

## Porous Pavement



## WIDE RANGE OF INTERVENTION



# FLOOD MITIGATION

Rain Garden



WIDE RANGE OF  
INTERVENTION

SOURCE  
Roof-top Water Retention

SOURCE  
Porous Pavement

SOURCE  
Rain Garden

PATHWAY MEASURE  
Conveyance

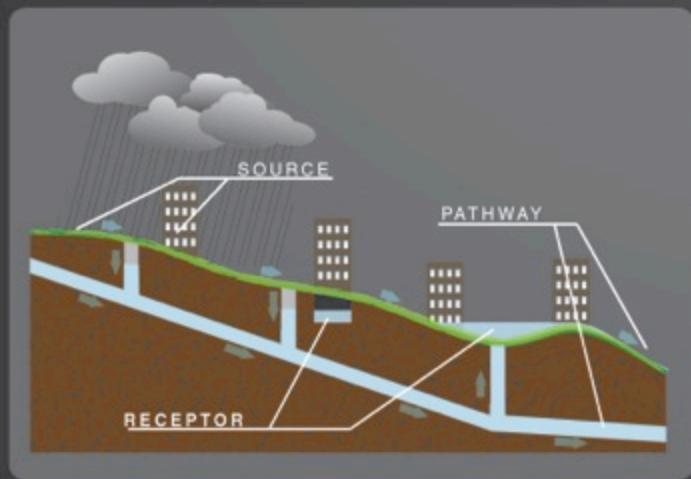
PATHWAY MEASURE  
Storage

RECEPTOR  
Urban Flood Plain



RECEPTOR  
Raised Thresholds

RECEPTOR  
Anti Flood Barrier



# FLOOD MITIGATION

## Roof-top Water Retention



## WIDE RANGE OF INTERVENTION

SOURCE

Roof-top Water Retention

SOURCE

Porous Pavement

SOURCE

Garden

PATHWAY MEASURE

Conveyance

PATHWAY MEASURE

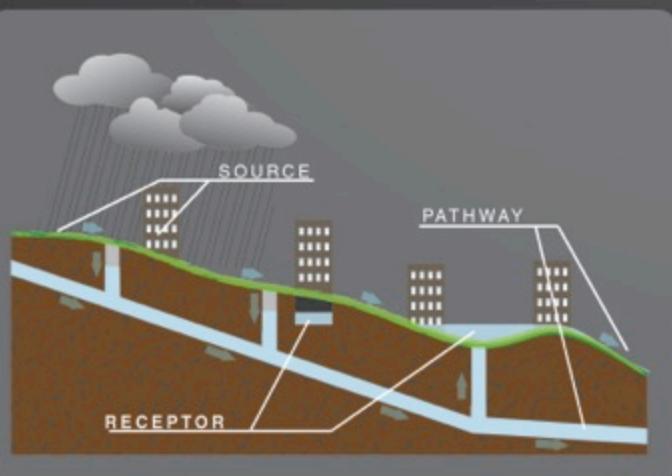
Storage

RECEPTOR

Raised Thresholds

RECEPTOR  
Anti Flood Barrier

RECEPTOR  
Urban Flood Plain

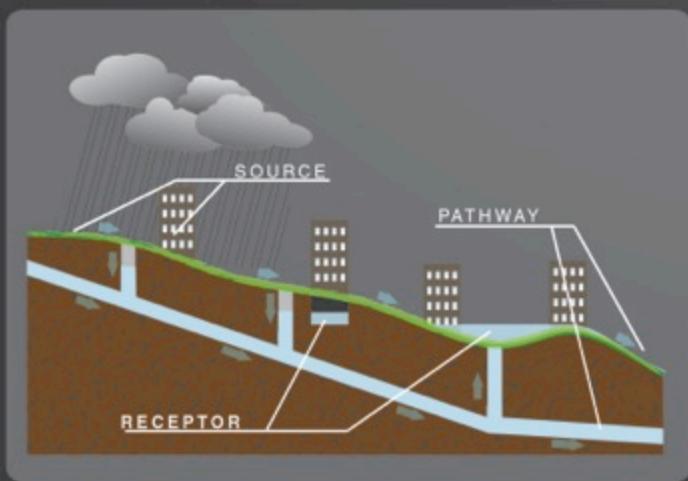


# FLOOD MITIGATION

## Raised Thresholds



## WIDE RANGE OF INTERVENTION

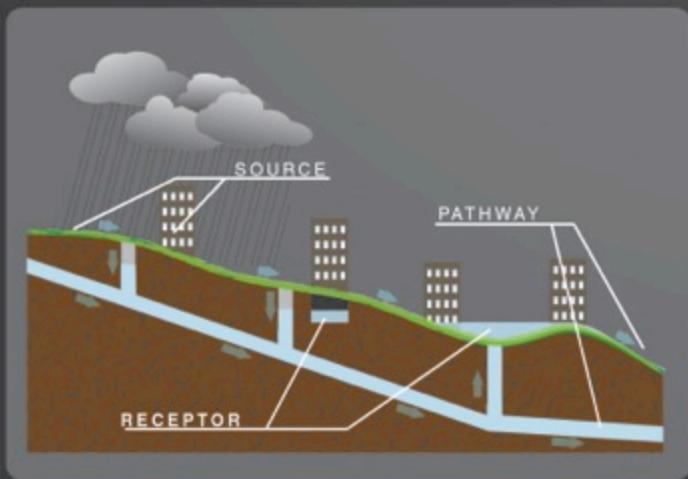


# FLOOD MITIGATION

## Urban Flood Plain



## WIDE RANGE OF INTERVENTION

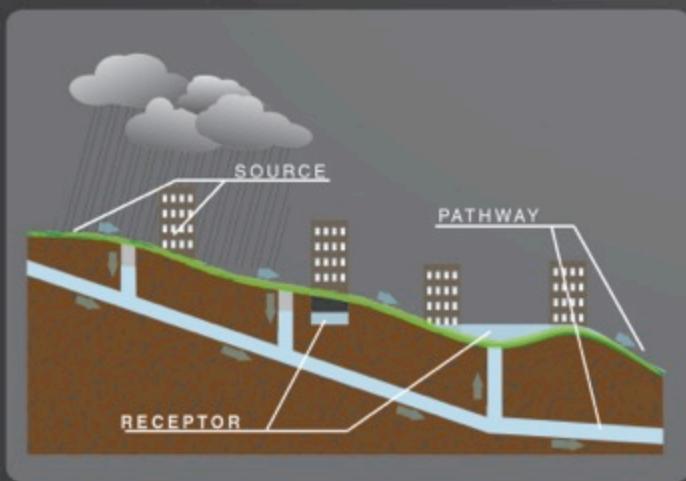


# FLOOD MITIGATION

## Pathway Conveyance



## WIDE RANGE OF INTERVENTION

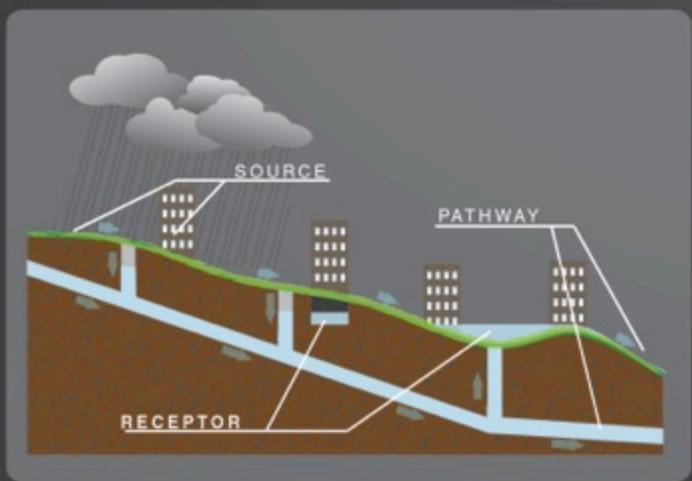


# FLOOD MITIGATION

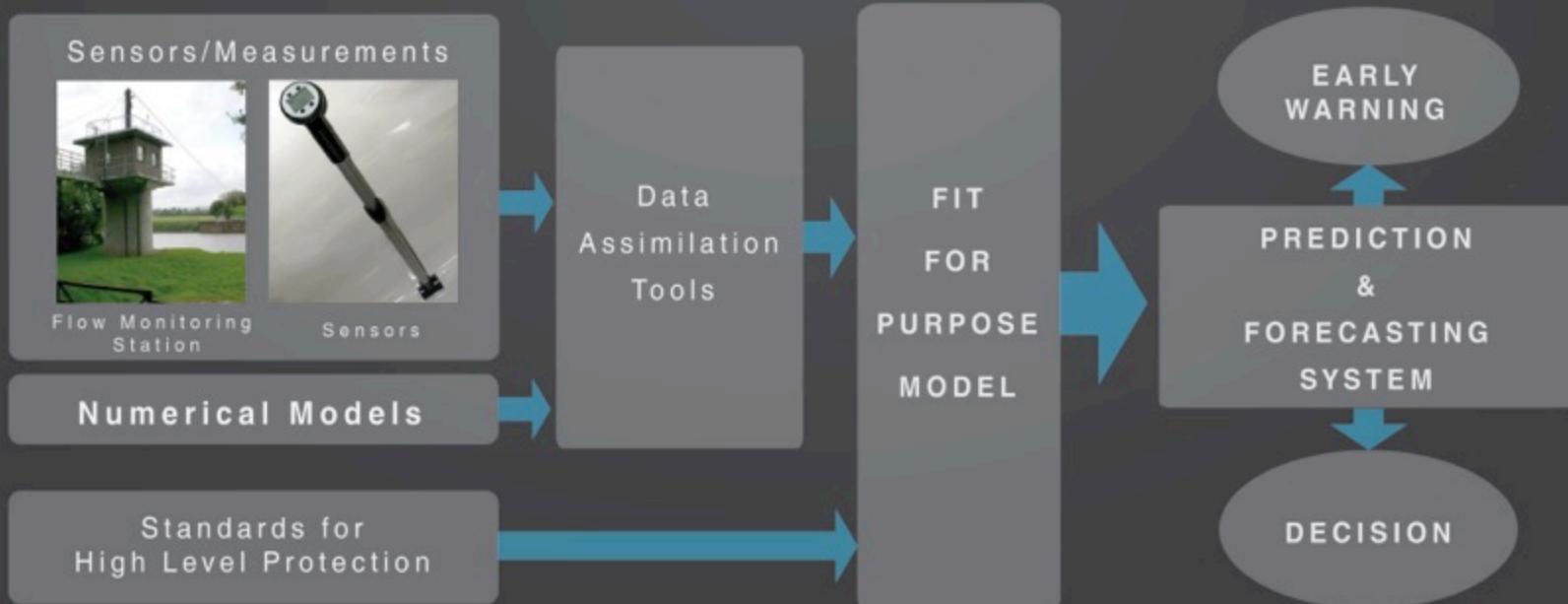
## Pathway Storage



## WIDE RANGE OF INTERVENTION



# PUBLIC ENGAGEMENT & EARLY WARNING



# FLEXIBLE & ADAPTIVE SYSTEMS TO MANAGE FUTURE UNCERTAINTY

ENERGY COSTS

CLIMATE CHANGE

EXTREME STORMS

EXTREME DROUGHTS

WATER SCARCITY

RESOURCE SCARCITY

AVOID  
HIGH ENERGY COSTS

ONE INFRASTRUCTURE  
DELIVERS  
MULTIPLE BENEFITS

PHASED IN OVER  
A PERIOD OF TIME



# Flood Protection: Information

## Low Impact Development

- Reduce the volume and peak rate of flow
  - Controlling the water quality
  - Recharge of storm water with decentralized on-site detention
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# Flood Protection: Information

Hydraulic capacity extension of the sewer systems

Flow monitoring

Sewer quality sampling

Dredging of contaminated soils

The construction of large underground storage tanks

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# Flood Protection: Issues

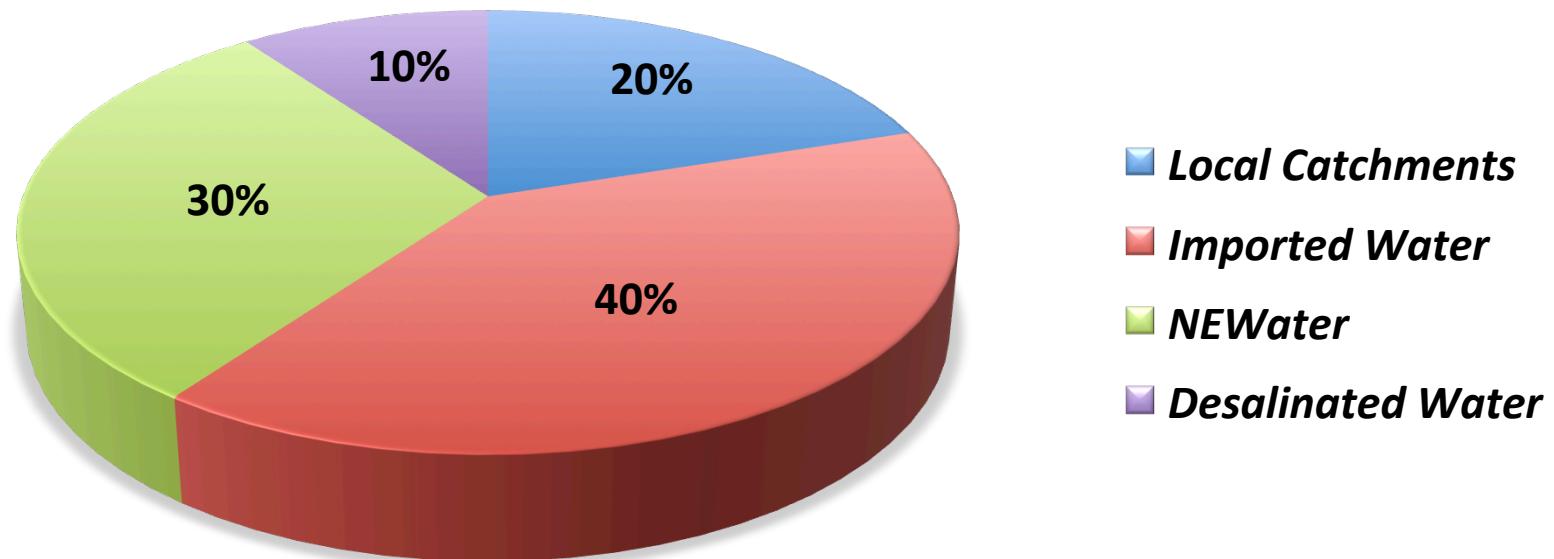
Designing infrastructure needed to address the expected flood events that integrate low impact developments



# Water Supply

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# Water Supply: Information



# Water Supply: Local Catchment Water

Network of drains, canals, rivers, storm-water collection ponds and reservoirs

Water from the remaining streams and rivulets near the shoreline using technology that can treat water of varying salinity.

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# Water Supply: NEWater

NEWater is high-grade reclaimed water produced from treated used water.

By 2060, it is planned to triple the current NEWater capacity and meet 50% of our future water demand.

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# Water Supply: Desalinated Water

Singapore has one of Asia's largest seawater reverse-osmosis plant

The Plant produces 30 million gallons of water a day  
(136,000 cubic meters)

By 2060, the capacity will increase by almost 10 times (30% of the water demand in the long term)

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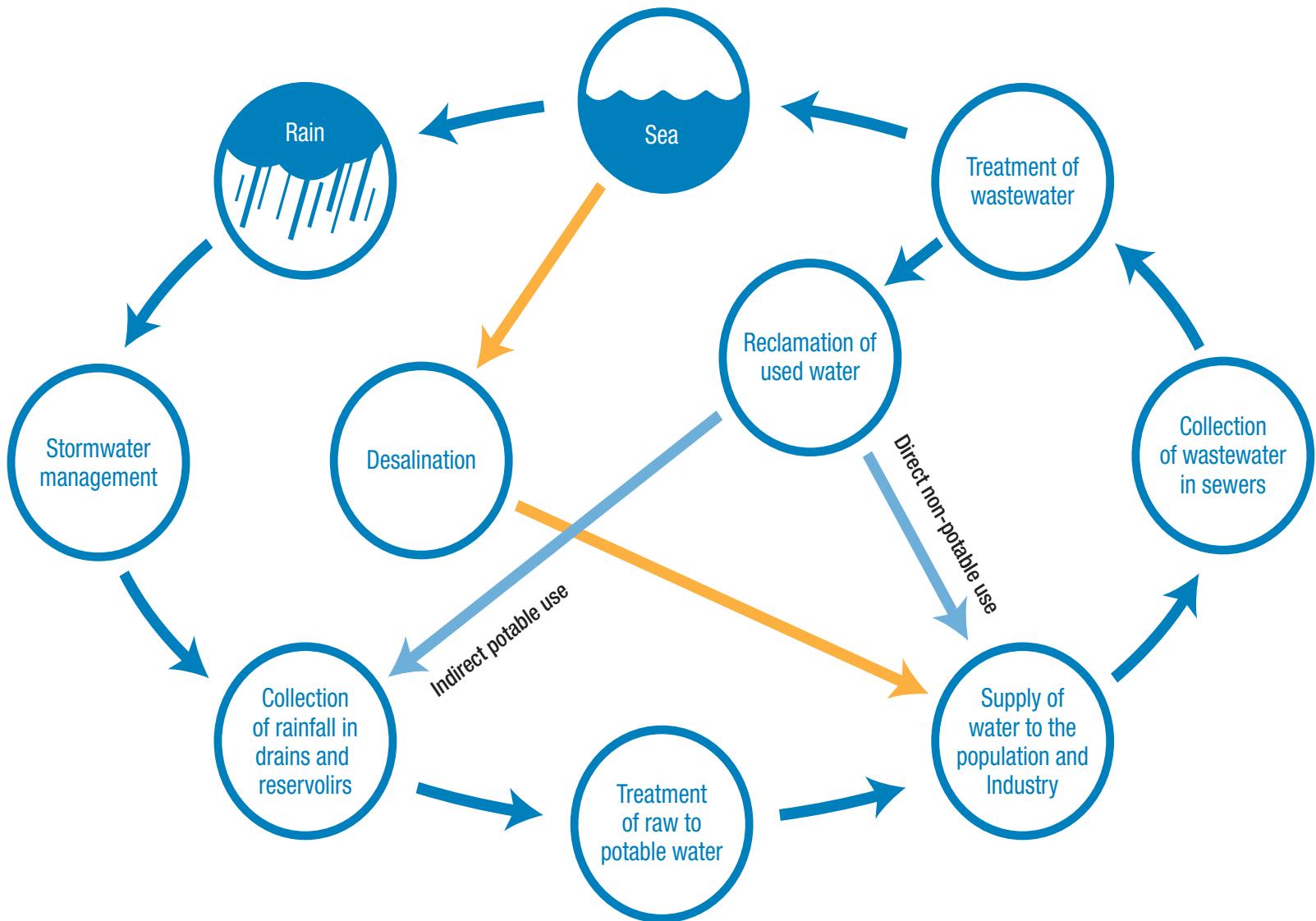
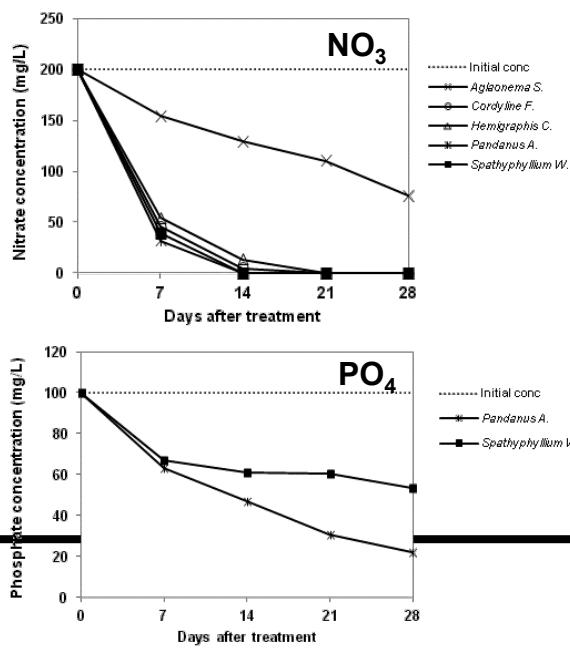


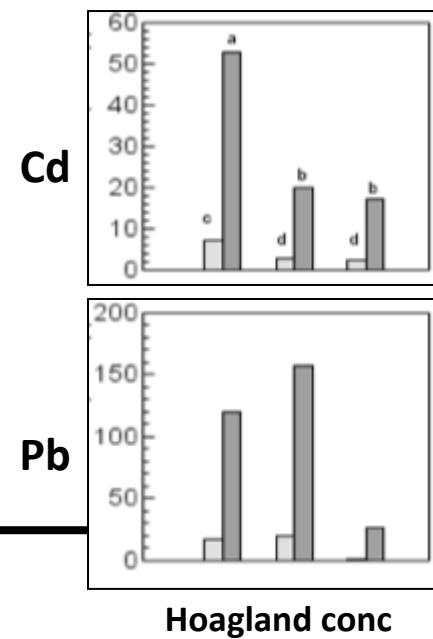
Fig. 1: Singapore's Water Cycle. With desalination and wastewater reclamation, water resources are managed within a closed water loop.

# Bioremediation potential of tropical plants

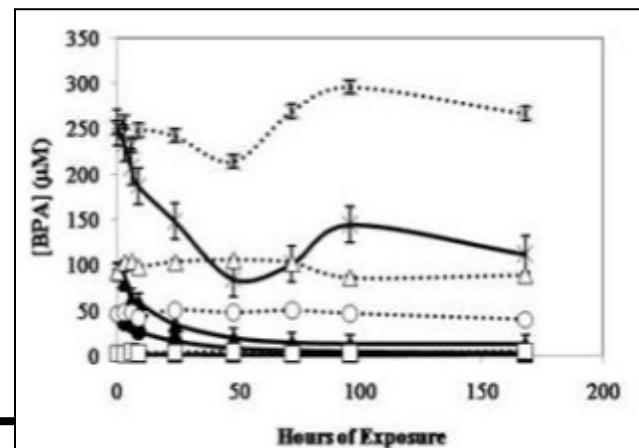
## I. Nutrients



## II. Heavy metals



## III. Chemicals

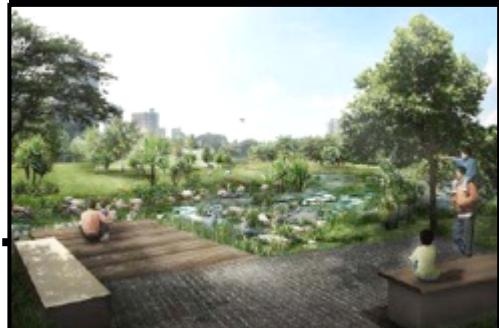


# Bioremediation

*A fresh application in ecological engineering*

- Common tropical, ornamental plants show effective pollutant removal
- Certain terrestrial plant species with remediation capabilities are adaptive to aquatic environment
- Phytoremediation presents a low energy and cost efficient way to improve water quality
- Effective plants can be cultivated in Water Sensitive Urban Designs (WSUDs)

**Naturalised canals**



**Urban wetlands**



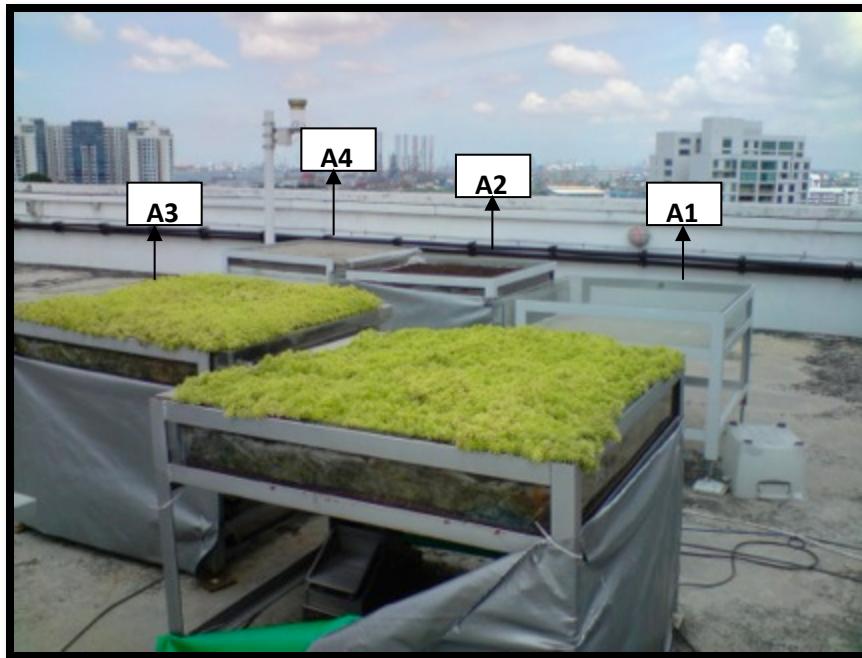
**Rain gardens**



**Green roofs**



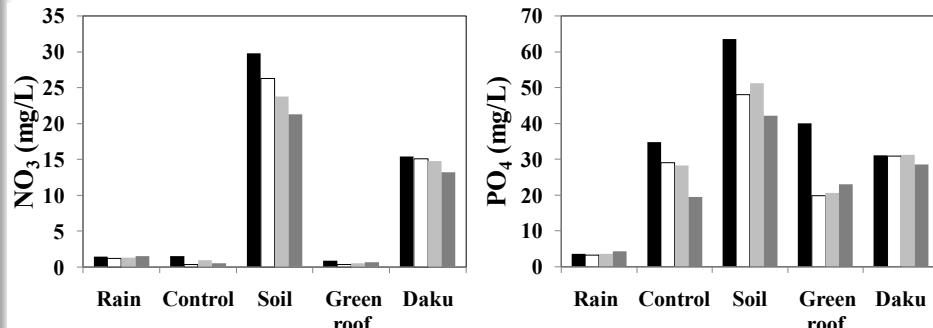
# Studies on Improvement of Water Quality



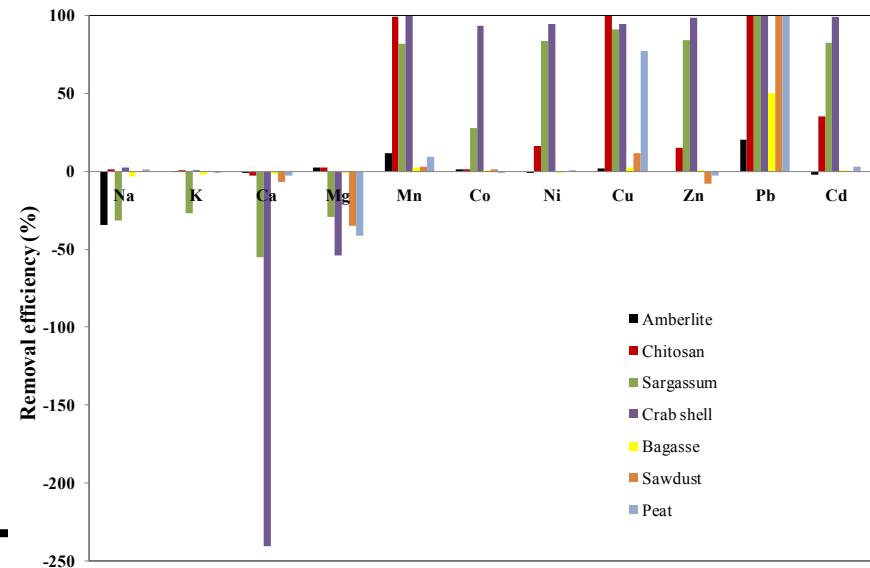
Green roof assemblies in EA rooftop in National University of Singapore



Different sorbents used to treat urban runoff

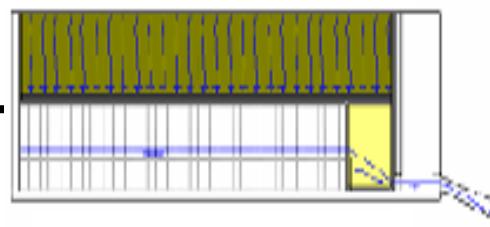
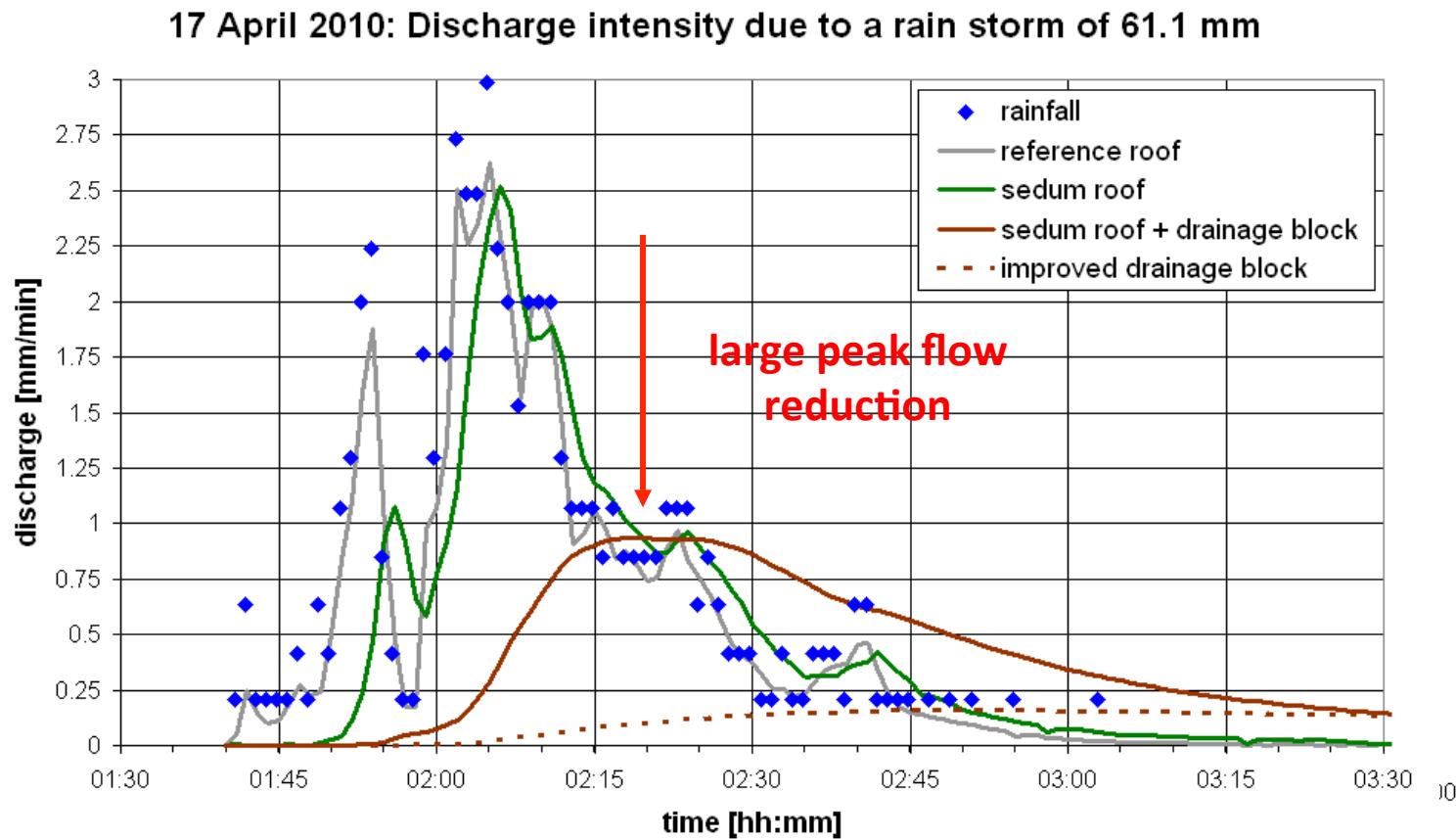


Quality of runoff from different assemblies



Performance of different sorbents to remove metal ions from urban storm water runoff

# Change of Hydrograph with improved green roof



# Water Supply: Issues

Is there 5<sup>th</sup> National Tap?

Ensure that each technology is optimized and practical to meet the demand of fresh water in Singapore.

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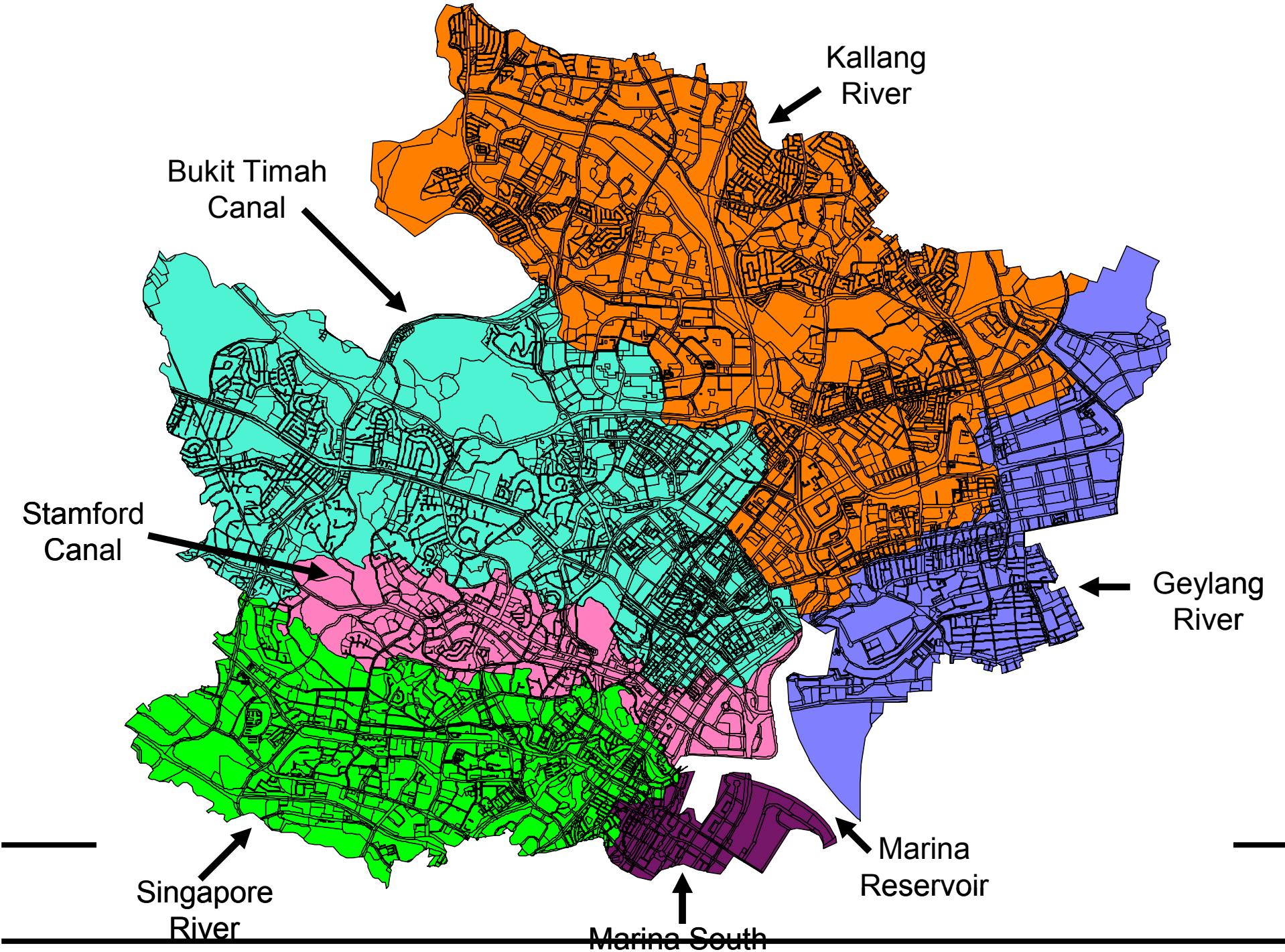
Balance recreation, flood  
protection, and fresh water  
supply

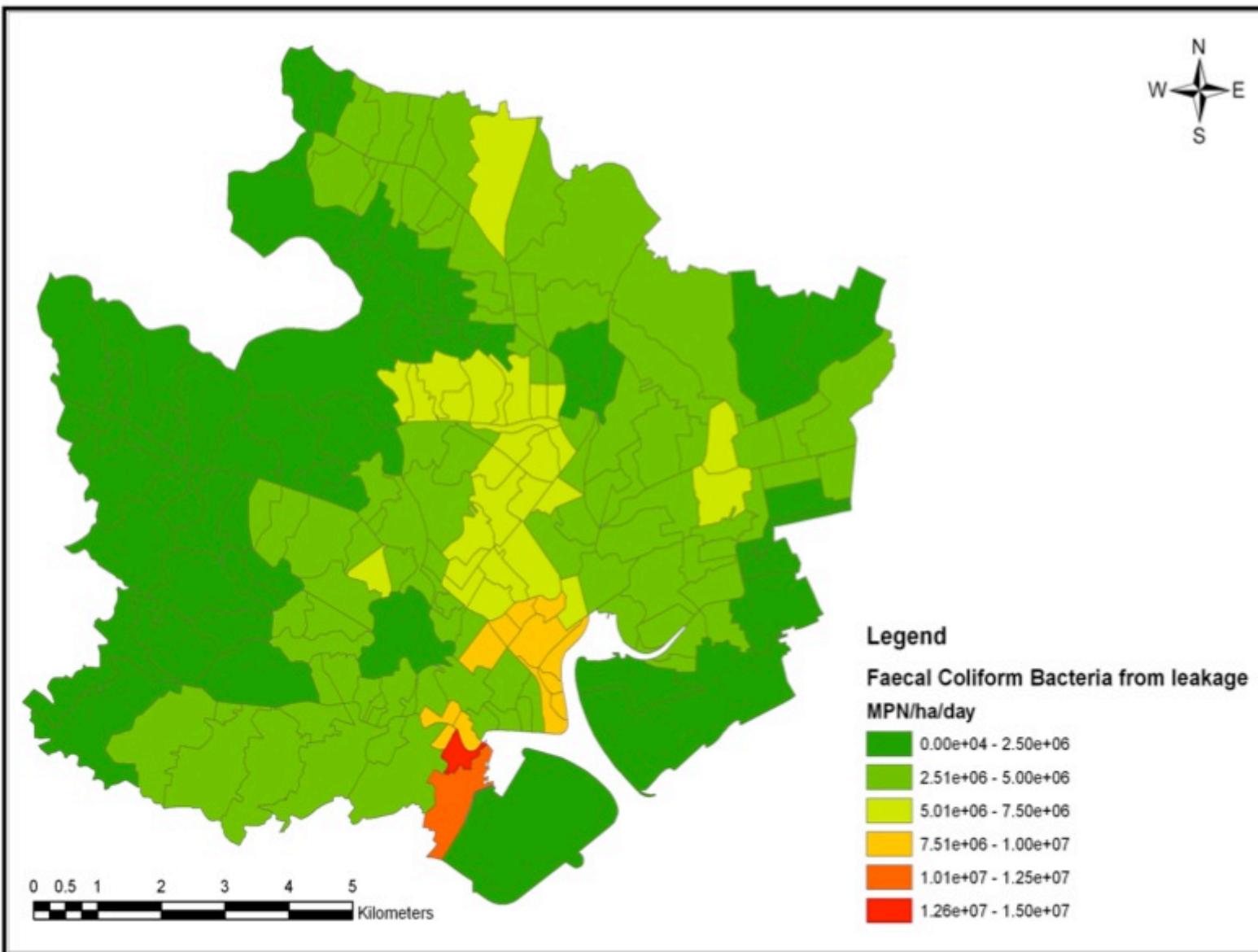
*Engineer*

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# Landuse types based upon Master Plan 2003

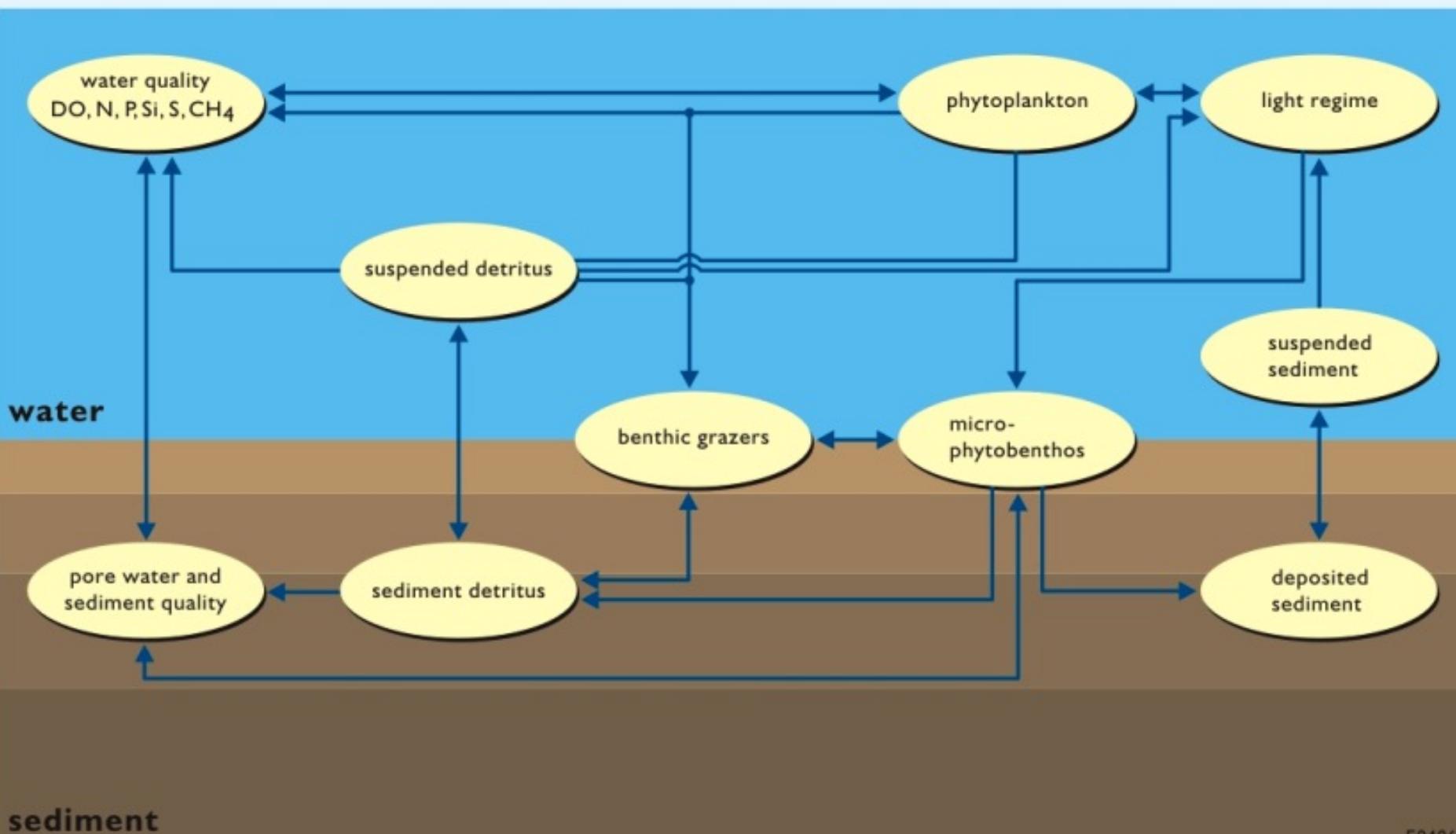




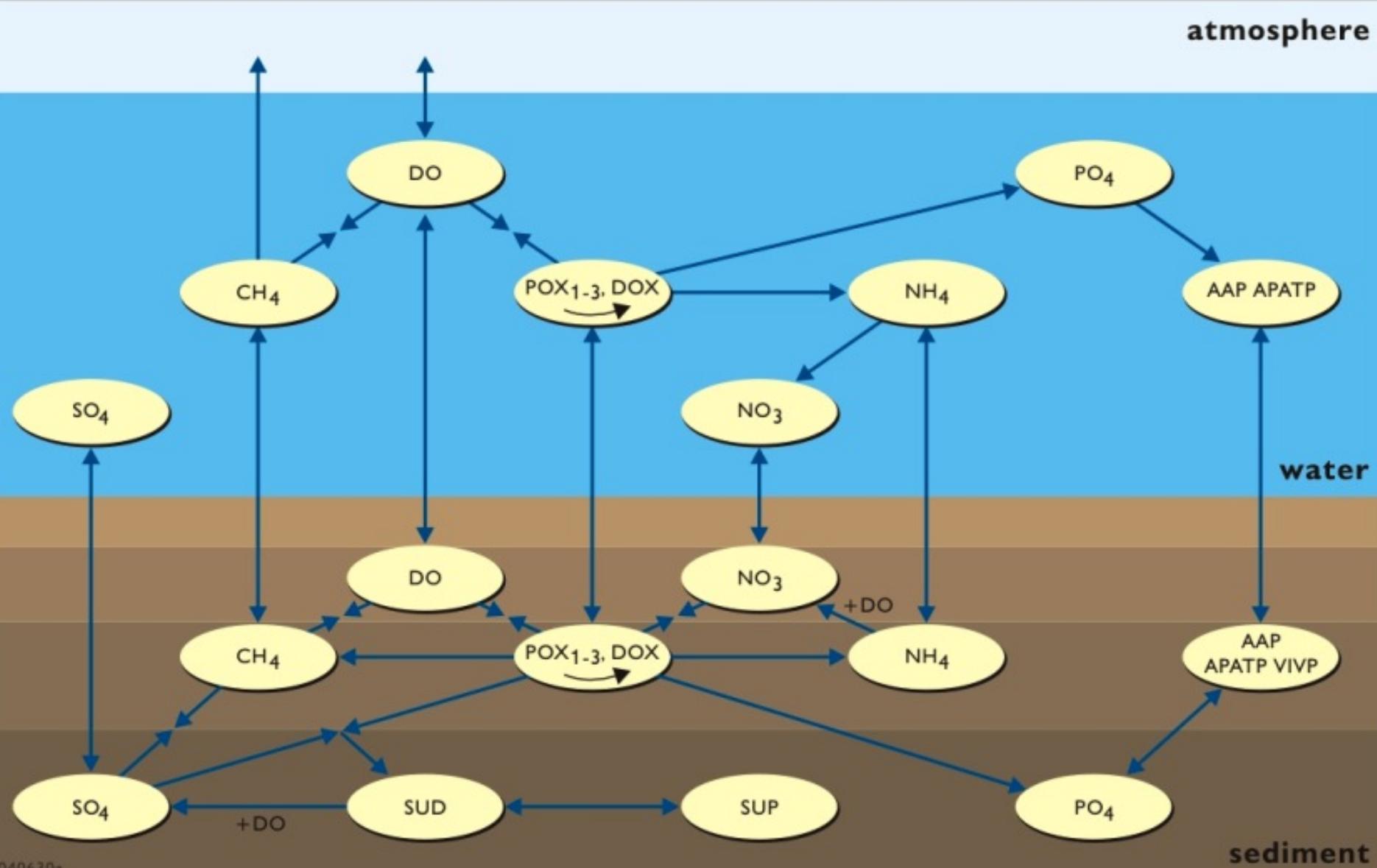


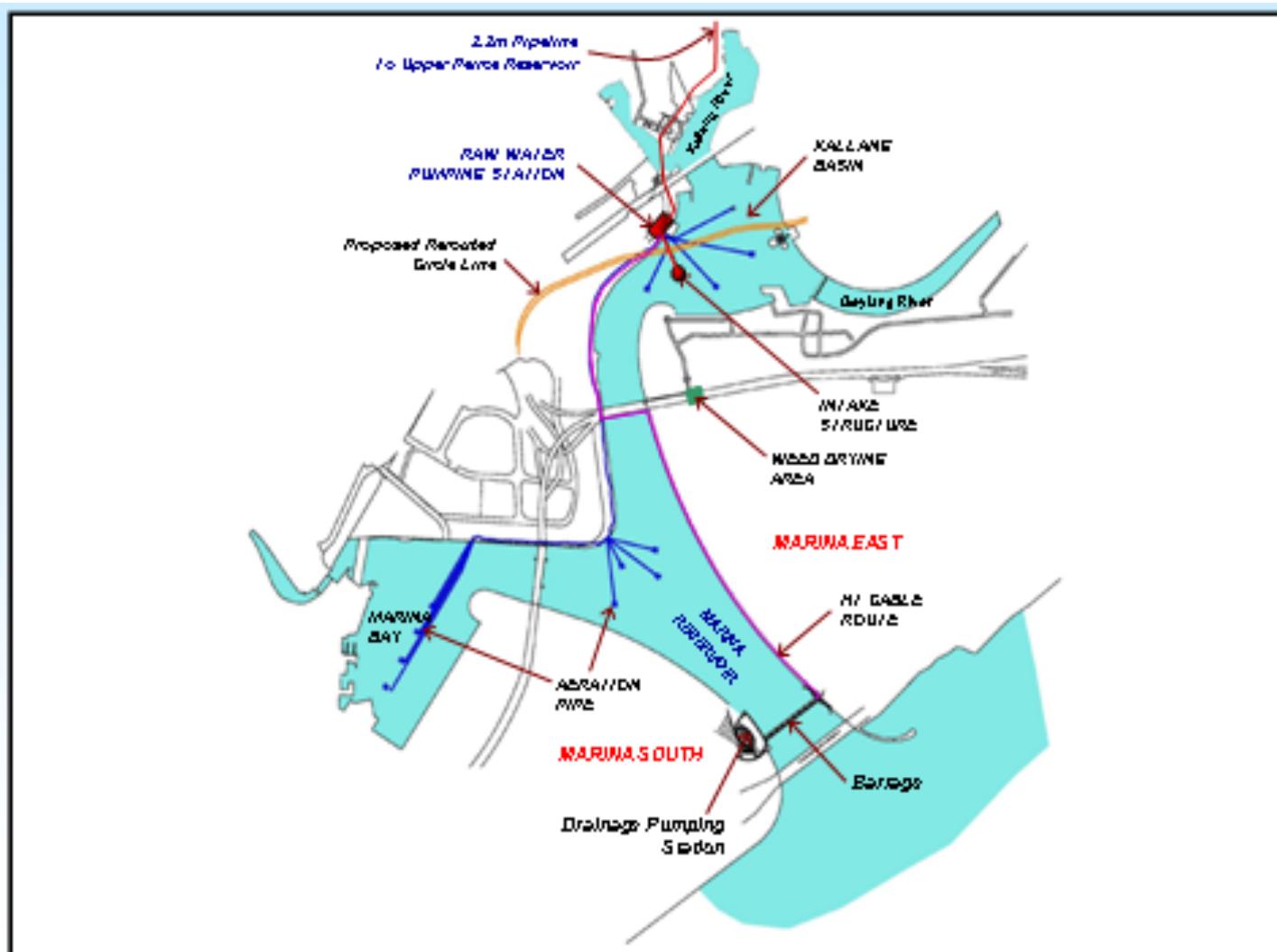
# Water quality

atmosphere



# Water quality



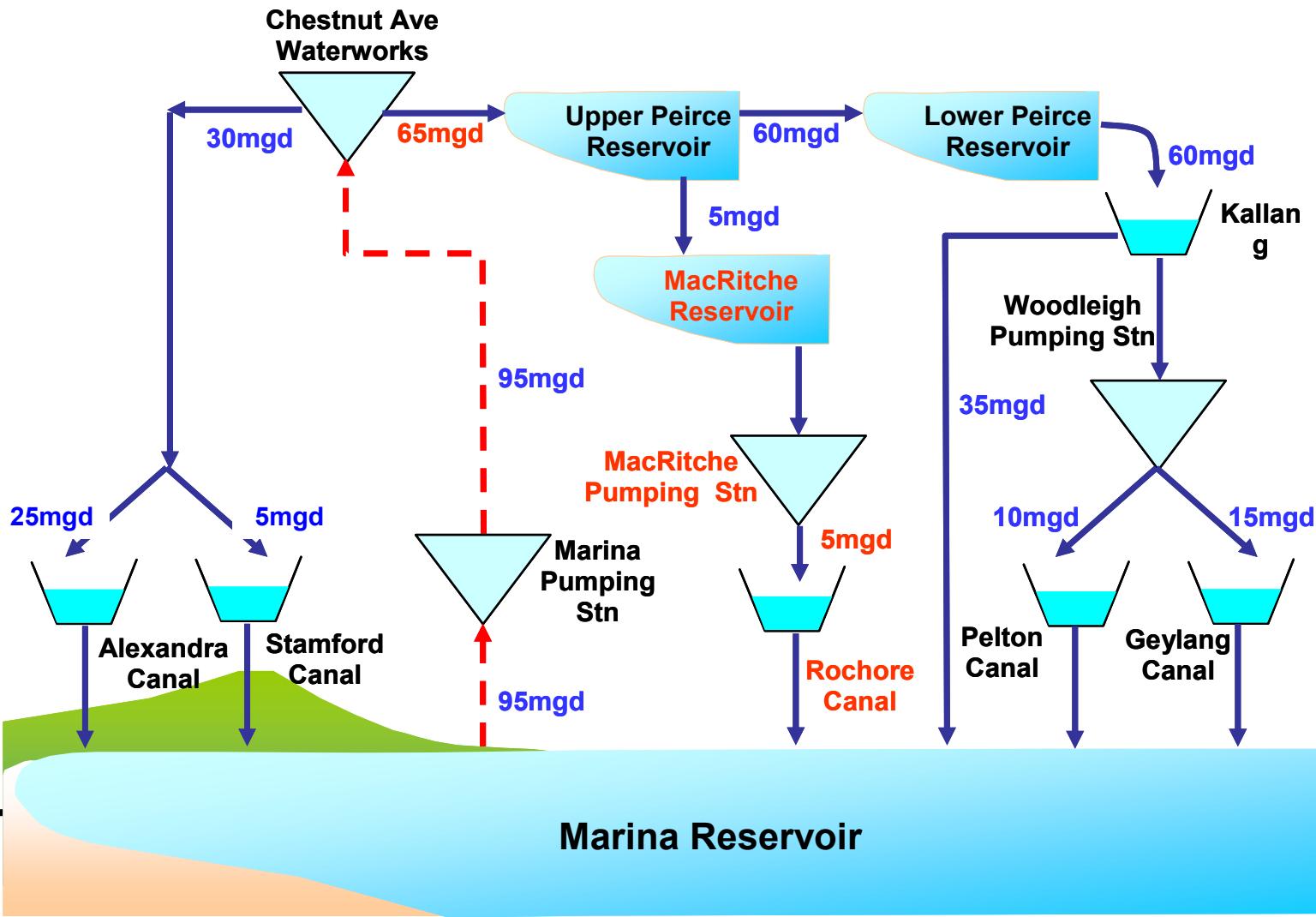


Aeration to improve circulation in the reservoir



Reduces stagnation and improves water quality in the main tributaries and reservoir

## REVISED MARINA RESERVOIR RECIRCULATION SCHEME -









# Balance of Water Systems: Marina Barrage

Dam built across the 350-metre wide Marina Channel to keep out seawater

Comprehensive flood control scheme to alleviate flooding in the low-lying areas in the city

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# Balance of Water Systems: Marina Barrage

During heavy rain, the dam will be activated to release excess storm water into the sea when the tide is low.

In the case of high tide, giant pumps (Olympics-size swimming pool per minute) will drain excess storm water into the sea.

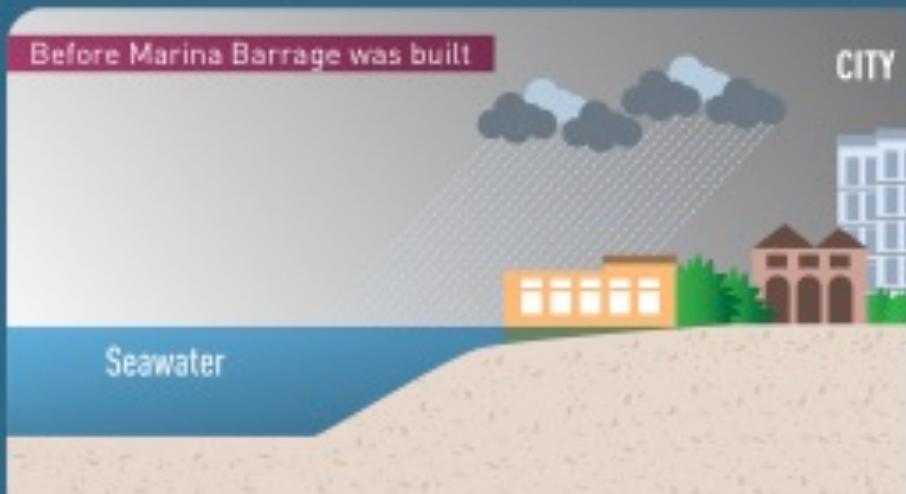
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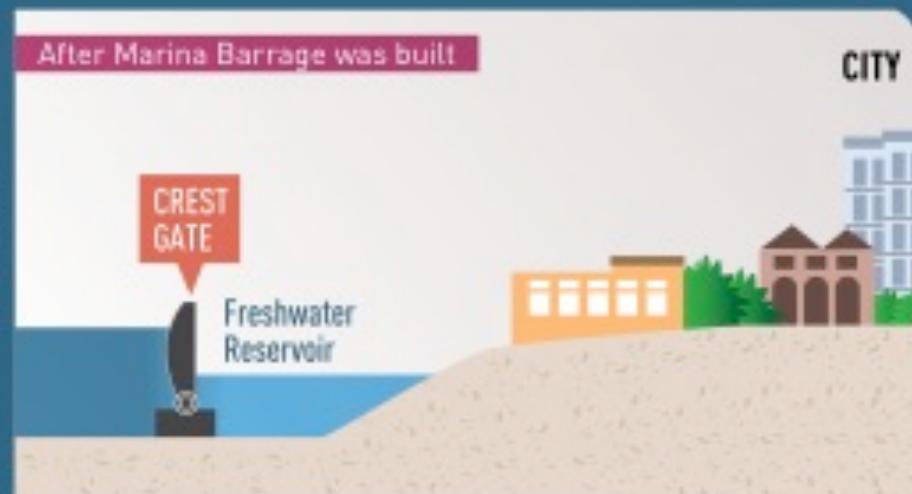
## Flood Control

Keeps out seawater, acting as a tidal barrier to alleviate flooding in the low-lying areas in the city.

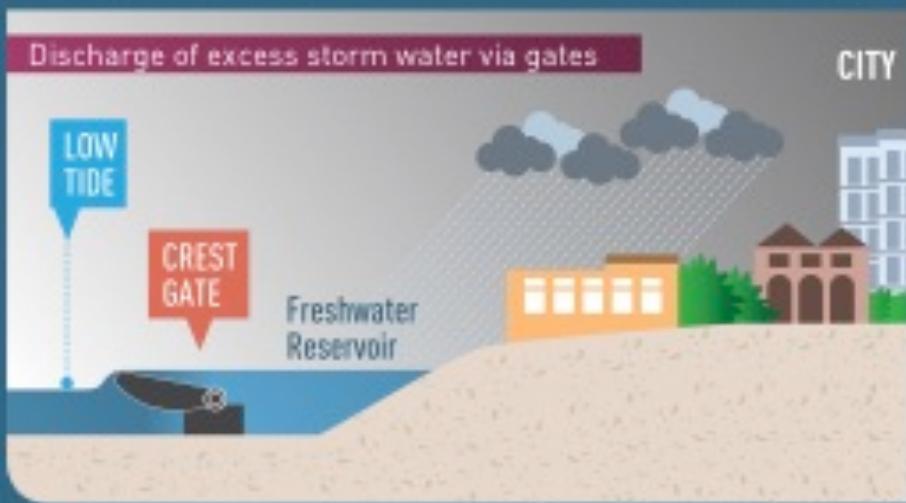
Before Marina Barrage was built



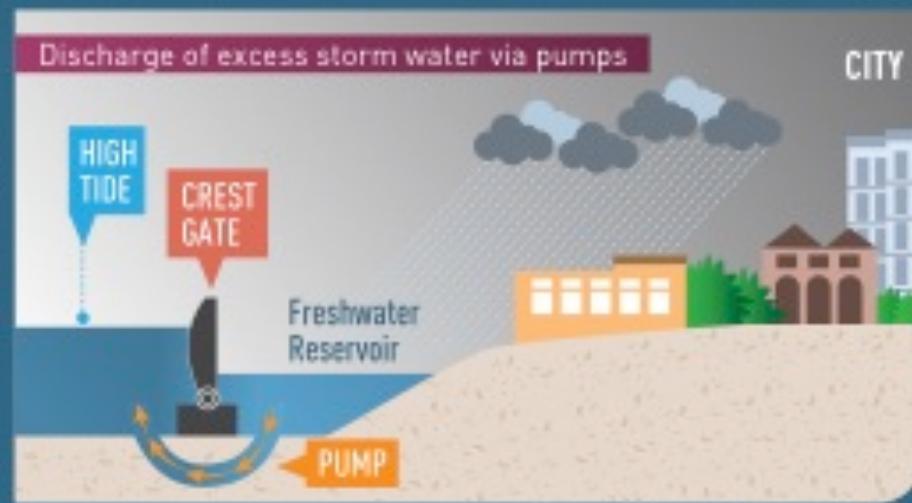
After Marina Barrage was built



Discharge of excess storm water via gates



Discharge of excess storm water via pumps



# Balance of Water Systems: Issues

Design and implementation to seizing these three objectives.

Systems that will interact to achieve optimal conditions.

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