

Have smart water systems come of age?



Guangtao Fu

Alan Turing Institute Fellow
Royal Society Industry Fellow

智者乐水, 仁者乐山

A wise person loves water; a virtuous person loves mountains.

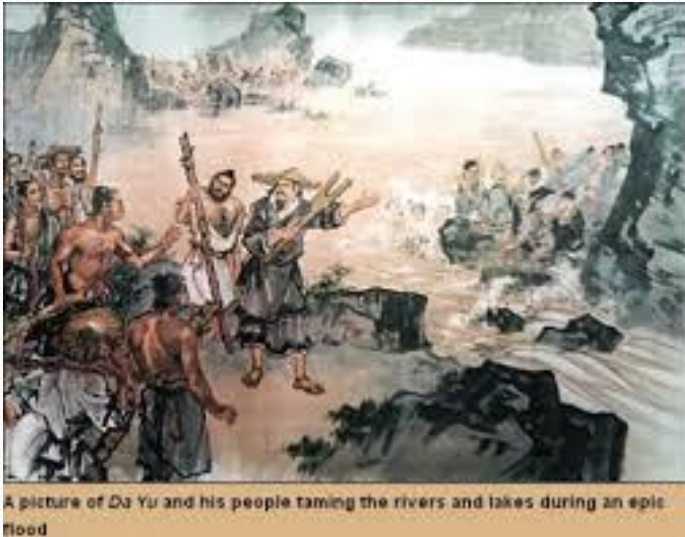
The Spring and Autumn Period

Confucius (551–479 BC)¹



Great Yu controls the waters

Yu the Great (c2200-2100BC) 水在于疏而不
Dredging and diverting instead of building c



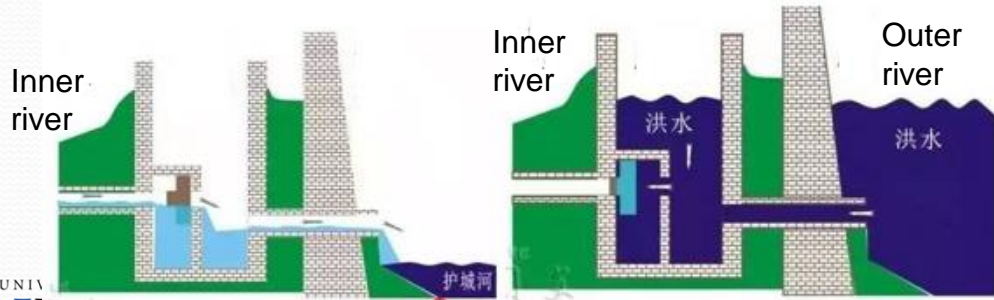
A picture of Da Yu and his people taming the rivers and lakes during an epic flood



Wu et al., Outburst flood at 1920 BCE supports the Xia dynasty, Science, 2017.

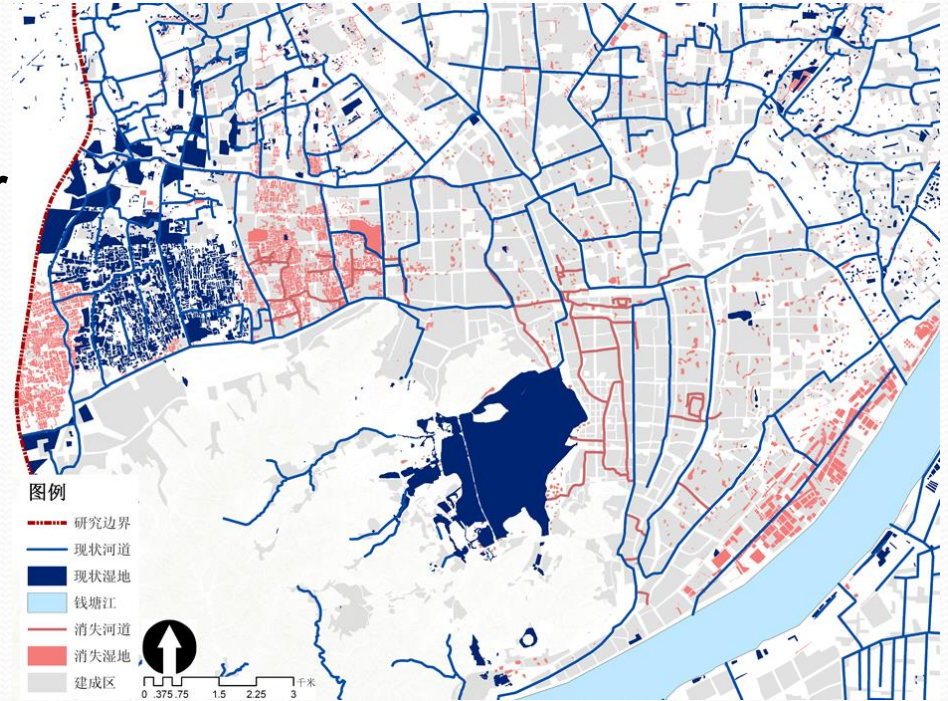
Flood control in ancient Chinese cities

- Ganzhou, **赣州**
- 900 yr old drainage



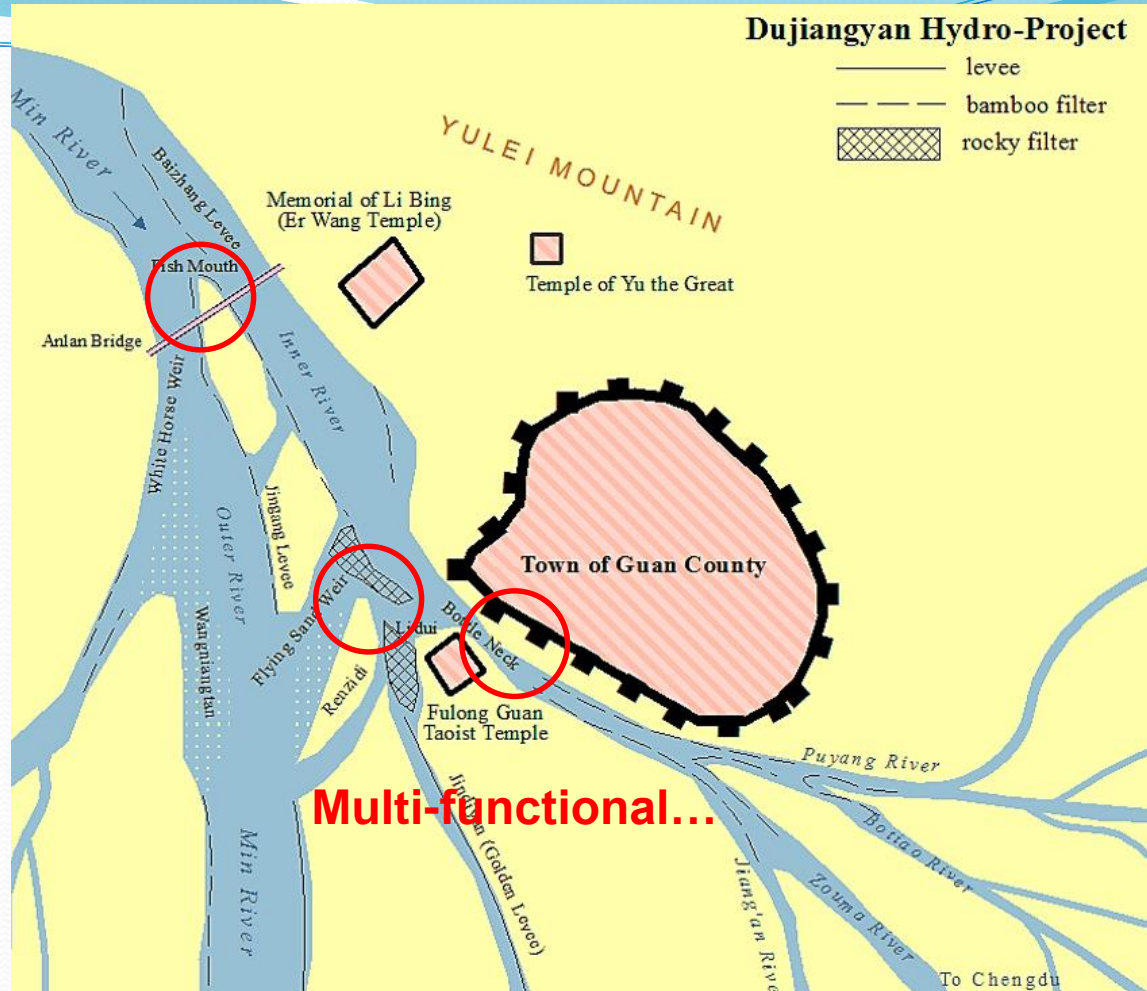
Su Shi (1037-1101AD) Hangzhou

- Writer, poet, painter, a statesman and **water engineer**
- Redesigning river systems
- Dredging rivers, and building reservoirs for water supply
- Making space for water.



Dujiangyan

- Constructed 256 BC
- Three key components:
 - Fish mouth levee
 - Flying sand weir
 - Bottle-neck channel
- Flood control, irrigation, silt control
- Irrigate 5,300 km² of the Chengdu Plain

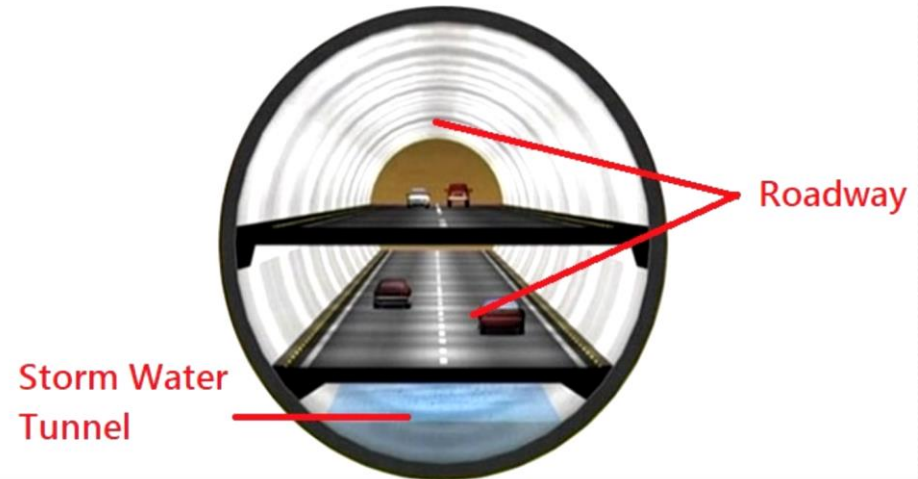


SMART Tunnel

- Storm drainage and road structure, 9.7km long
- Reduce the occurrence of floods and traffic jams in Kuala Lumpur
- Three operation modes: no rain, moderate and extreme events



Cross-Sectional View of the SMART Tunnel



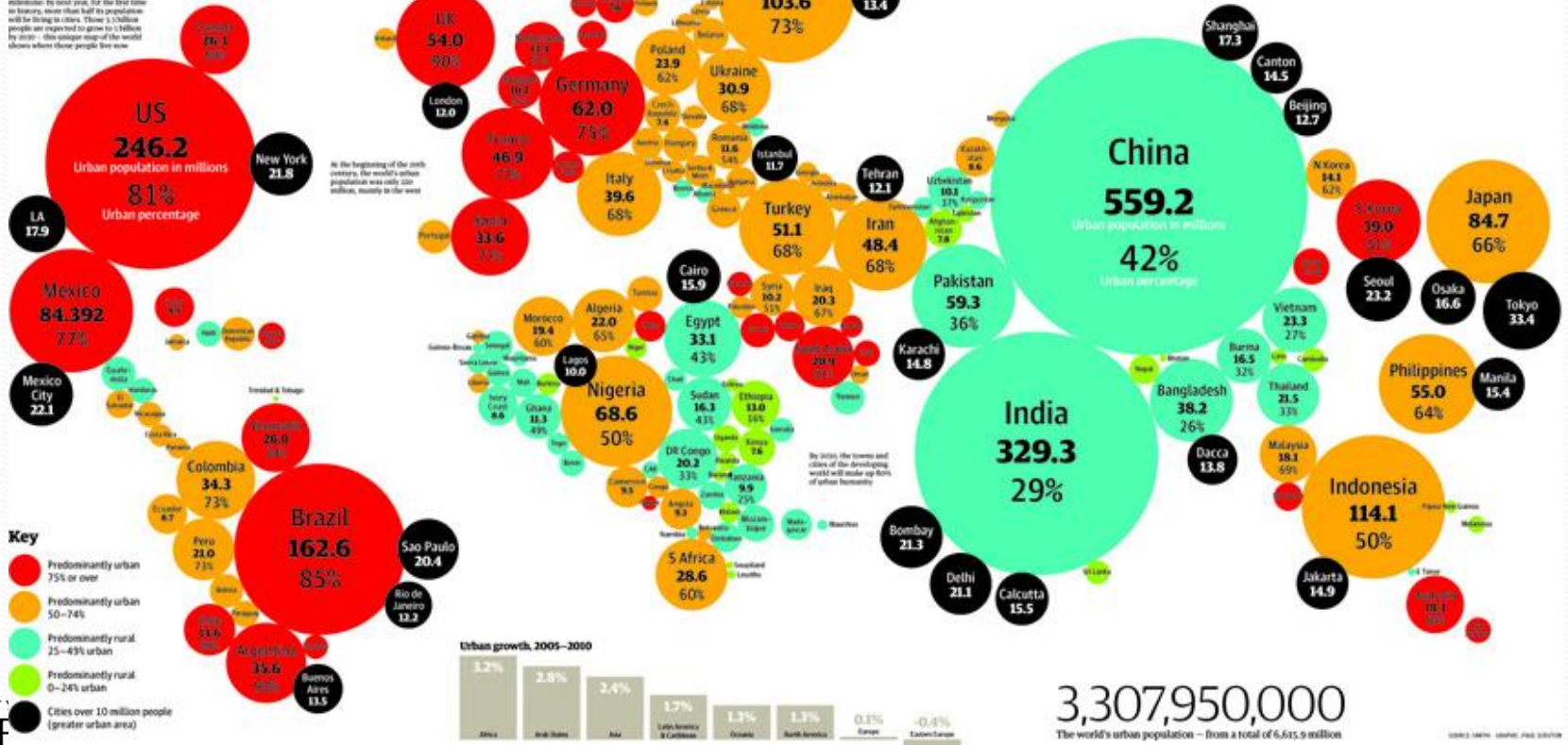
Global Urbanization

The new urban world

The world reaches a momentous milestone: for the first time in history, more than half its population will be living in cities. These 3.3 billion people are expected to grow to 3 billion by 2030 - this unique map of the world shows where these people live now.

In the beginning of the 20th century, the world's urban population was only 200 million, mostly in the west.

By 2030, the towns and cities of the developing world will make up 60% of urban humanity.



Changes in night light 1990-2010

China:

Urbanisation = 58.52%

Urban pop=813 million

102 cities with > 1m people

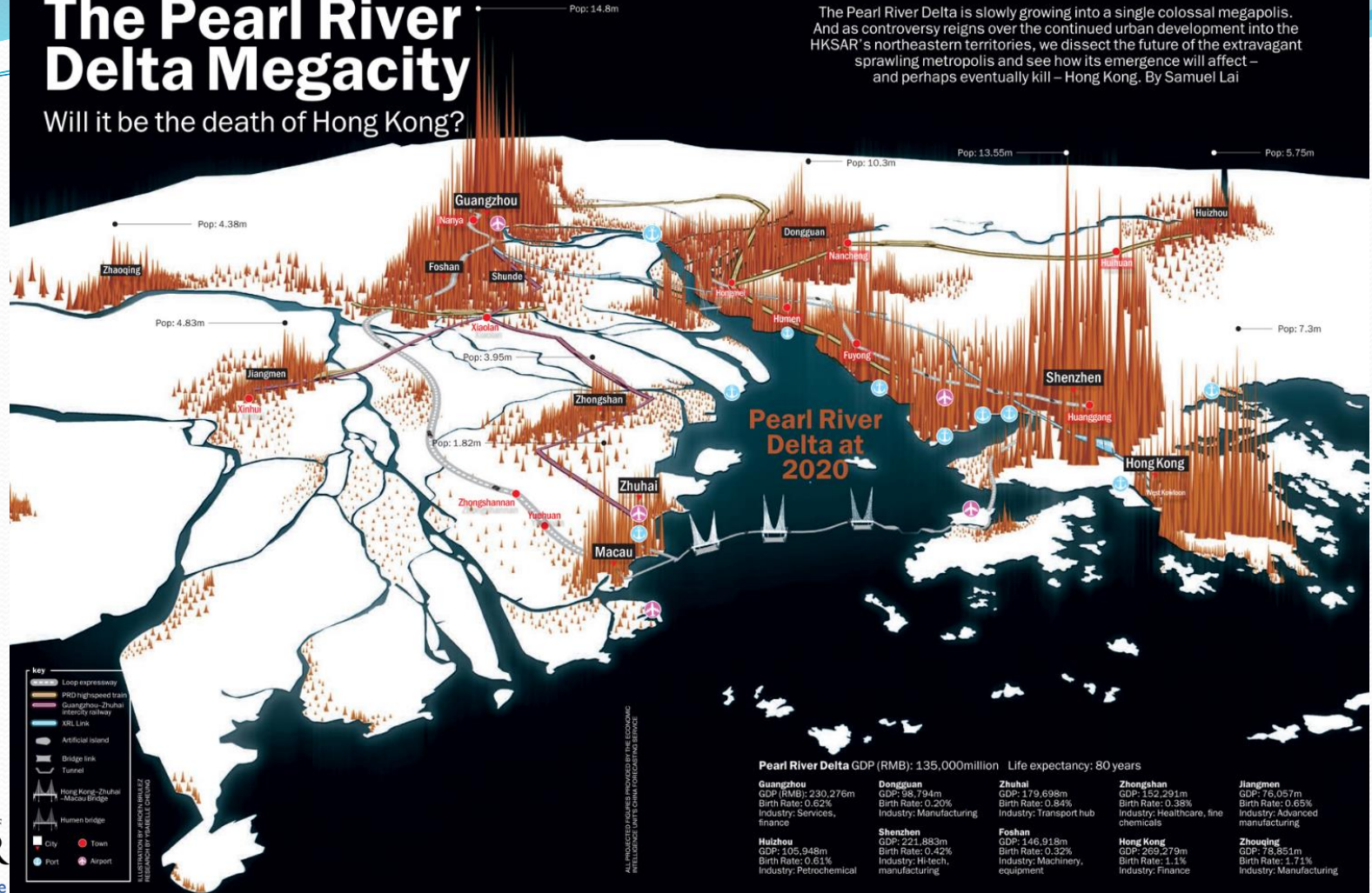


Source: Google Earth

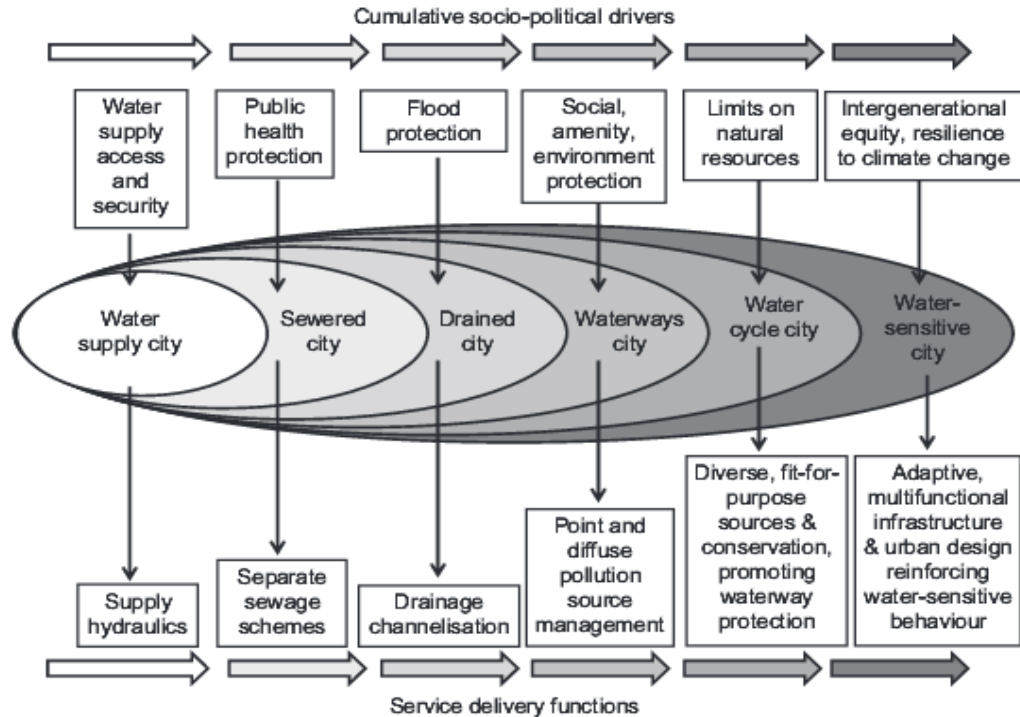
The Pearl River Delta Megacity

Will it be the death of Hong Kong?

The Pearl River Delta is slowly growing into a single colossal megapolis. And as controversy reigns over the continued urban development into the HK SAR's northeastern territories, we dissect the future of the extravagant sprawling metropolis and see how its emergence will affect – and perhaps eventually kill – Hong Kong. By Samuel Lai



Evolution of Urban Water Systems



Water wise city?

Sponge City?

Blue-green city?

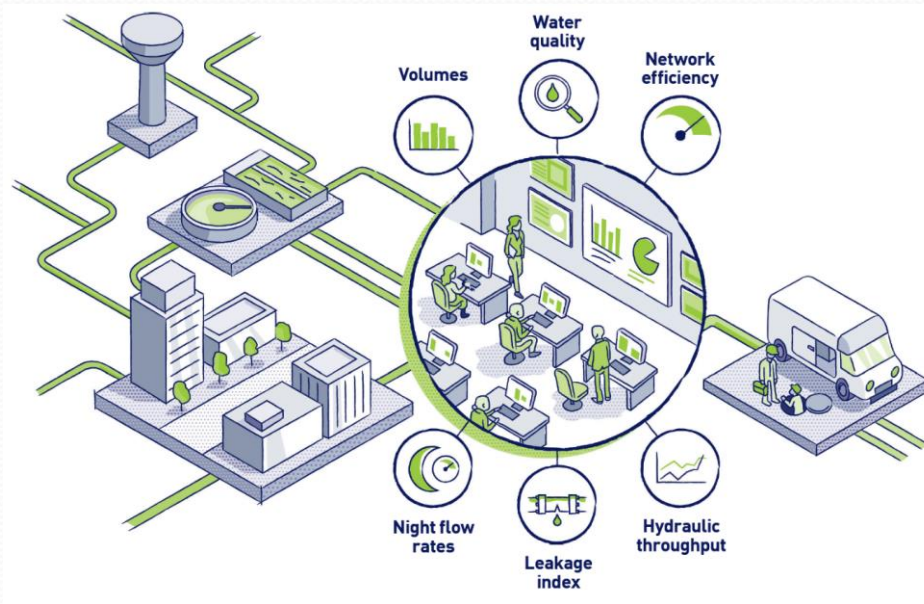
Smart city?

Resilient city?

.....

(Ashley et al., 2013)

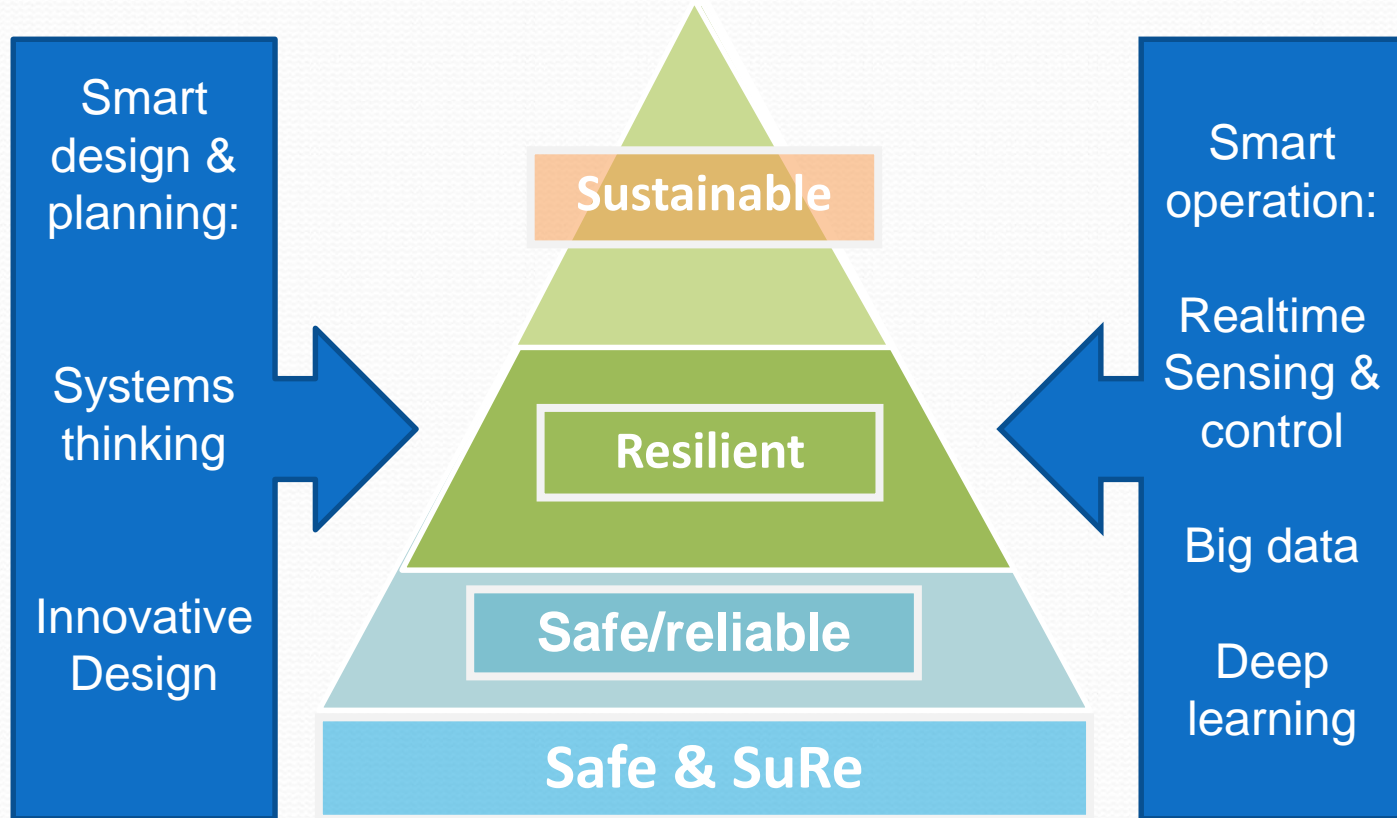
What is a smart water network?



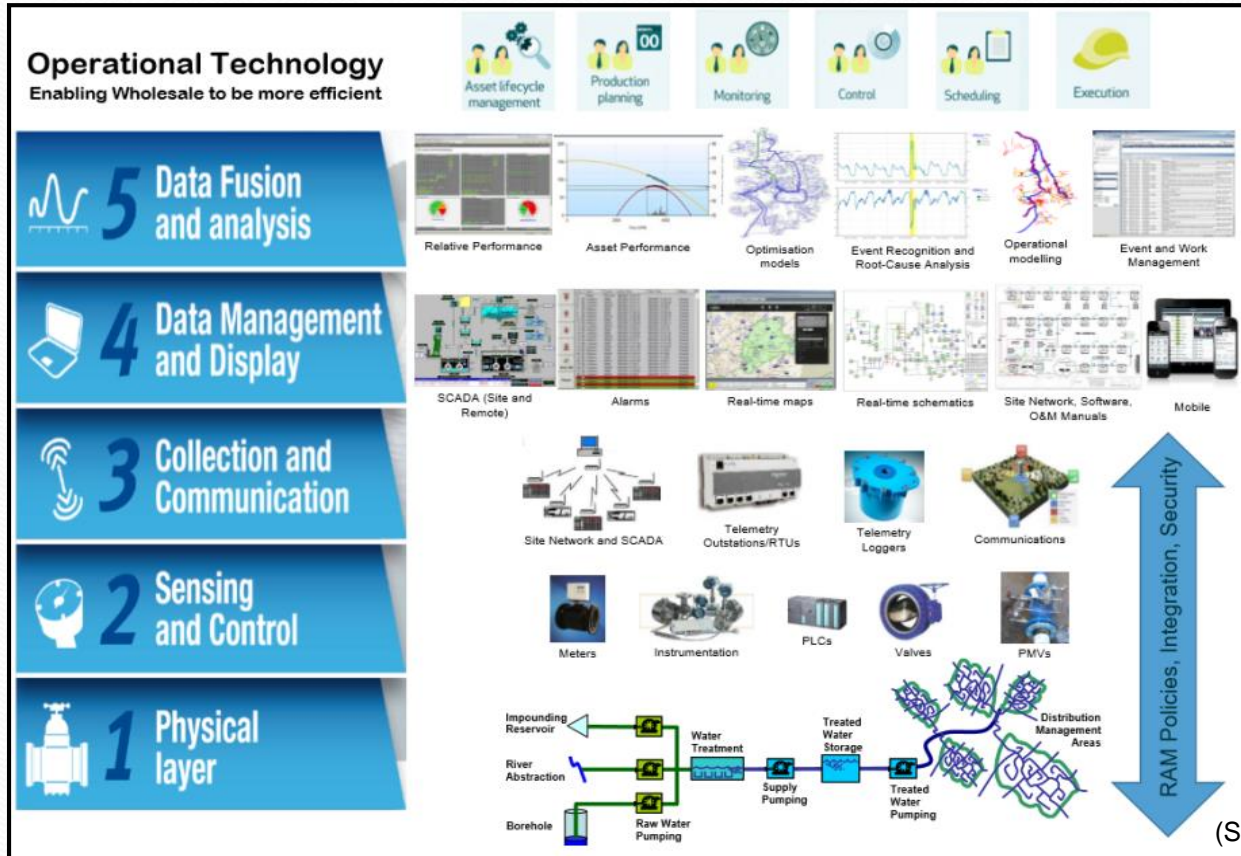
Smart Water Network solutions improve the **efficiency, longevity, and reliability** of the underlying **physical water network** by better **measuring, collecting, analysing, and acting upon** a wide range of network events. This can take shape in different phases of the utility process, such as **real-time monitoring** and **automation, operational readiness, or network planning**

Source: The Smart Water Networks Forum

Smartness is a means...



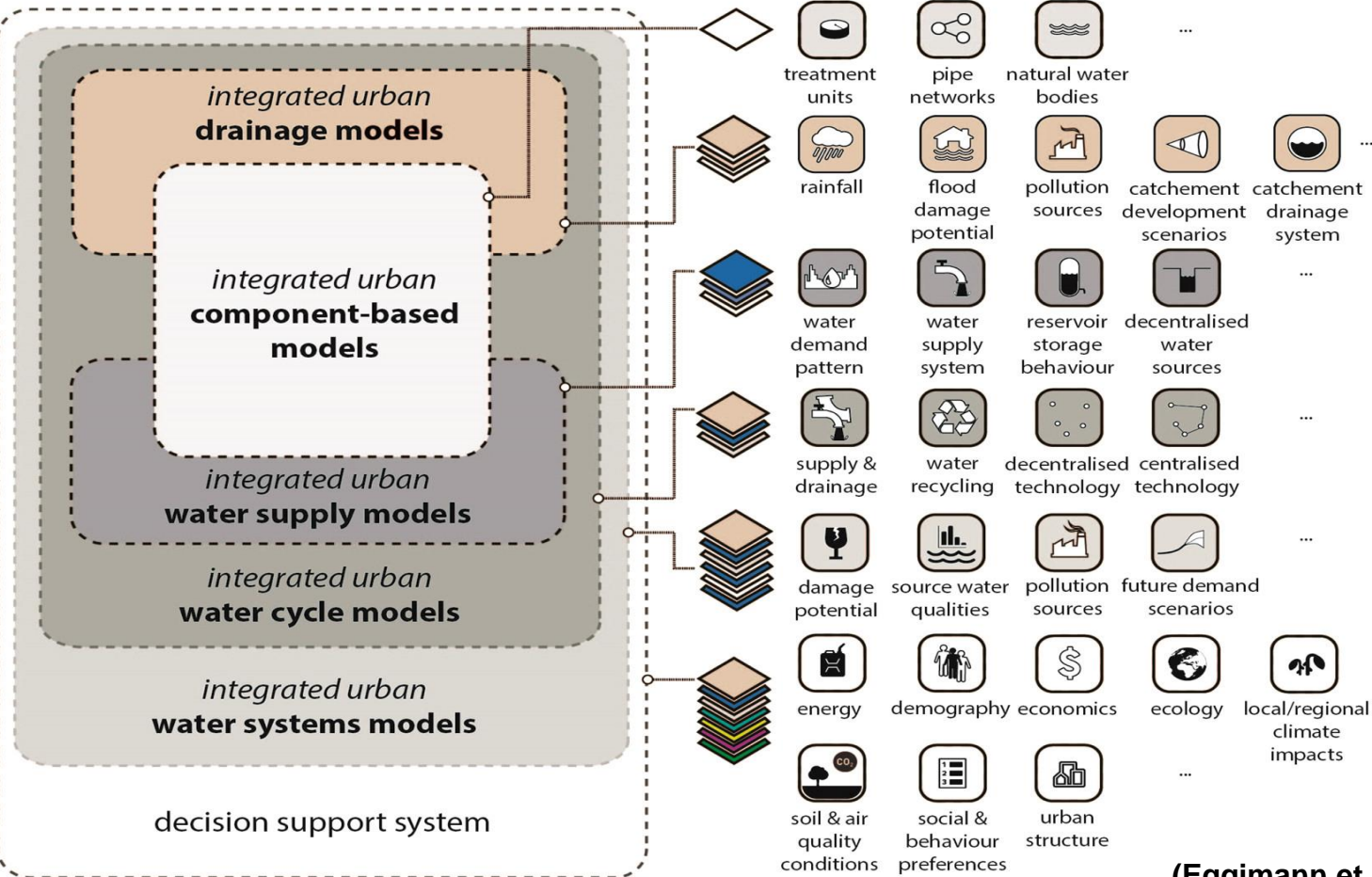
Smart system architecture



(Source: United Utilities)

Integration models

Sources of data & information



(Eggimann et al., ES&T, 2017)

data

“All models are wrong; but some are useful”

George Box, 1979

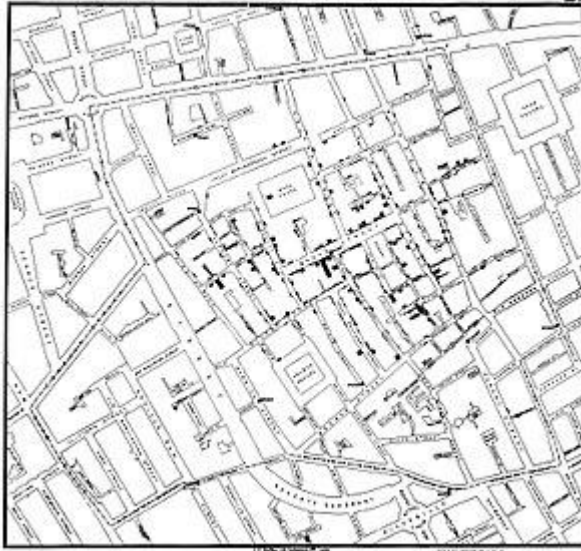
“All data are wrong, but some are useful?”

Tsagbey et al. (2017)

“All data are useful, but some are more useful”

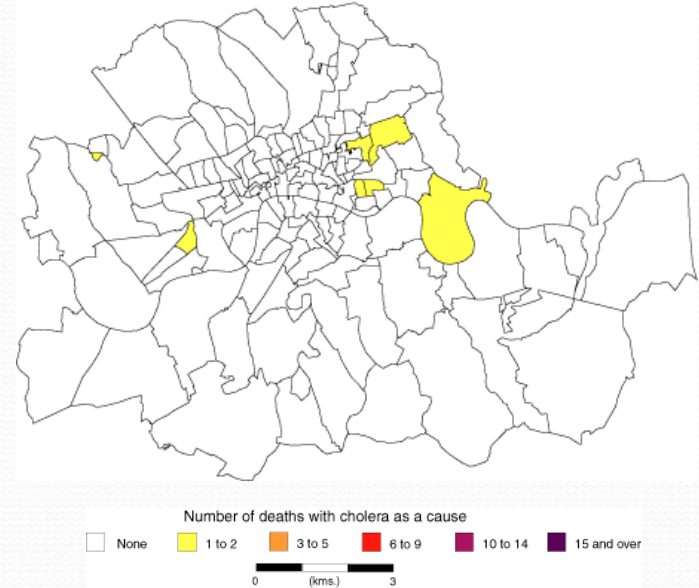
Data driven approach

John Snow (1813 – 1858)



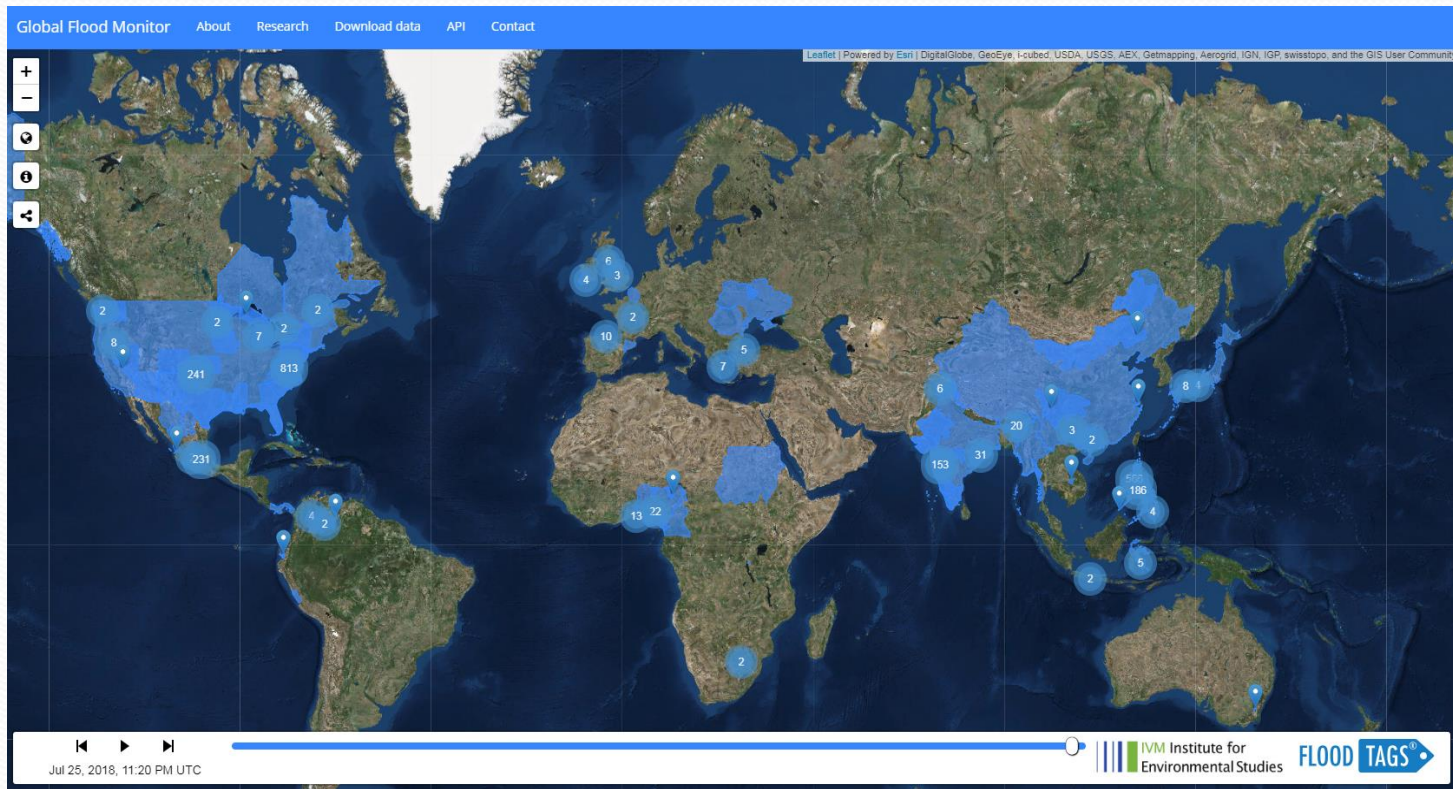
Soho cholera outbreaks in 1854

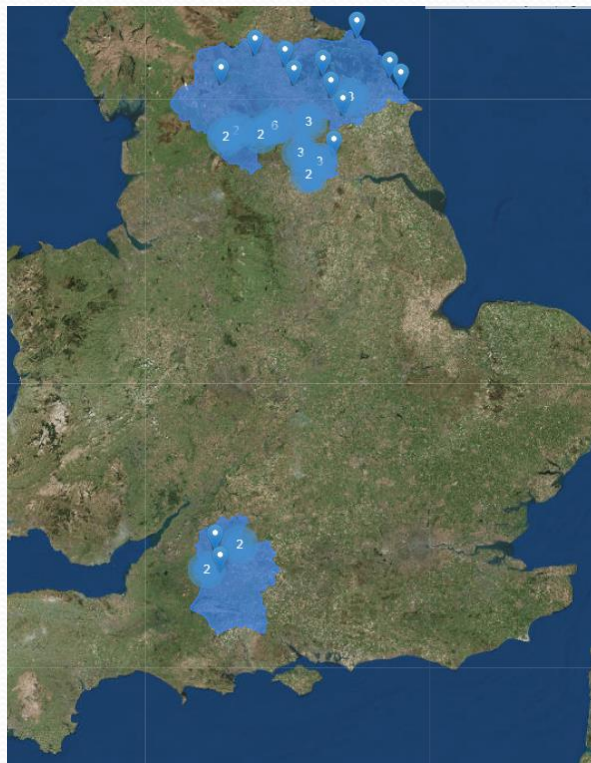
19/7 to 26/7



Bromley cholera outbreak in London in 1866

Global Flood Monitor

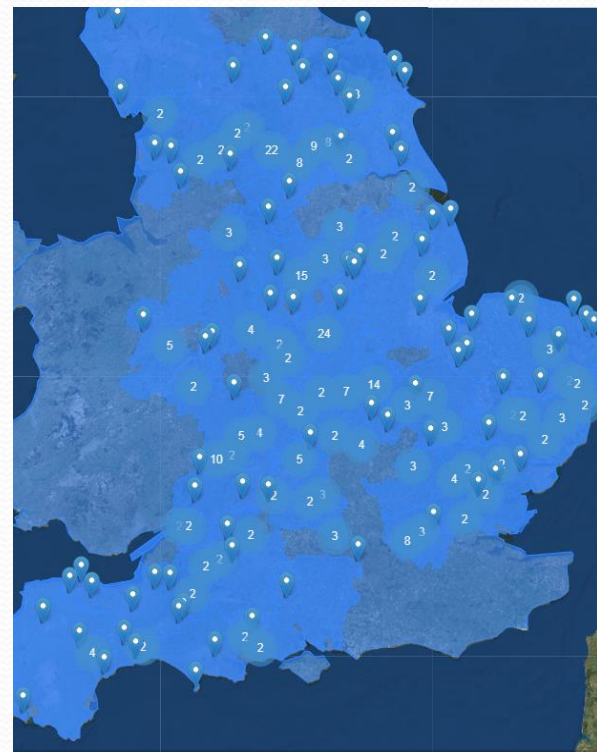




29 March 2018

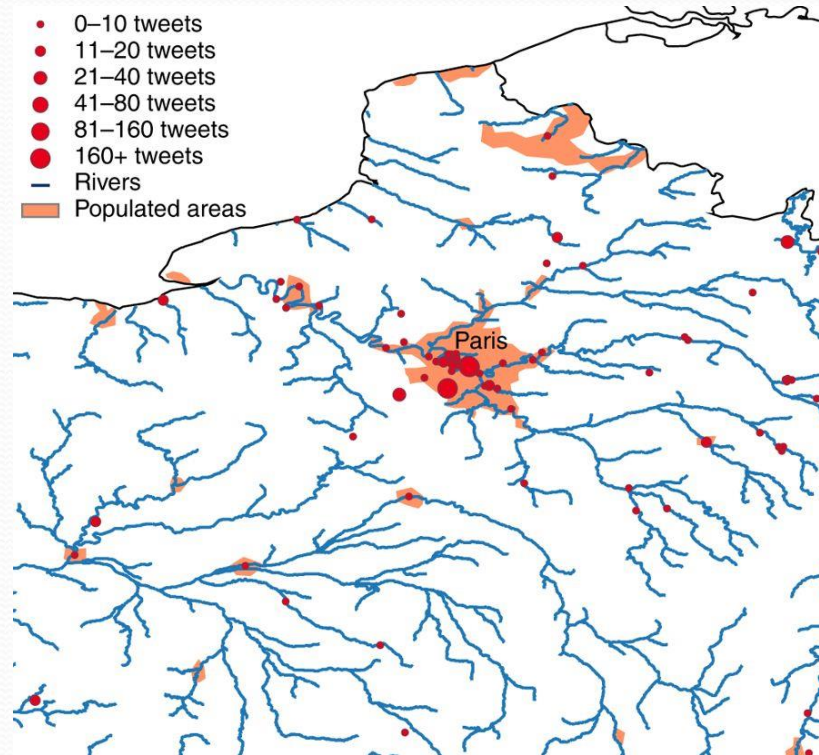


31 March 2018



1 April 2018

January 2018 floods in France



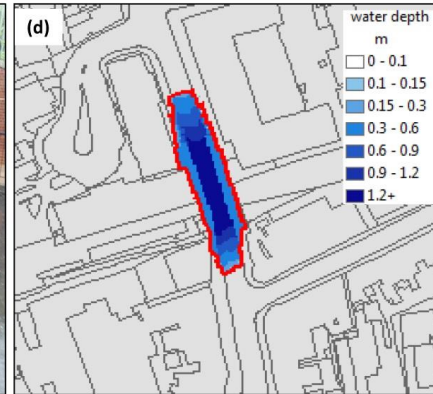
June 2016 event modelling



Flood at 14:50 on 7th June, 2016



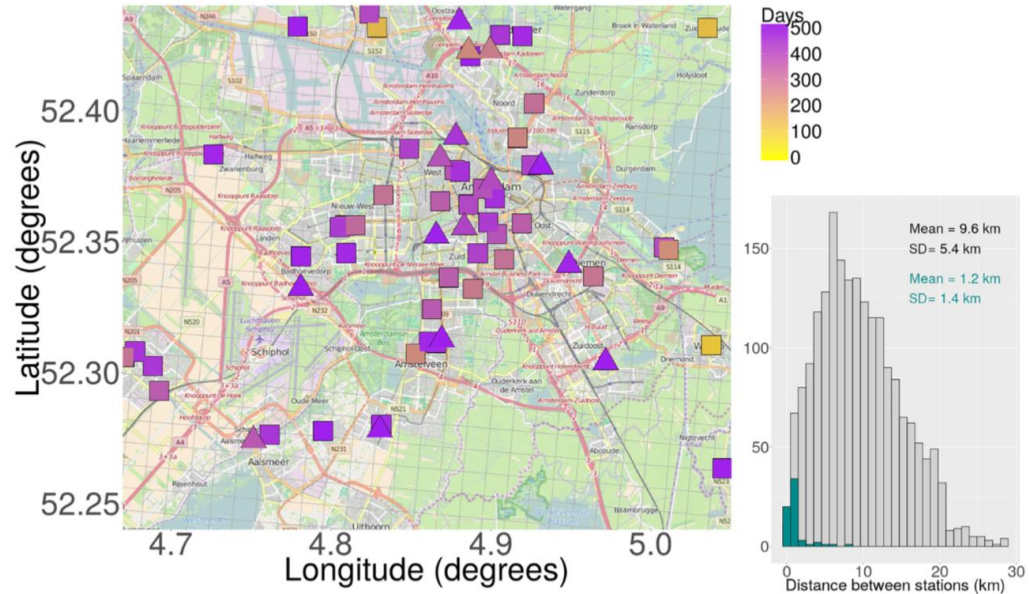
Flood simulation using social media data



Red boundary line: the flood areas at 14:50

Crowd sourcing rainfall data

- US NOAA, the Precipitation Identification Near the Ground (PING) project in 2012
- To encourage regular citizens to report their observation type (rain, fog and hail)
- Country-wide map of rainfall intensity for the Netherlands using received signal level data from microwave links in cellular communication networks
- Significantly improved accuracy using images from smartphones, surveillance cameras, cars etc.



63 personal weather stations in Amsterdam

Source: Vos et al. HESS, 2017

Time: 16/10/2014 06:05 PM to 16/10/2014 06:10 PM

Fast response - 16 Oct 2014 Exeter



Legend

- Central Exeter
- Intensity (mmh)
- 0 - 0.1
- 0.11 - 1
- 1.1 - 5
- 5.1 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60
- 61 - 100

Localised



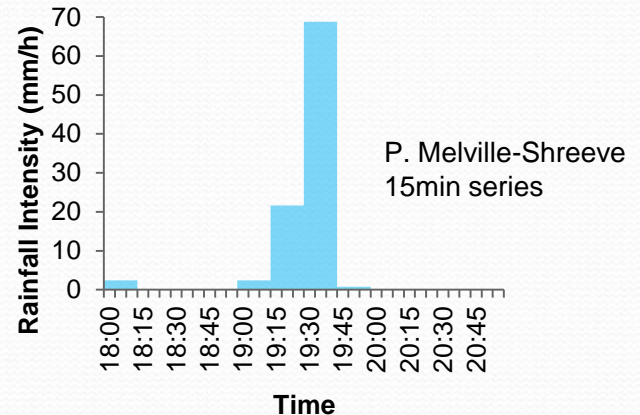
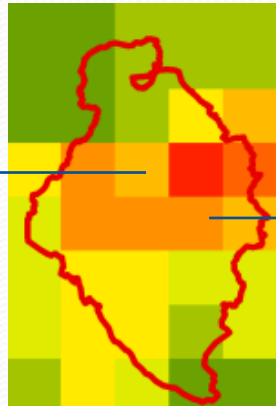
RR vs Raingauge

- Met Office RG @ Exeter Airport
 - 0.4mm/h peak intensity
 - 0.8mm in 3h
- Two private RGs

Dan Grey
41 mm in total

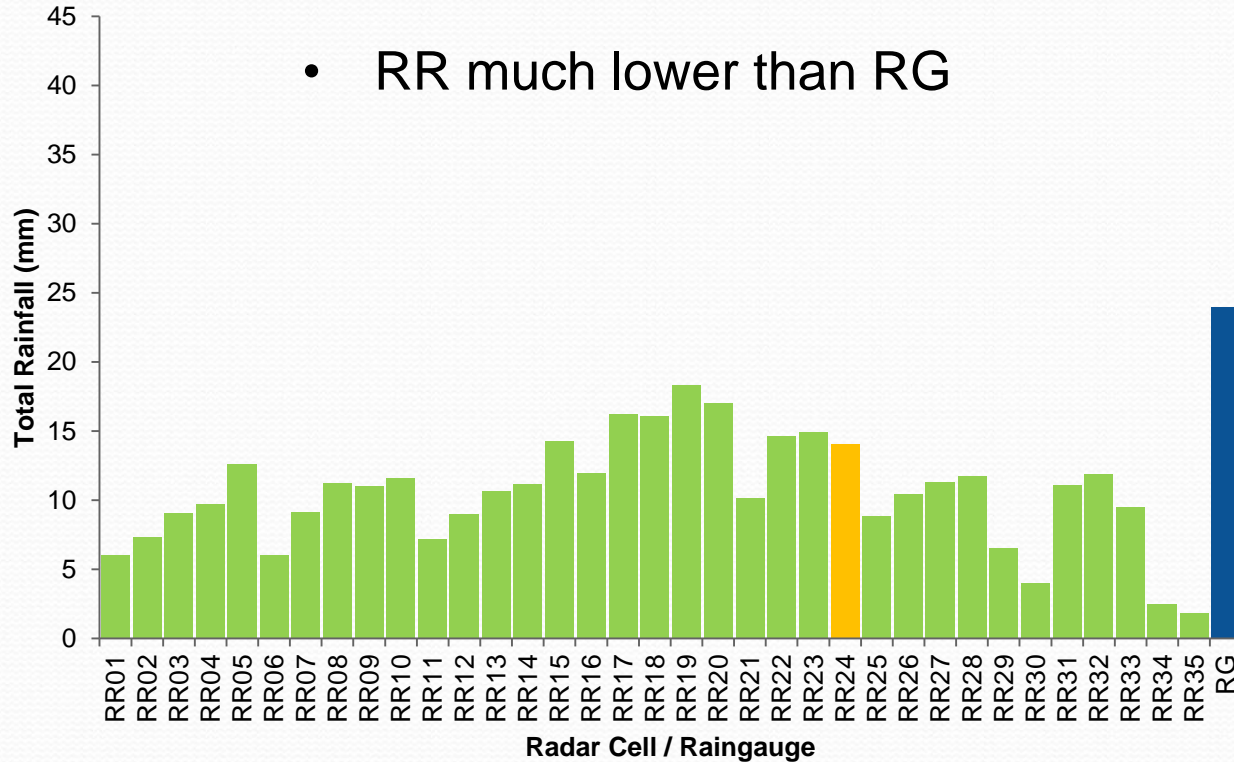


5 min covering the whole city

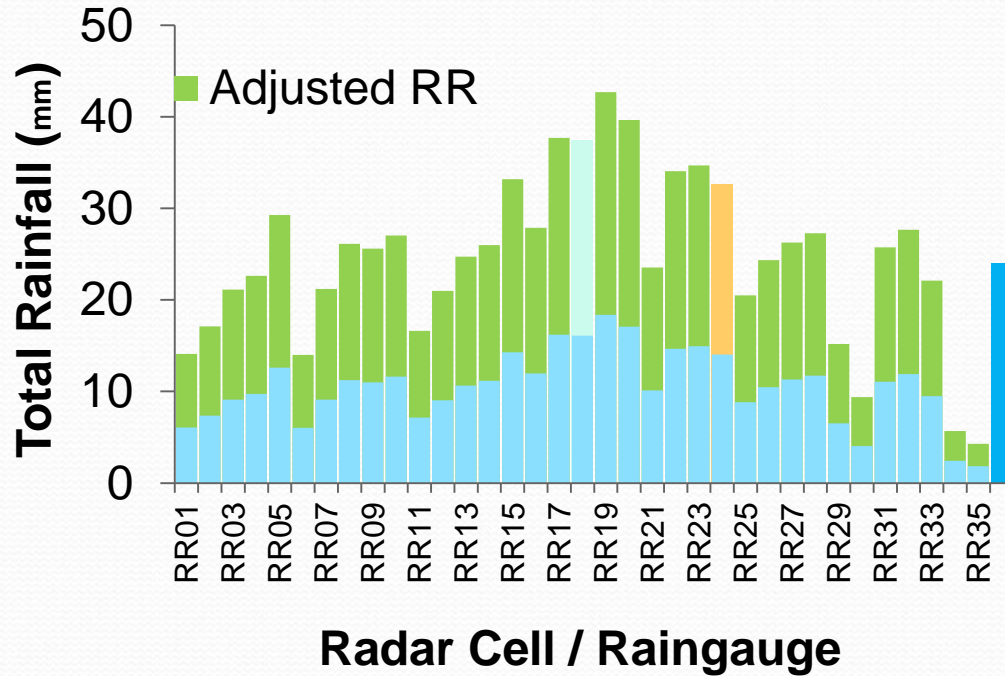


RR vs Raingauge

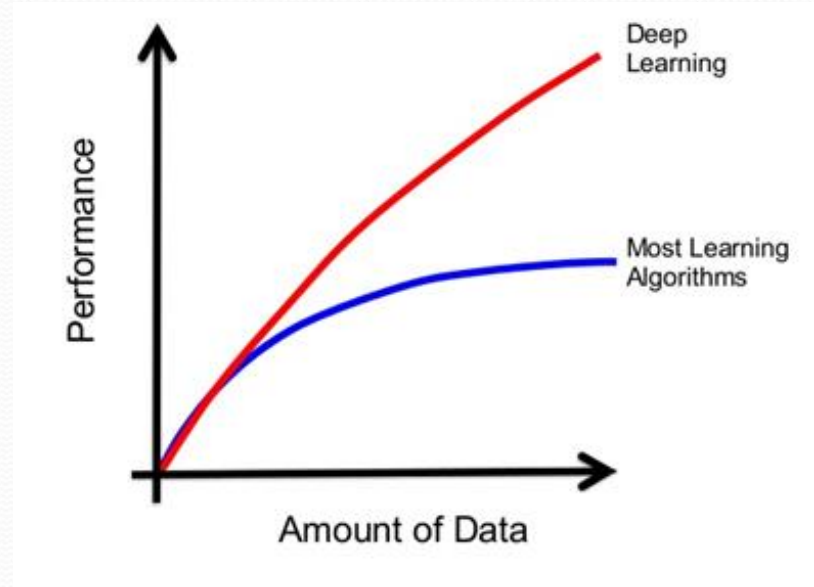
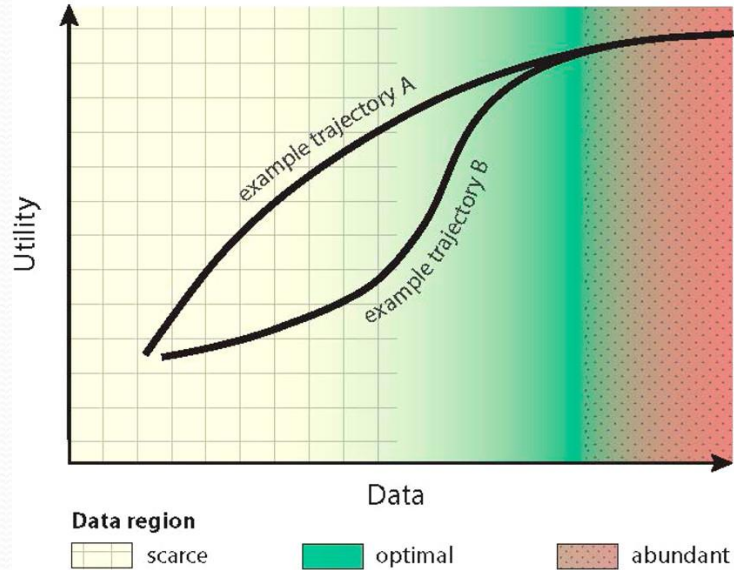
- RR much lower than RG



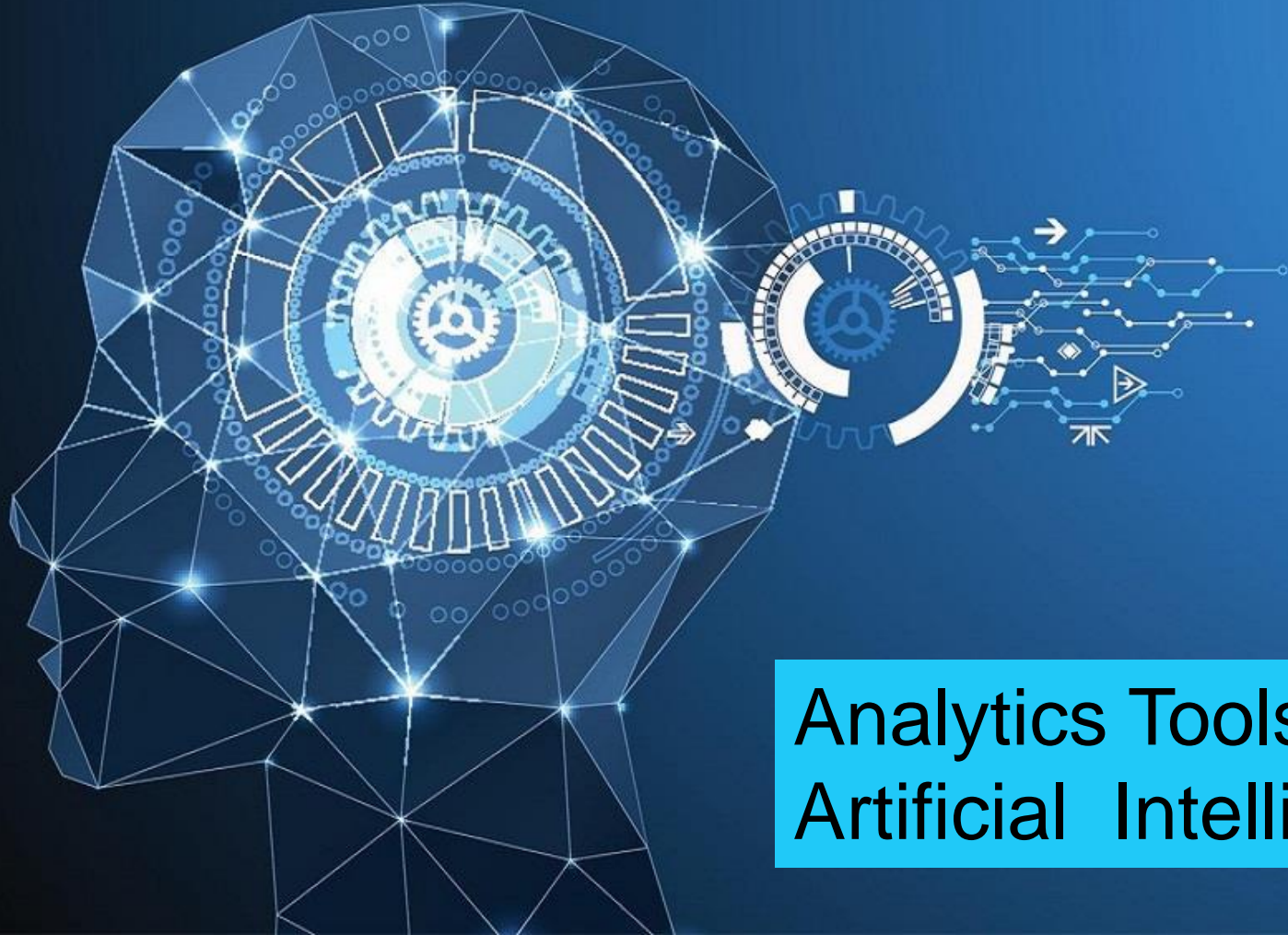
RR vs Raingauge



The Utility of Data

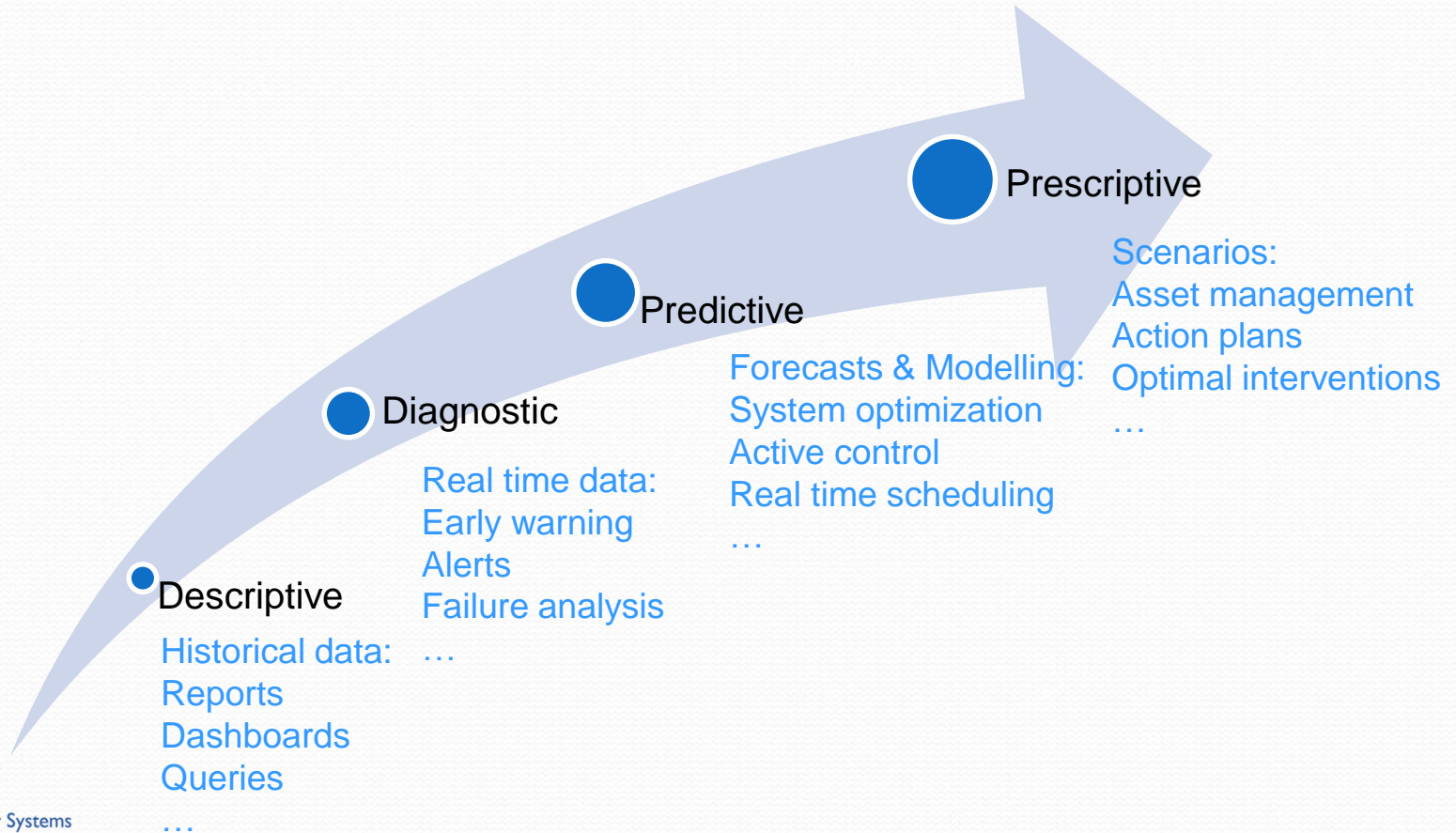


(Eggimann et al., ES&T, 2017)



Analytics Tools and Artificial Intelligence

Data and decision analytics



Algorithms

Signal analysis

- Filtering
- Outlier detection
- Statistical process control
- Auto-correlation
- Spectrum analysis
- ...

Statistical analysis

- Multivariate regression
- Principle component analysis
- ANOVA
- ...

AI

- Artificial Neural networks
- Evolutionary algorithms
- Genetic programming
- ...



Seconds

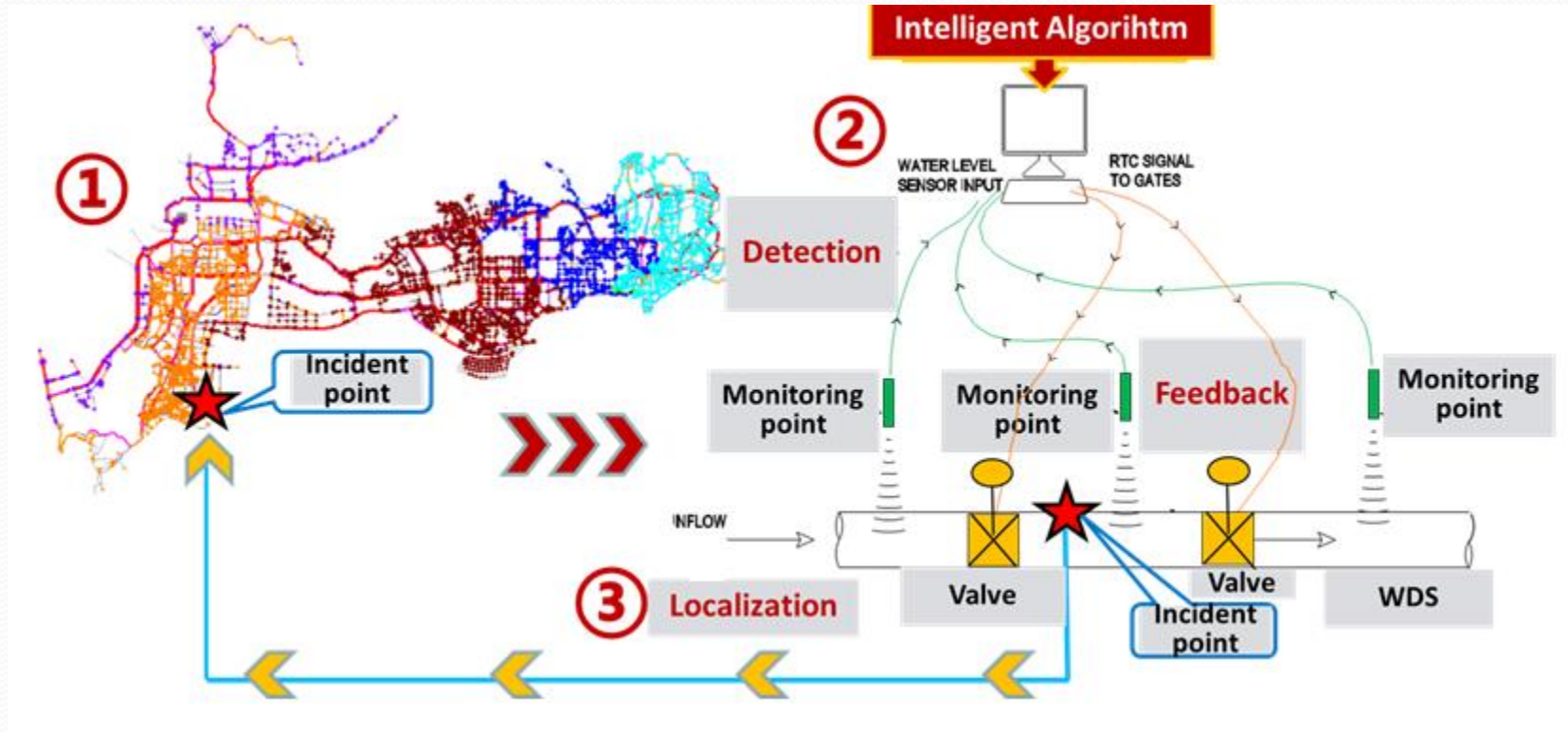
Minutes

Hours

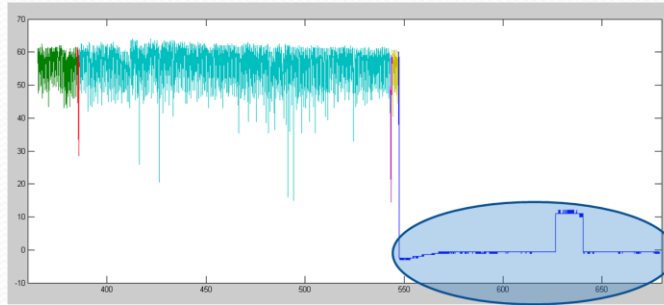
Days

Months

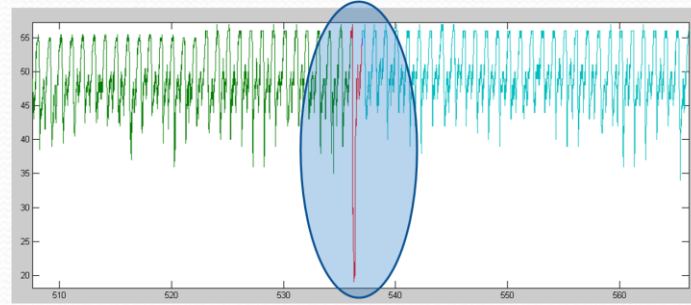
Years



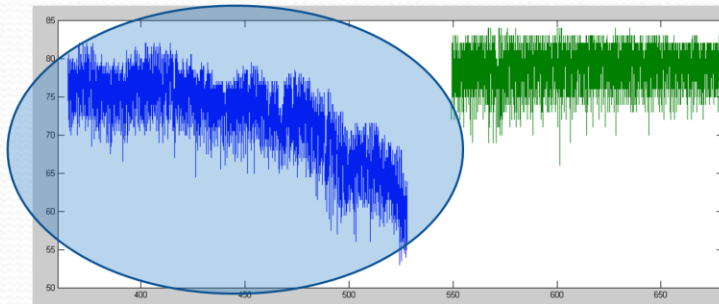
Real-time data issues



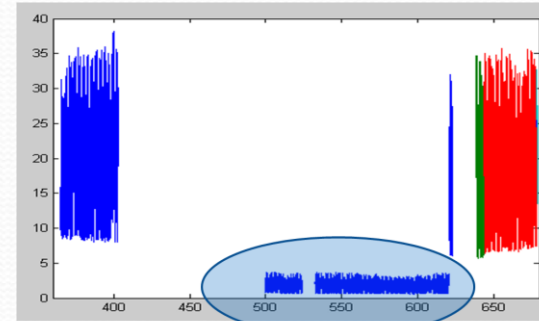
Instrument failure?



Short, abnormal measurements?

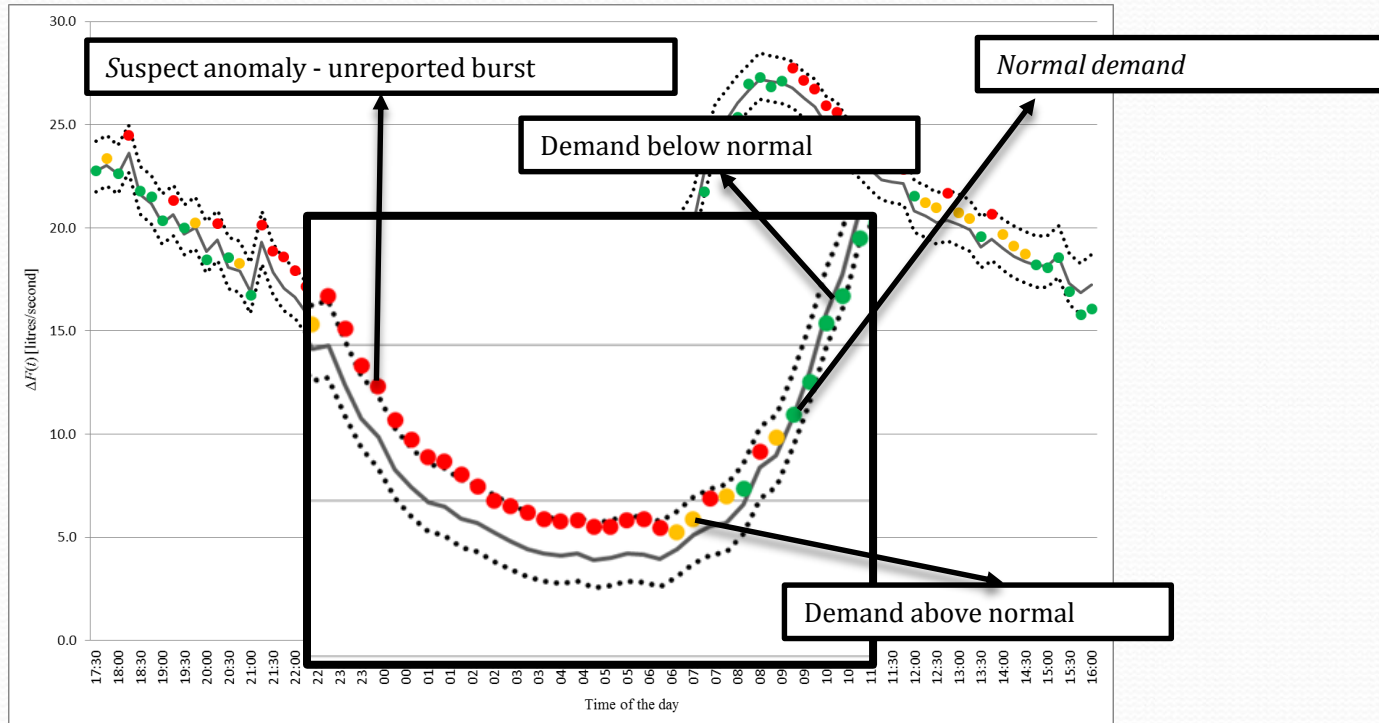


Sensor drift?



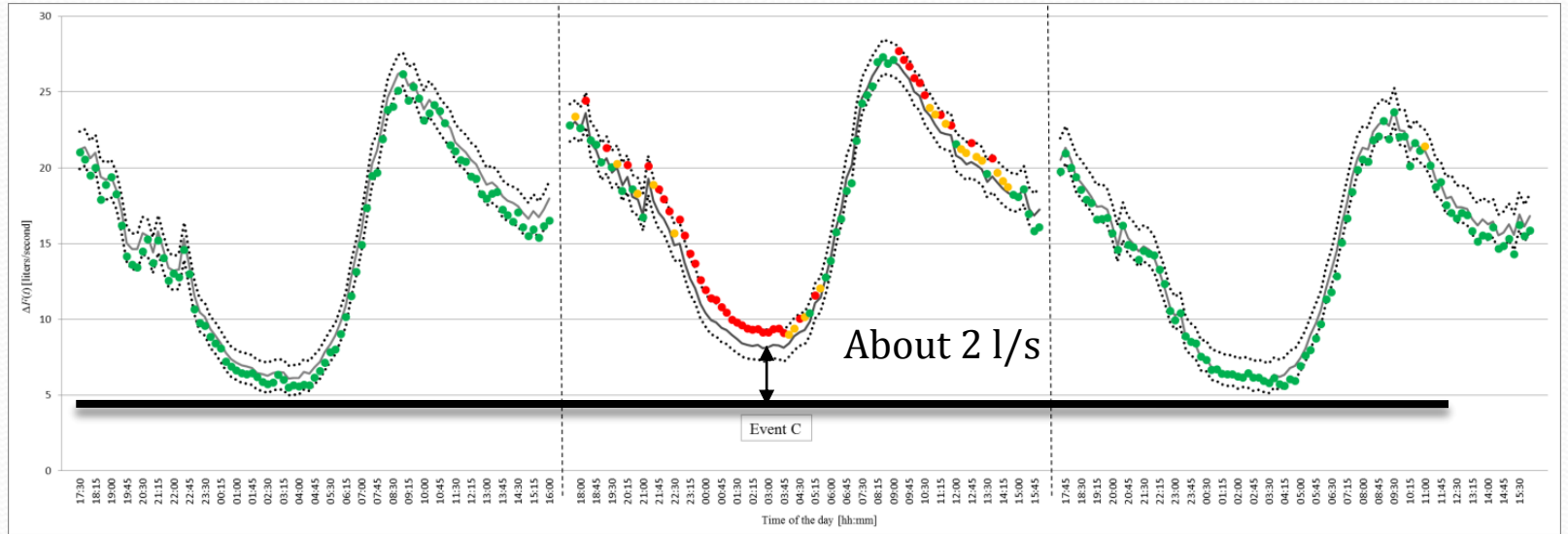
Possible system change?

Burst warning



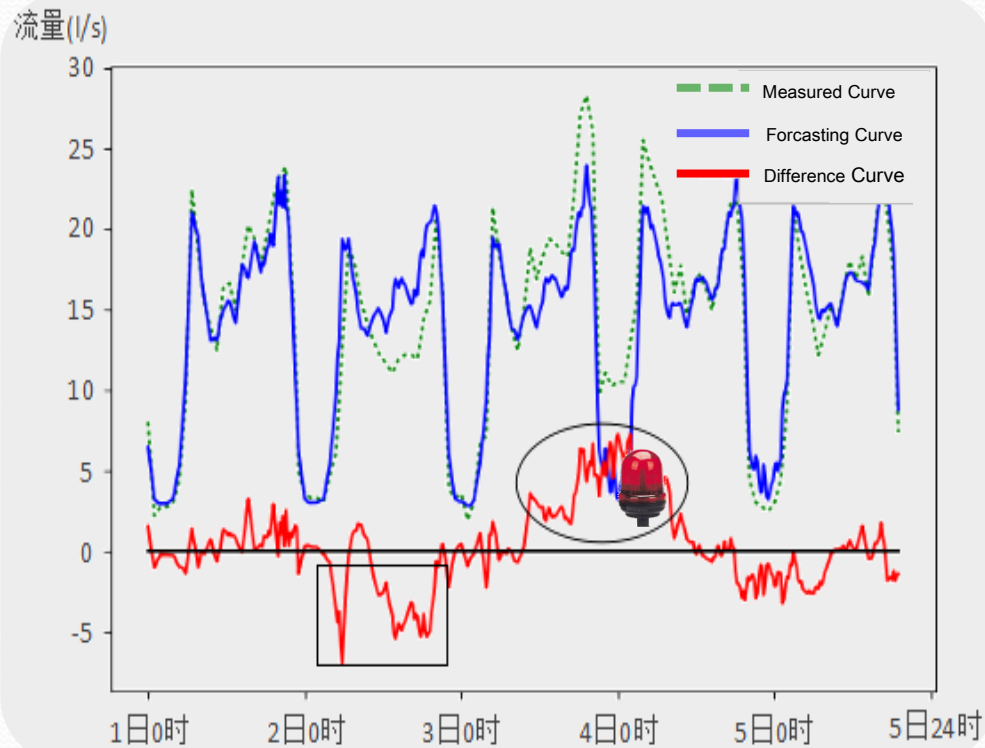
Laucelli, D., M. Romano, D.A. Savić, and O. Giustolisi. "Detecting anomalies in water distribution networks using EPR modelling paradigm." *Journal of Hydroinformatics* 18, no. 3 (2016): 409-427.

Background leakage



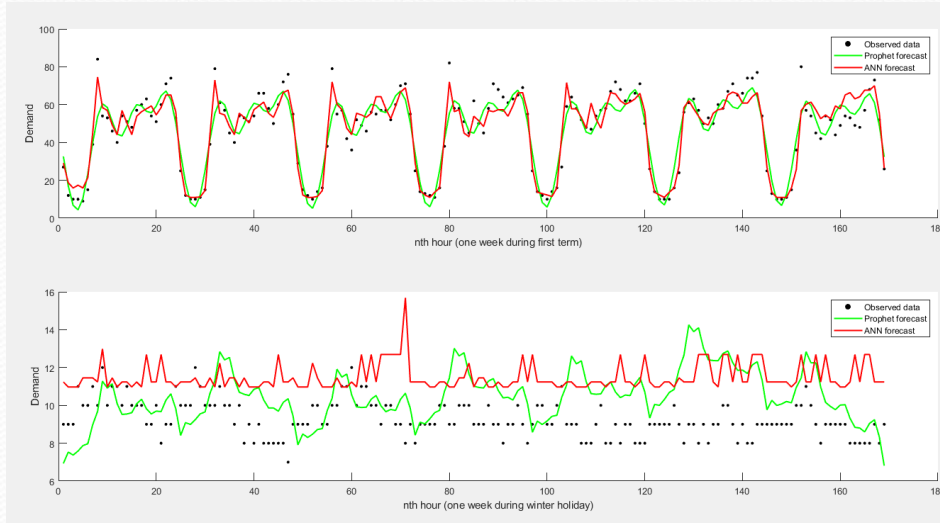
- 2 l/s shift upwards

Laucelli, D., M. Romano, D.A. Savić, and O. Giustolisi. "Detecting anomalies in water distribution networks using EPR modelling paradigm." *Journal of Hydroinformatics* 18, no. 3 (2016): 409-427.



1日0时 5日0时 3日0时 4日0时 2日0时 2日5时

Prophet vs. ANN

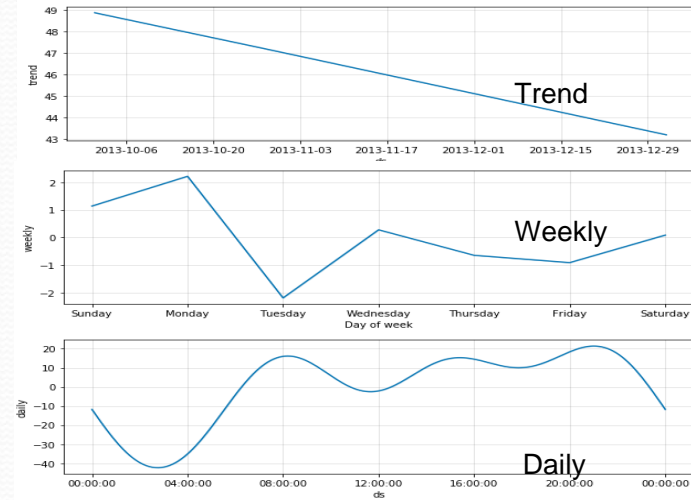


ANN

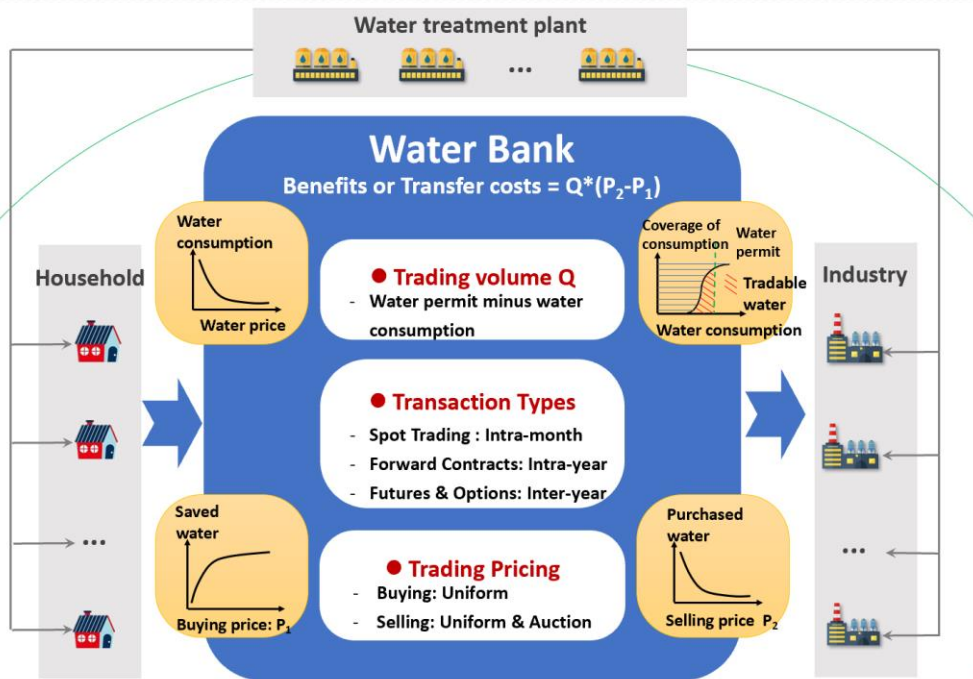
- Small error...but cannot simulate the holiday effects
- Fast fitting

Prophet

- Stable output
- *Decomposable model output*
- Easy parameter consideration



Water bank: platform



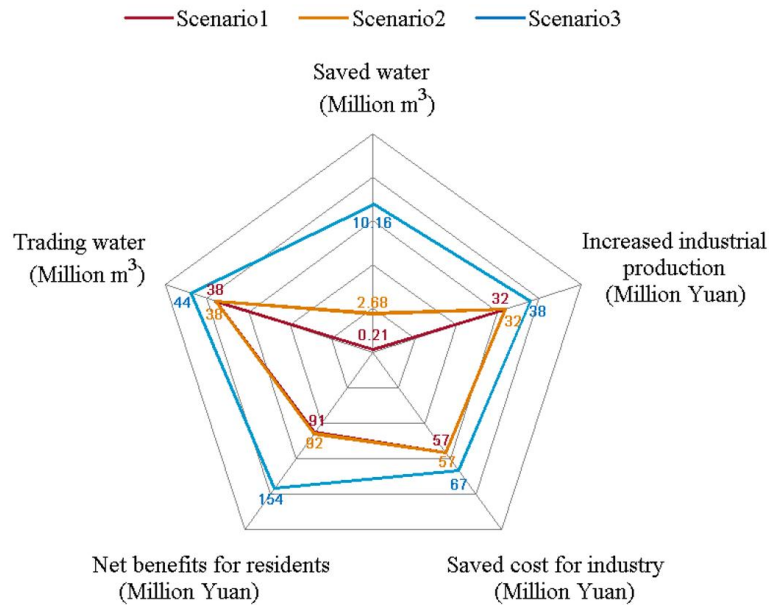
Government monitor and regulation

Risk Management

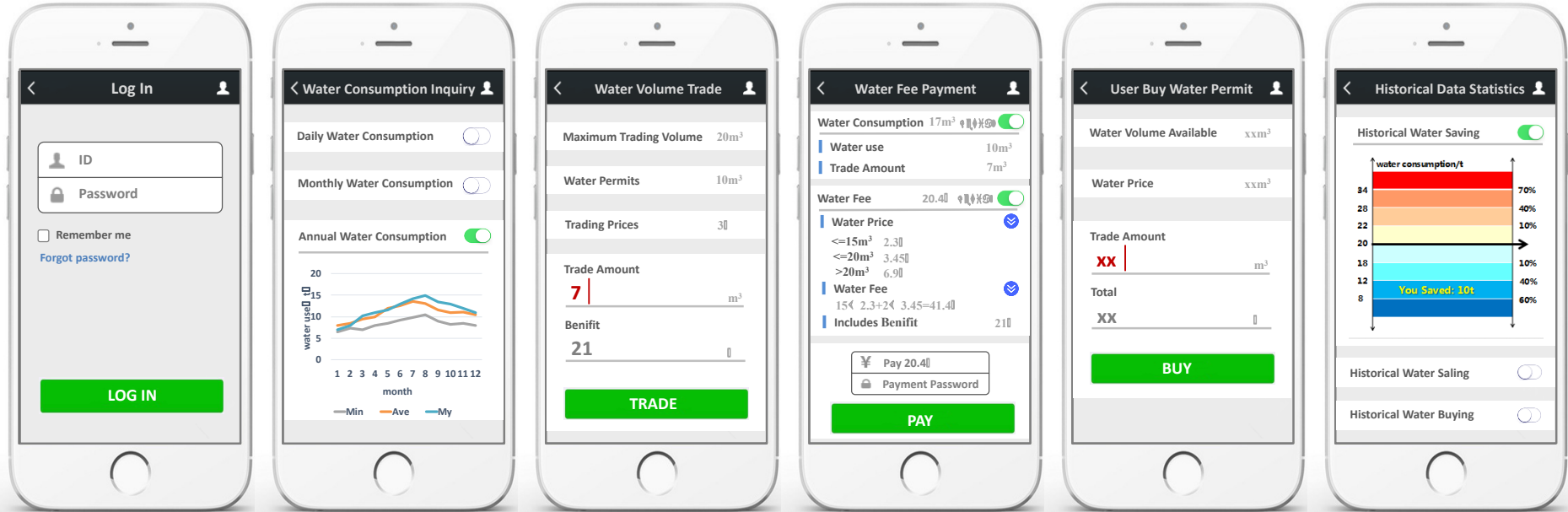
- Manage price and delivery risk
- Secure and regulate market

Guaranteed performance of trades

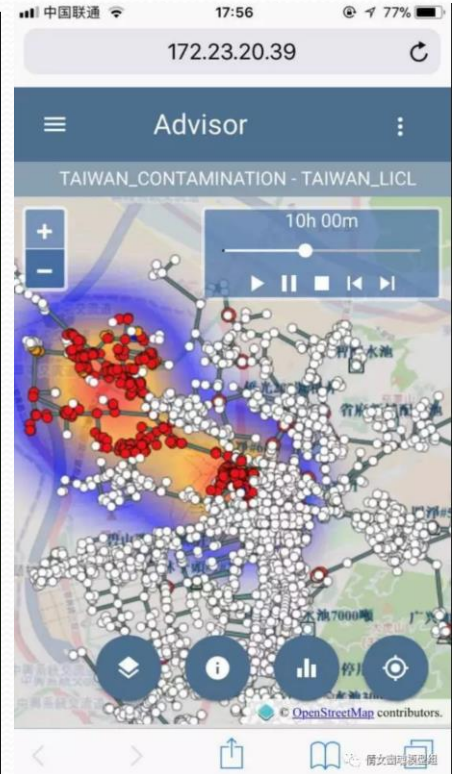
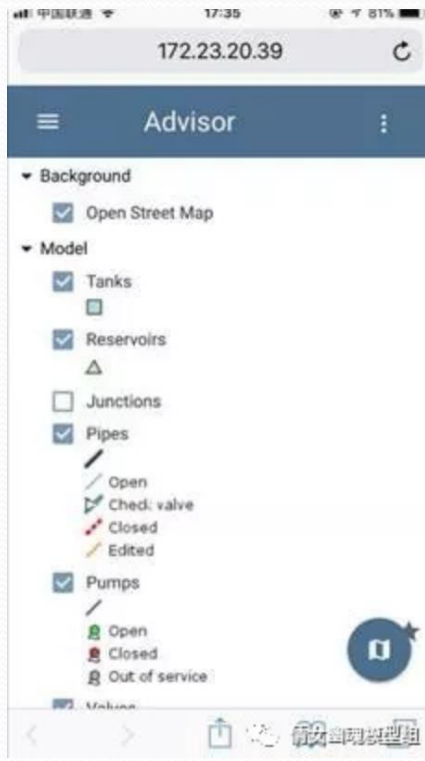
- Credit tracking mechanism
- Reward and punishment



Water bank: implementation



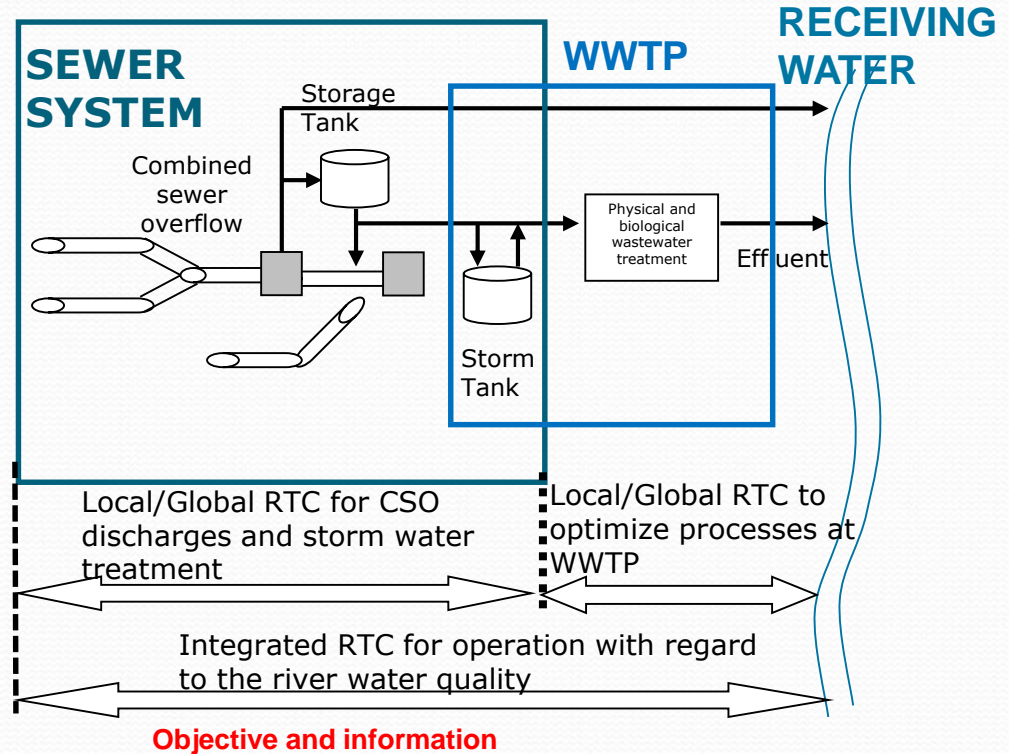
Hydraulic modelling on mobile



Integrated control

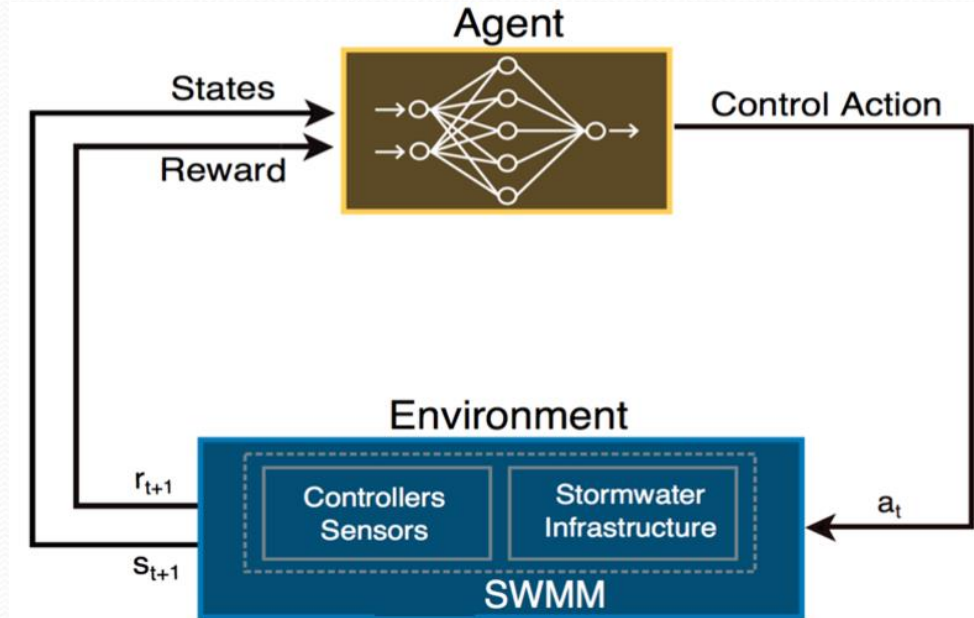
Previous work:

- **Chris Sweetapple:** GHG emissions; resilience analysis
- **Fanlin Meng:** operational permits; real time control; cost-benefit analysis
- **Maryam Astaraiie-Imani:** Combined impacts of urbanisation and climate change
- **Arturo Casal-Campos:** grey vs. green; reliability, resilience and sustainability; robust adaptation pathways
- **Biniam Arshagre:** Integrated catchment & case studies



Reinforcement learning

- Supervised learning
- Unsupervised learning
- Reinforcement learning
 - generalization of supervised learning
 - learn from interaction w/ environment to achieve a goal

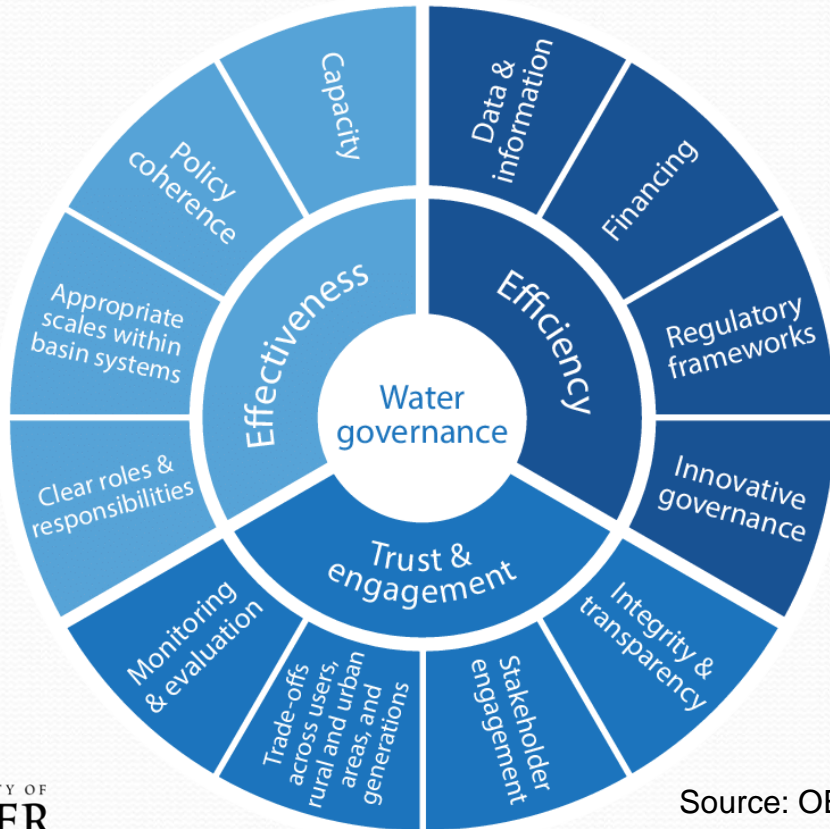


Source: Mullaipudi et al. (2016)

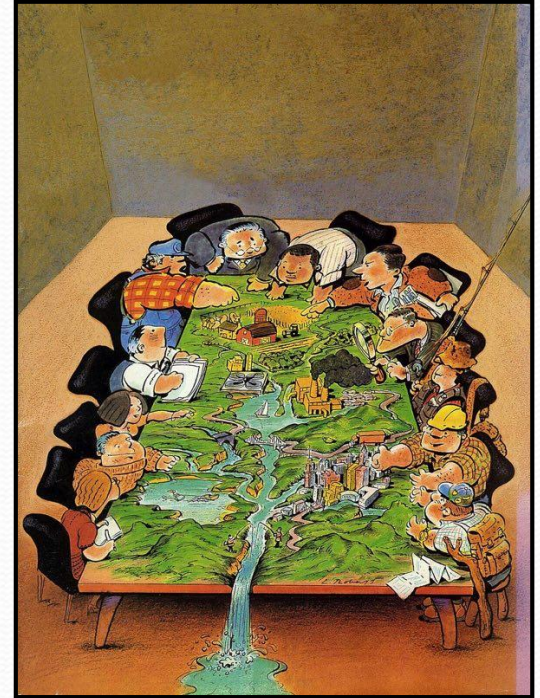
People



Smart water governance

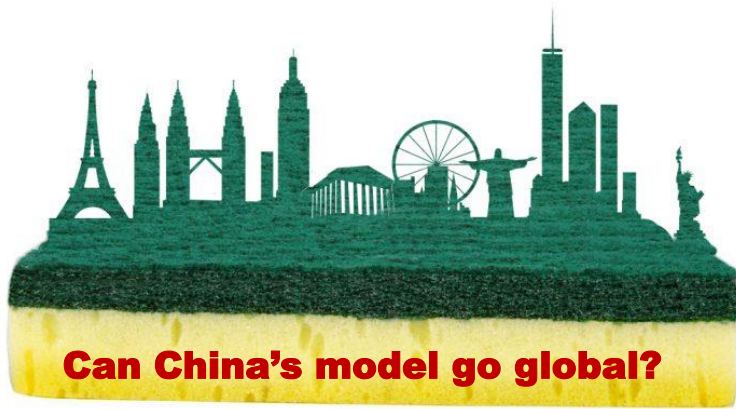


Source: OECD

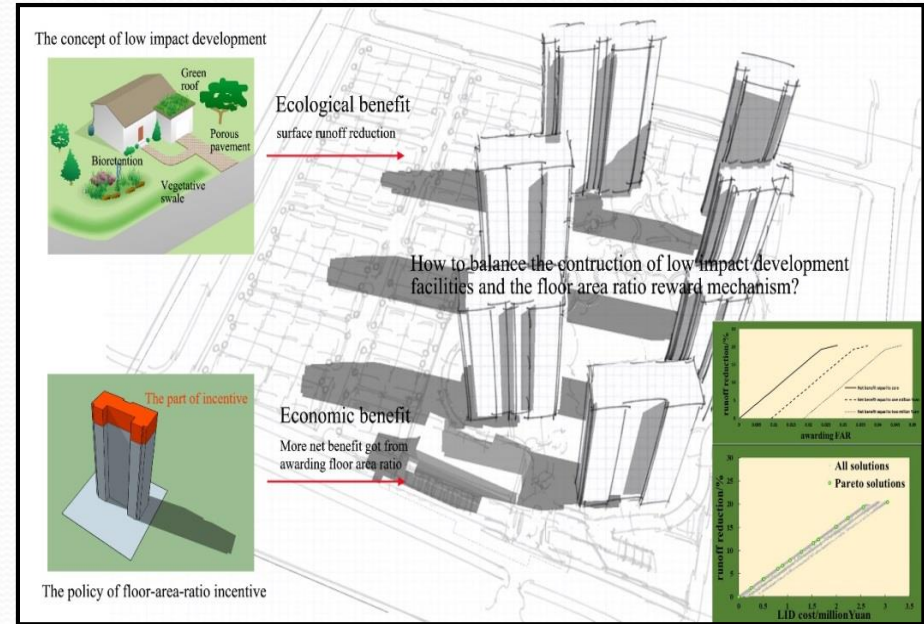


Source: Loucks and van Beek (2005)

Public Private Partnerships



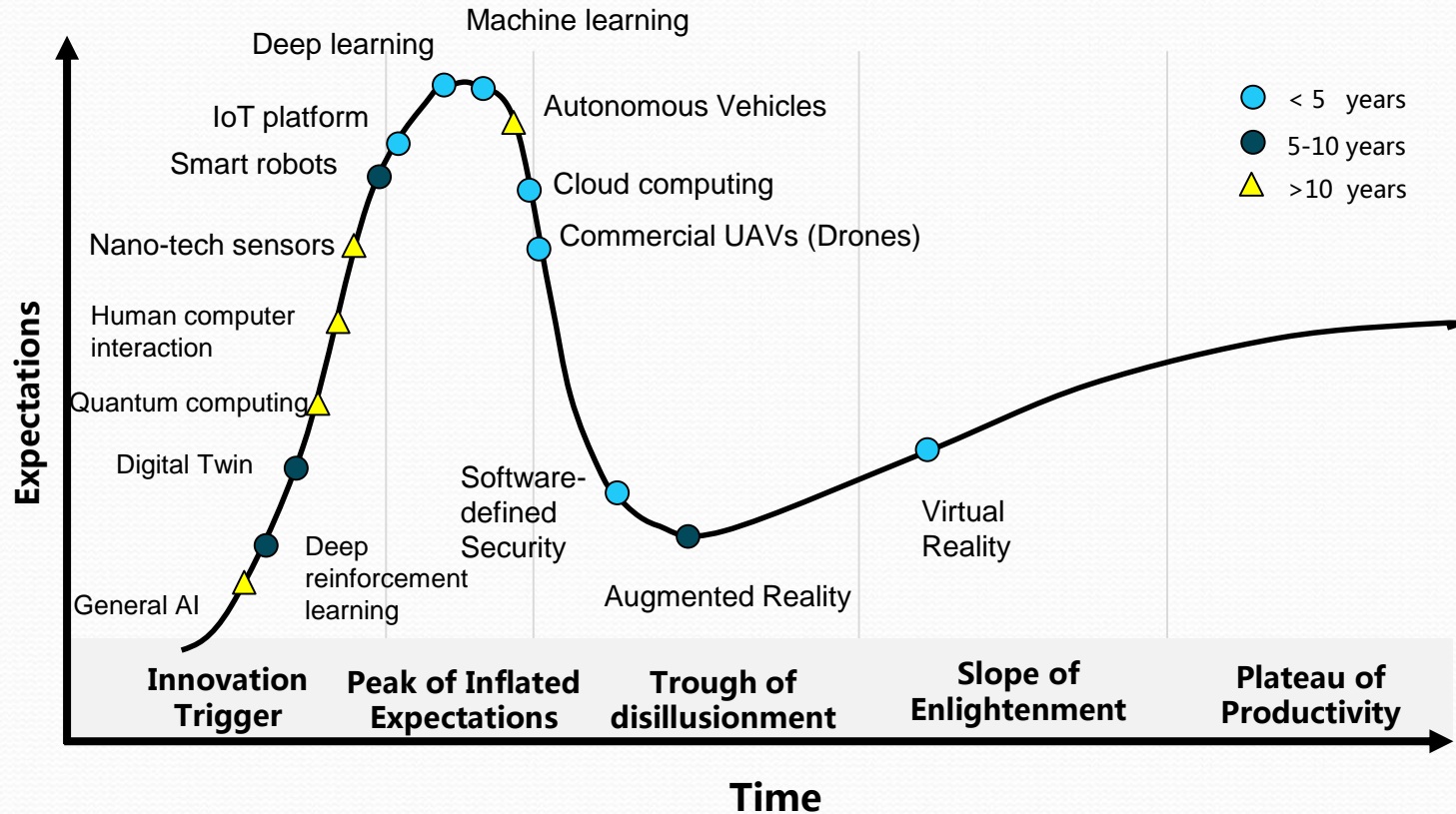
- A floor-area-ratio incentive
- Trade-off between runoff reduction and incentives



Source: *The Source* by IWA
(May 2017)

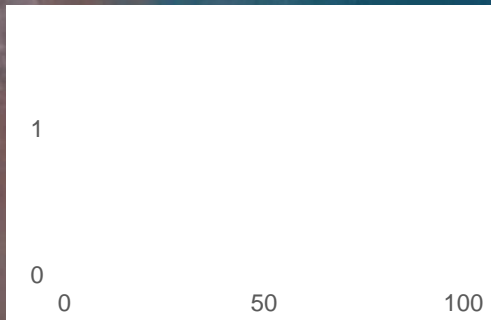
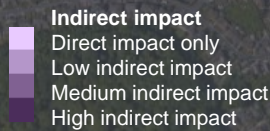
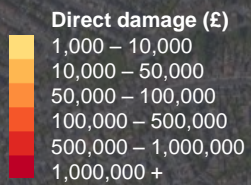
Source: Cheng M. et al. (in press)

Gartner Hype Cycle



Flood Impact to Paignton

*1 in 200 year Coastal Overtopping Event
with 50 years Climate Change*





EU-CIRCLE

Digital Twin: Virtual Singapore



CIM & analytics to ease decision making

Conclusions

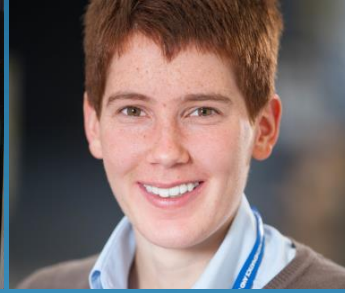
- **Smartness**

- Embedded in planning, design, operation and management
- A means to achieve Safe & SuRe

- **Smart water systems**

- Links infrastructure, information and people
- Data are useful but should be used with care
- AI is great...but for now remains just a hopeful promise

Thank you!



Guangtao Fu
g.fu@exeter.ac.uk
University of Exeter