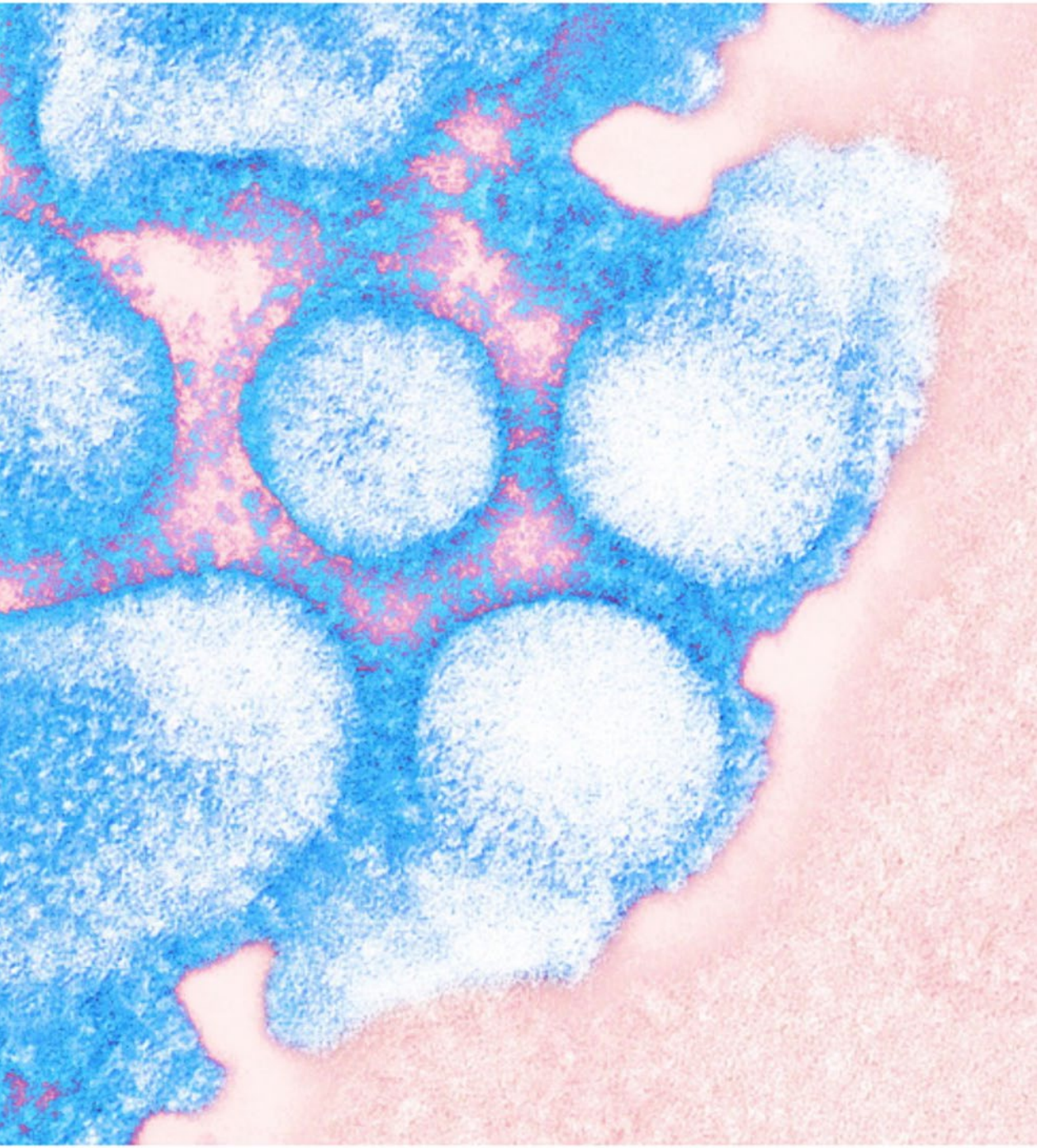


ARUP

Sewer Modelling for Wastewater-based Epidemiology

Mixing process in pipes, sewers and the natural environment from theory to practise

University of Sheffield

Joe Shuttleworth

April 2023

The Power of Wastewater

1

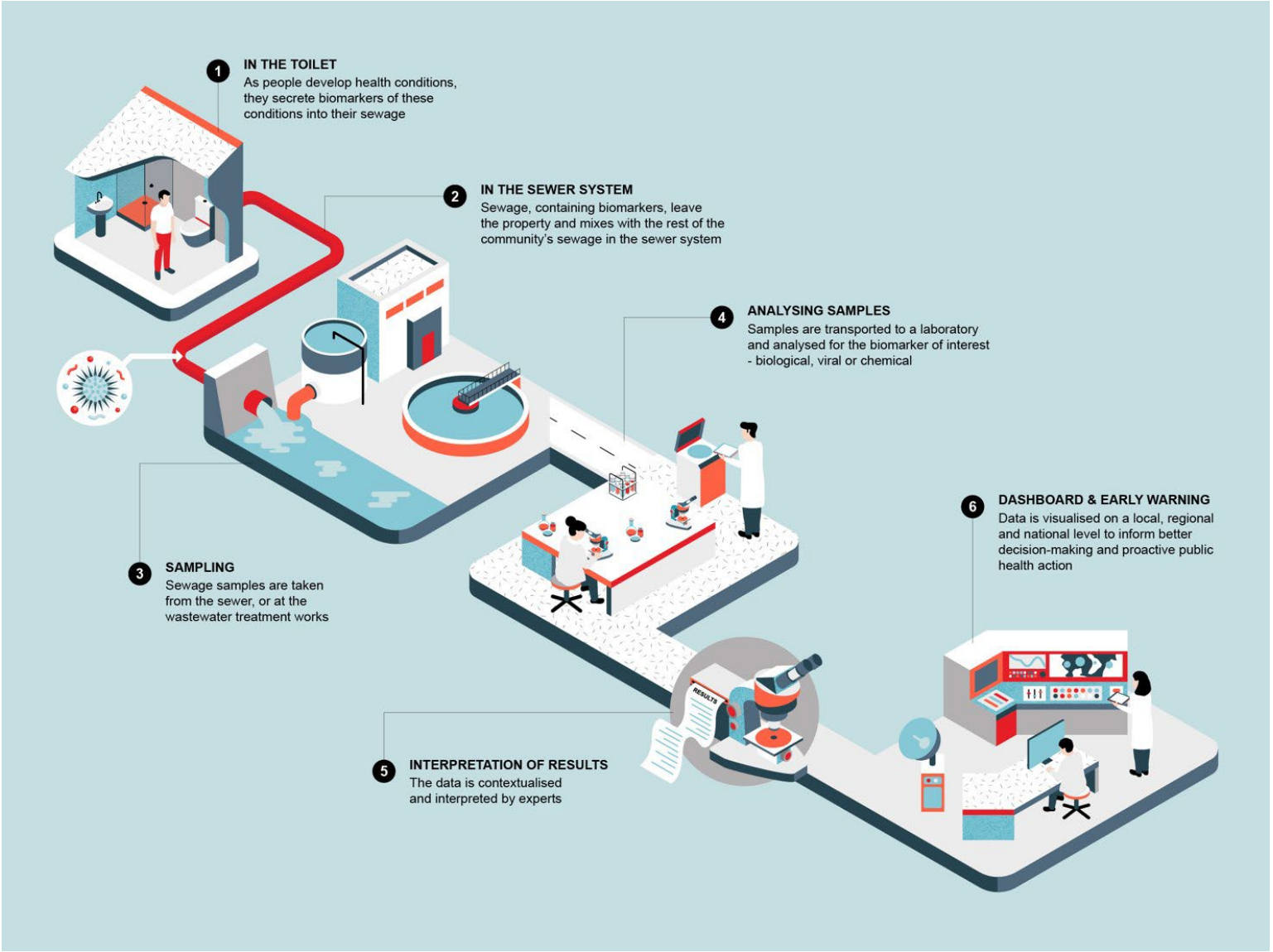
What is Wastewater-based Epidemiology?

ARUP

Background

The COVID-19 pandemic has reminded us of
the importance and impact of public health.

Through monitoring biomarkers, found in sewage, wastewater-based epidemiology (WBE) can give an indication of human health.

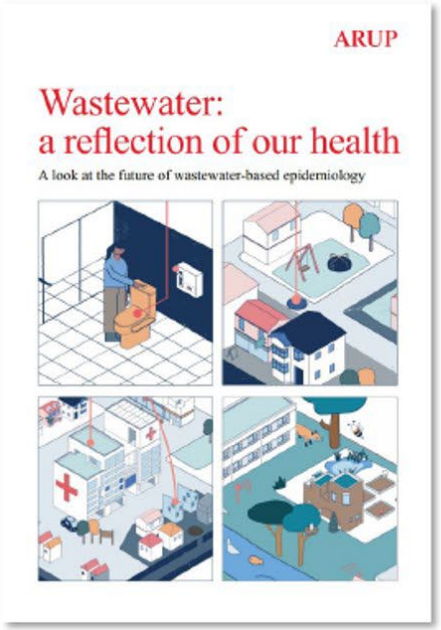


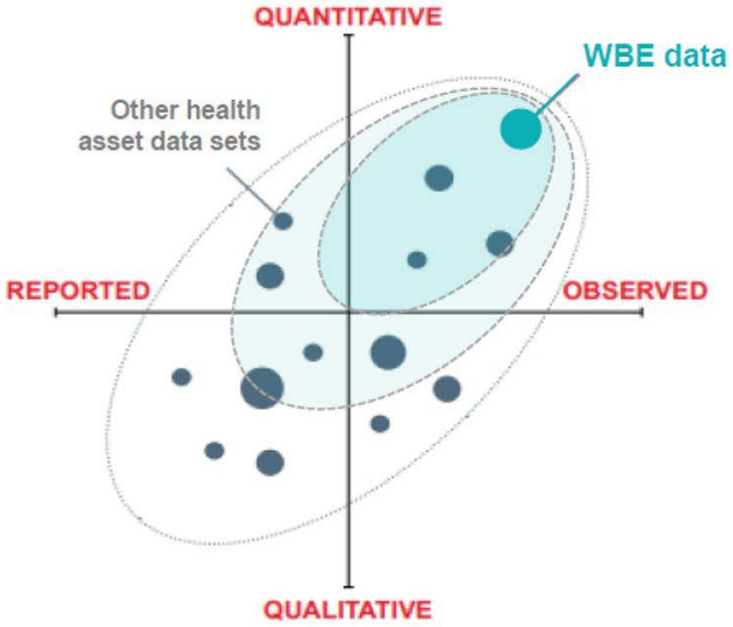
ARUP

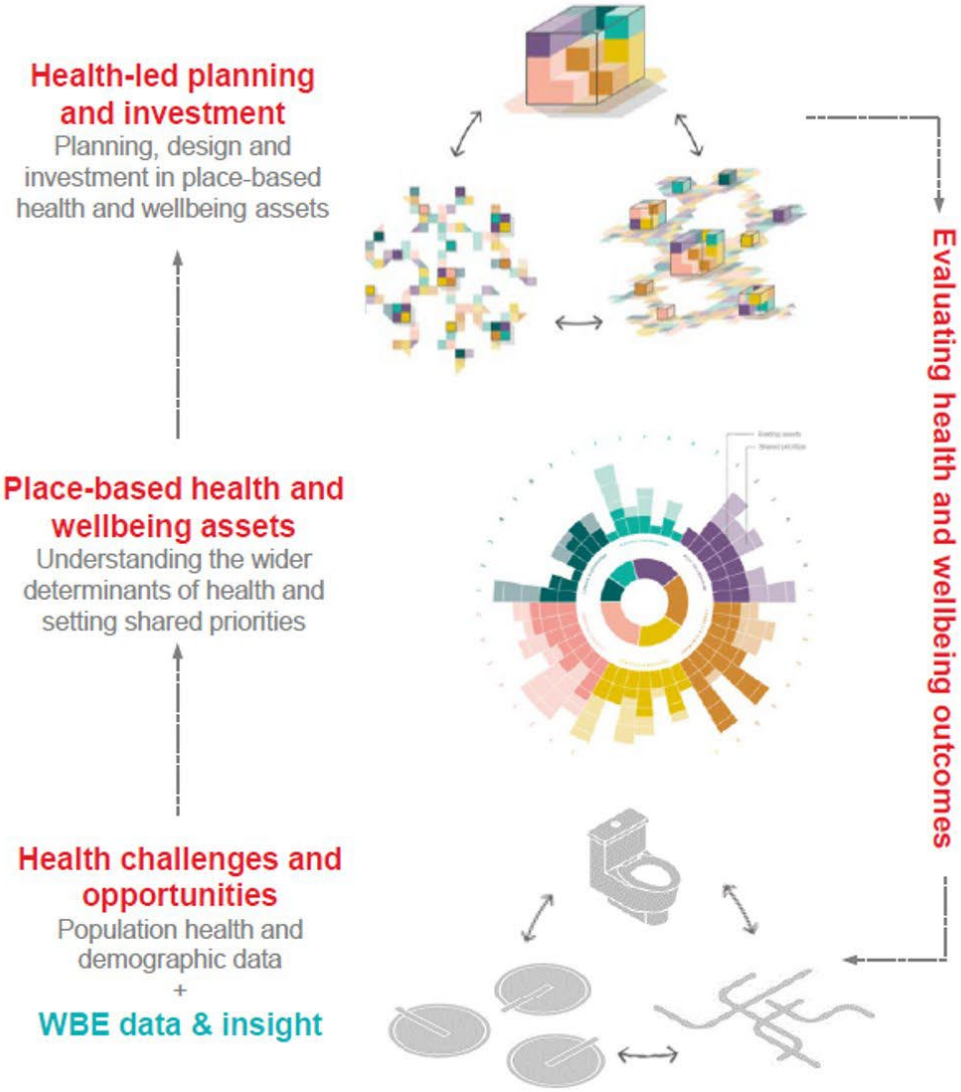
Data from Wastewater

Synthesising different types of data and insight

WBE data can contribute rich insight into population and environmental health and there is opportunity to extend this in the future. In combination with other sources of place-based data, there is potential for WBE to extend its role and impact as part of longer-term cross-sector approaches to urban health and wellbeing







WBE to proactively manage public health

ARUP

Data to insights

- Wastewater monitoring can help identify hotspots/ outbreaks
- Target areas for interventions and minimize impacts on other areas
- Feed into data led health policy

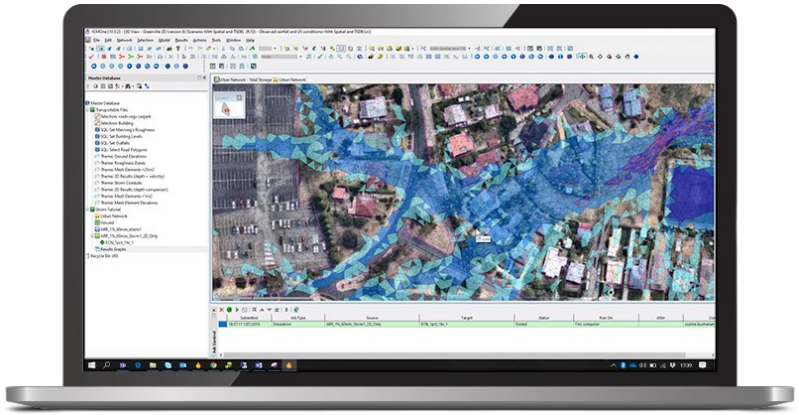
Insights Through Analytical Tools

2

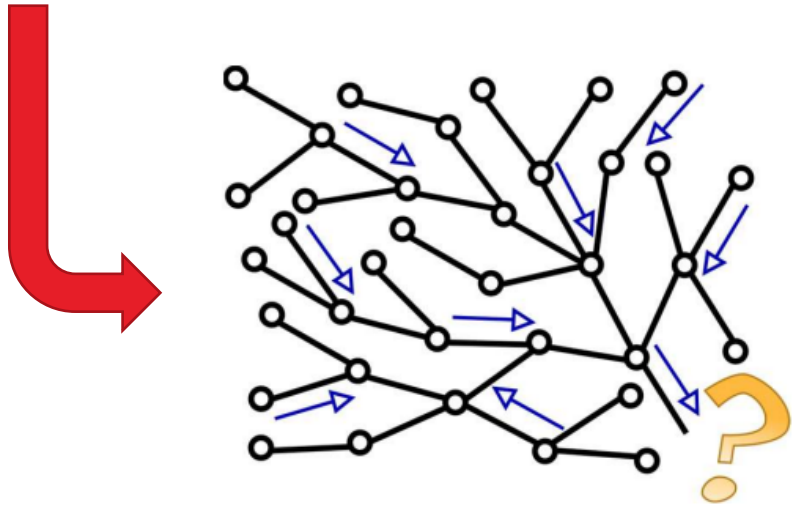
ARUP

Where did we start?

'Given a sample taken at a certain location and time, can we tell where that has come from by using a simple model?'

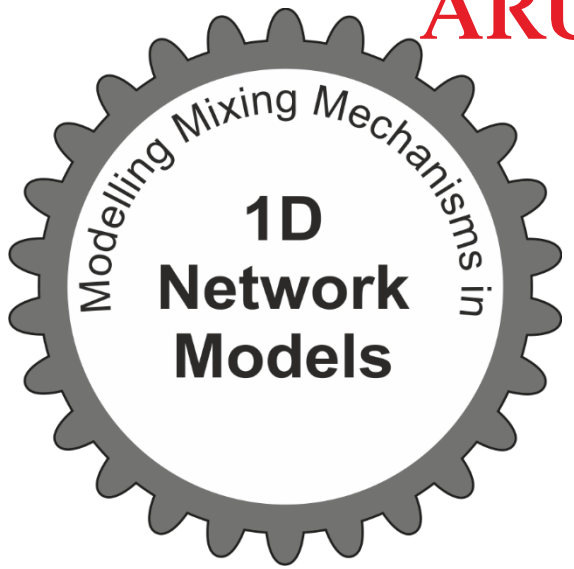


We wanted something that was accurate, fast and flexible and based around the outcome we were trying to achieve…



ARUP

What is the exam question?

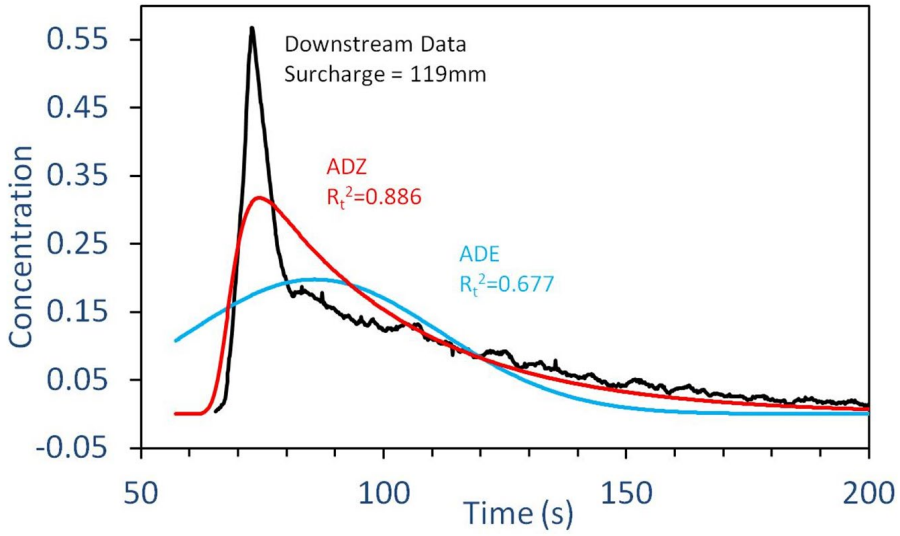


Aims:

- Obtain temporal tracer concentration distributions
  - $c(t)$
- Determine travel times and discharge
  - Centroid & area
- Describe mixing processes
  - Shape

Application:

- Investigate source localisation
- Quantify chemical & virus changes
- Validate WQ models, esp. storm conditions



How did we go about it?

1. Work with great partners!

UK Health Security Agency

SEVERN TRENT

United Utilities
Water for the North West

Dŵr Cymru
Welsh Water

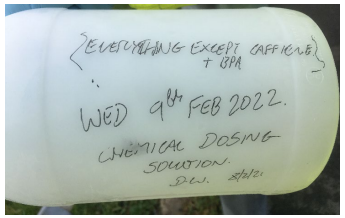
YorkshireWater

ATKINS
Member of the SNC-Lavalin Group

ARUP

2. Field work in 4 cities (95 traces!)

Vanessa and team getting set up



3. Great modelling team!

4. Develop ‘Sewer Fingerprint’

ARUP

Application

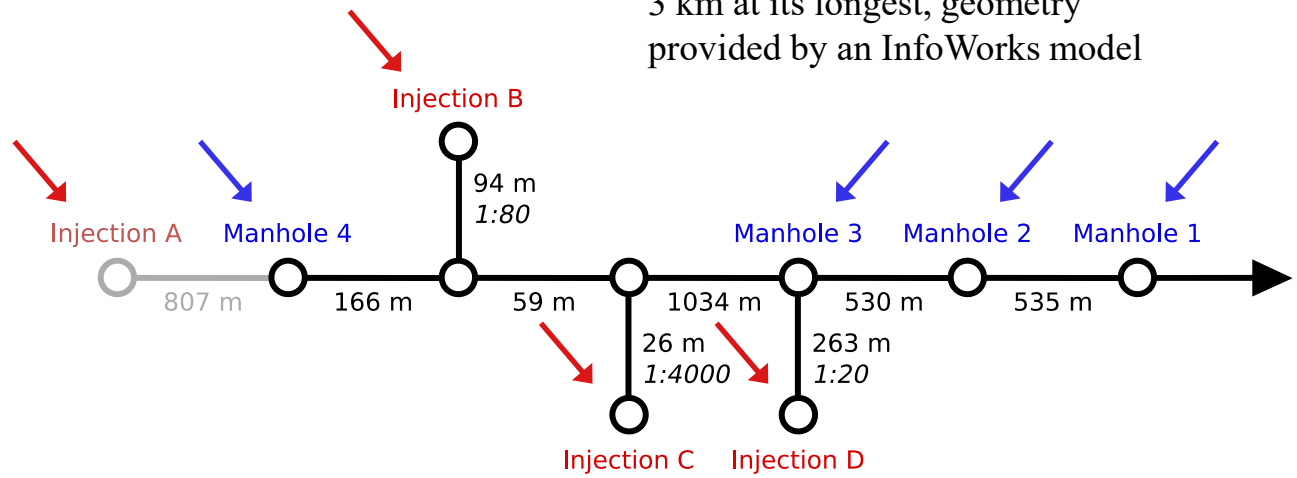
As part of our field work, simultaneous injections were carried

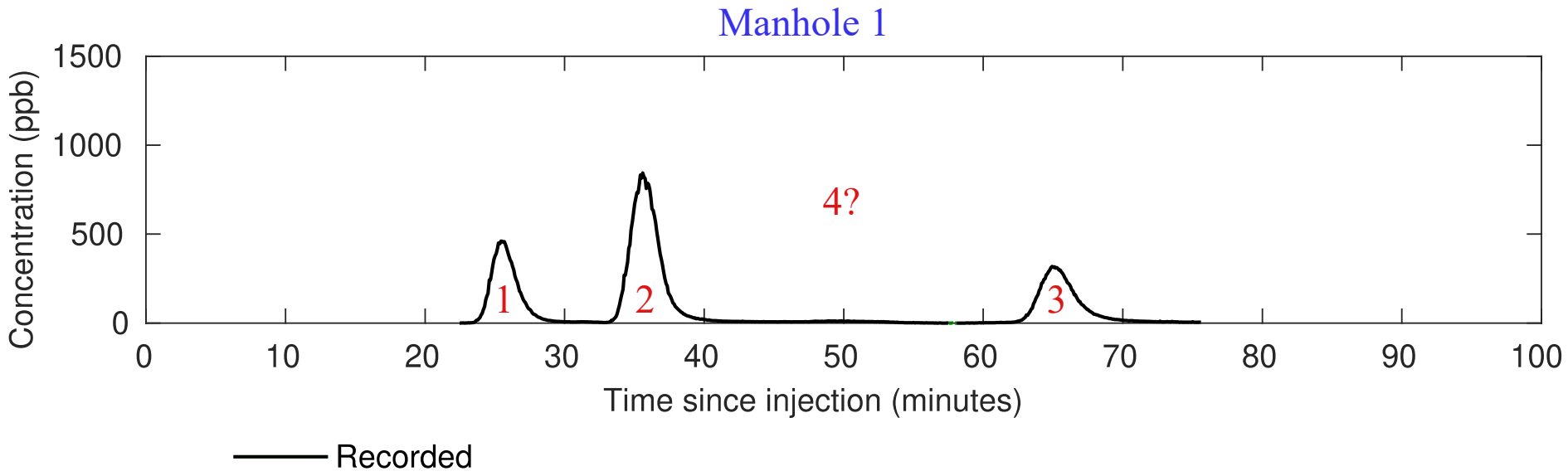
4 injection locations

4 monitoring locations

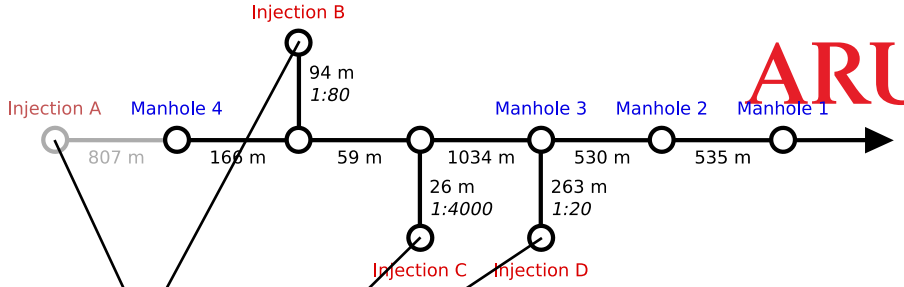
One peak observed at Manhole 4

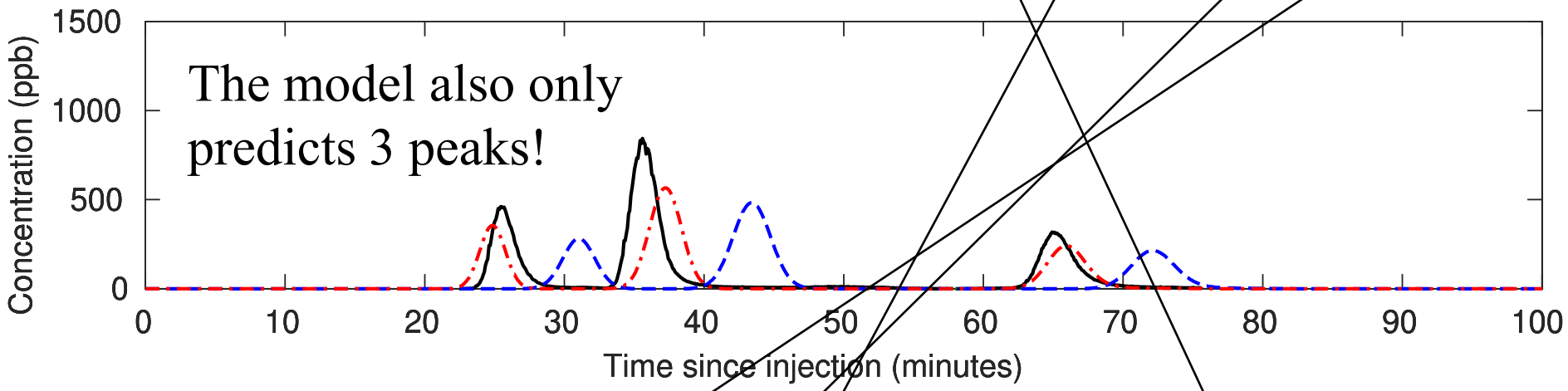
But…

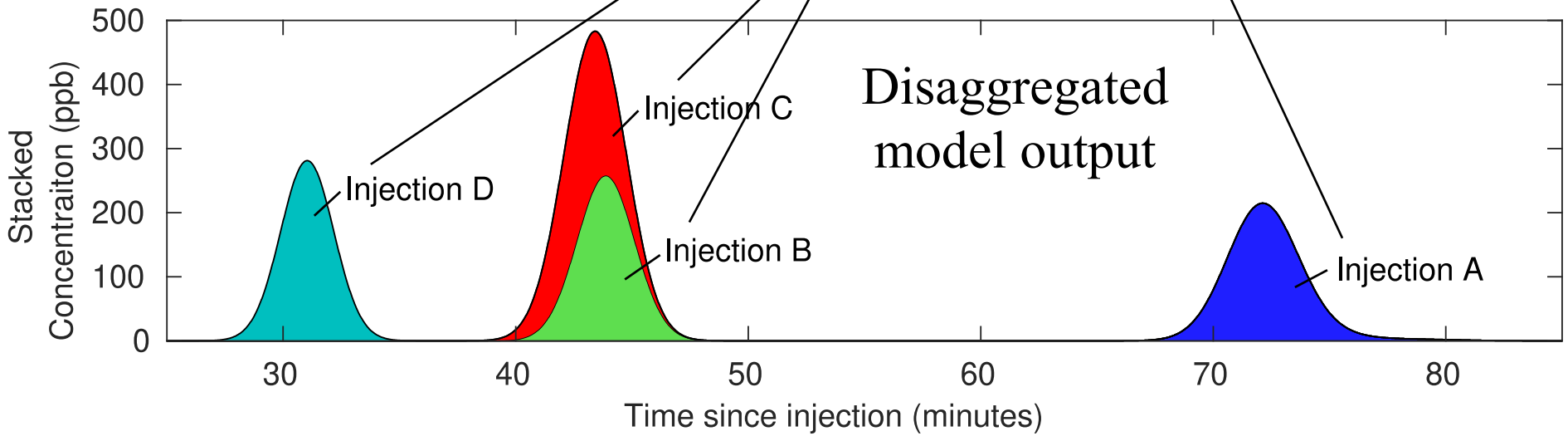




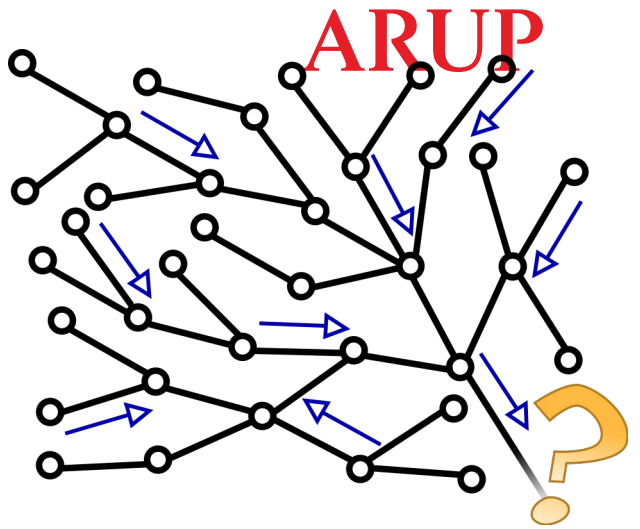
Application







Source localisation



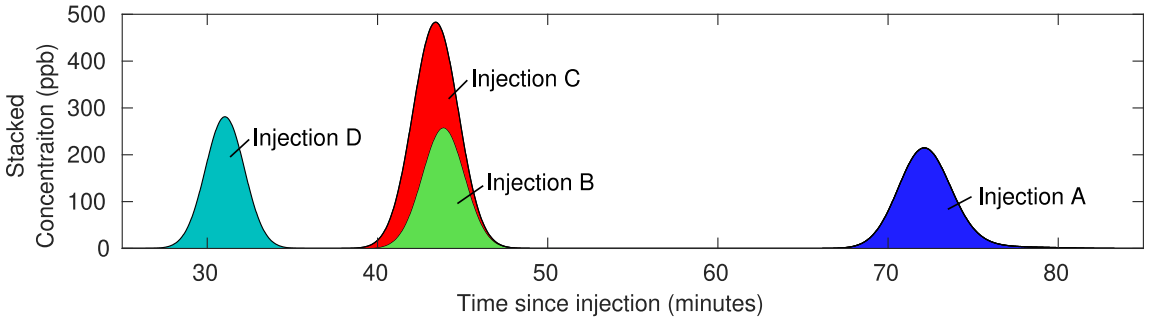
Working out injection location from monitored result

Most existing research focuses on sensor placement

Other approaches focus on matching measured and modelled spread of profiles

Instead, let's treat each downstream profile as a Residence Time Distribution (RTD)

Each RTD describes the unique response between an injection and monitoring location



The RTDs of a network can be thought of as similar to the ridges in a fingerprint…

ARUP

Network response

RTDs can be convolved with an input to predict a response

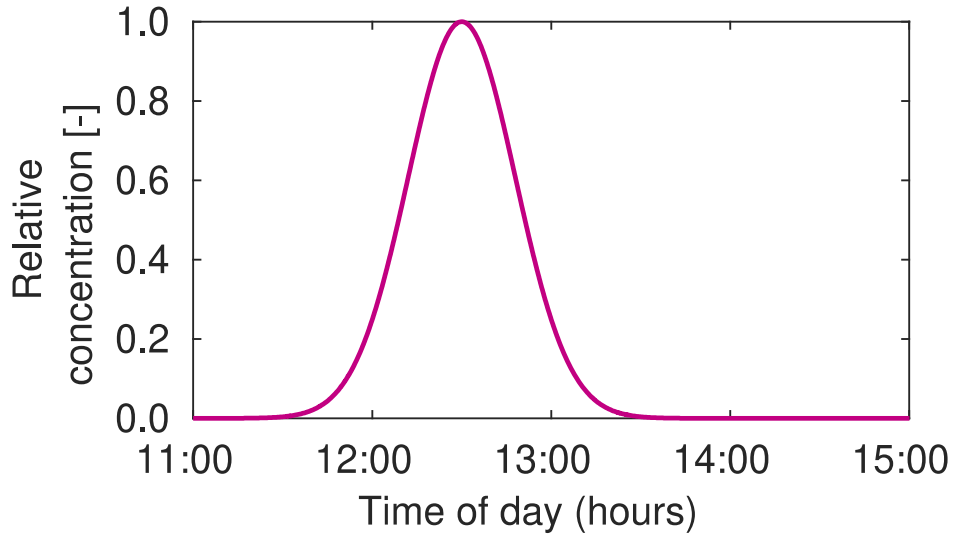
Let us assume an activity profile

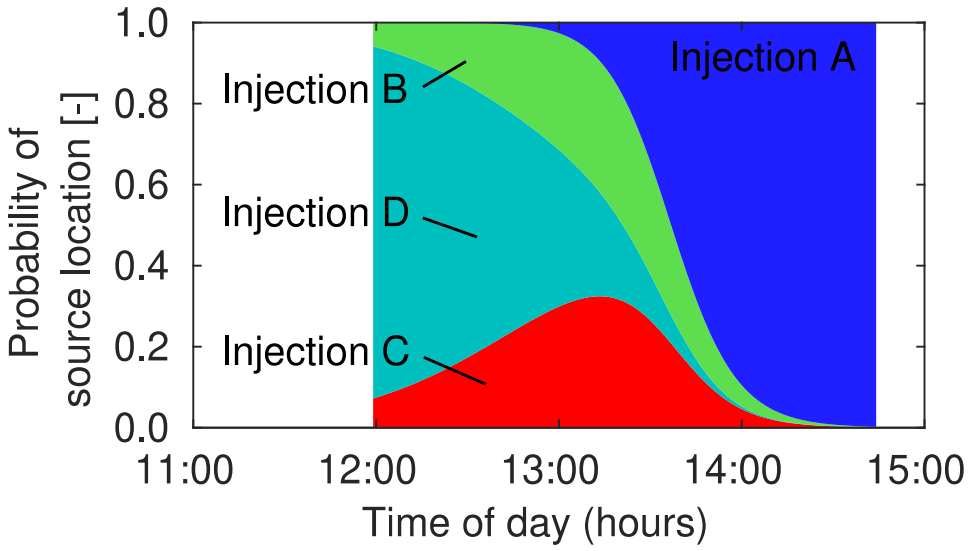
- E.g., more network use around lunch

Once convolved, we see a downstream prediction with timing related to activity

- Exact concentrations are challenging and in practice the material is all mixed together

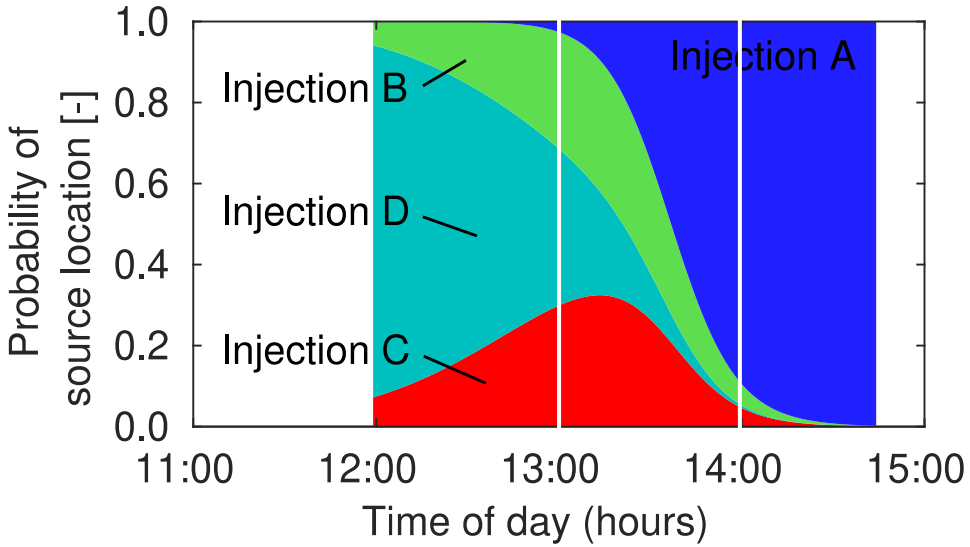
We can normalise by the amount of material predicted to estimate probability of source location

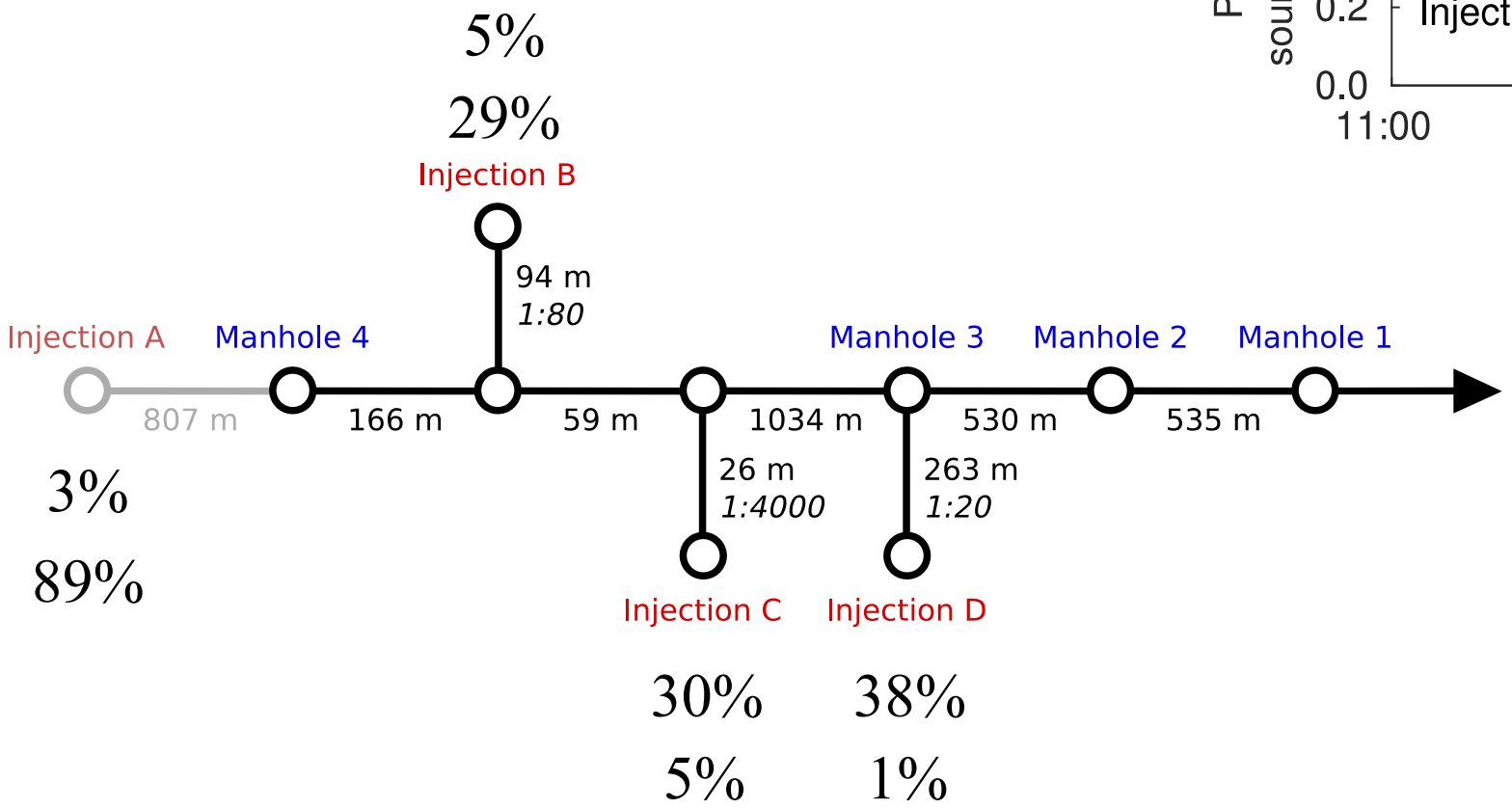




Impact of sampling time

- Importance of consistent sampling
- Existence of optimal sampling times?





Wider Applications

3

Sewage is polluting our waterways

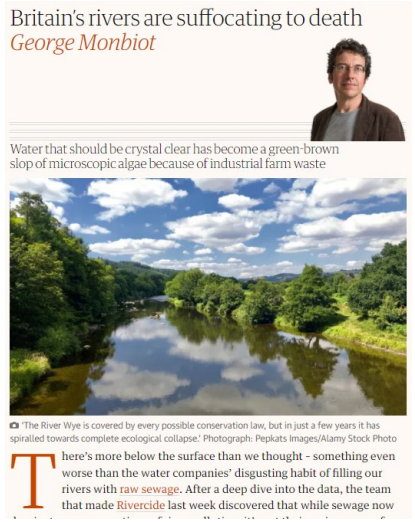
ARUP

Problem statement:

Wastewater pollution of waterways is getting increased attention and water utilities are under pressure to reduce pollution events.

Current approaches/solutions:

- Increase Capacity
  - Expand or replace infrastructure
  - Separate sewers
- Generalised catchment solutions/ pilot schemes
  - E.g. SUDs schemes (driven by available space/ potential benefits/ single design simulation)



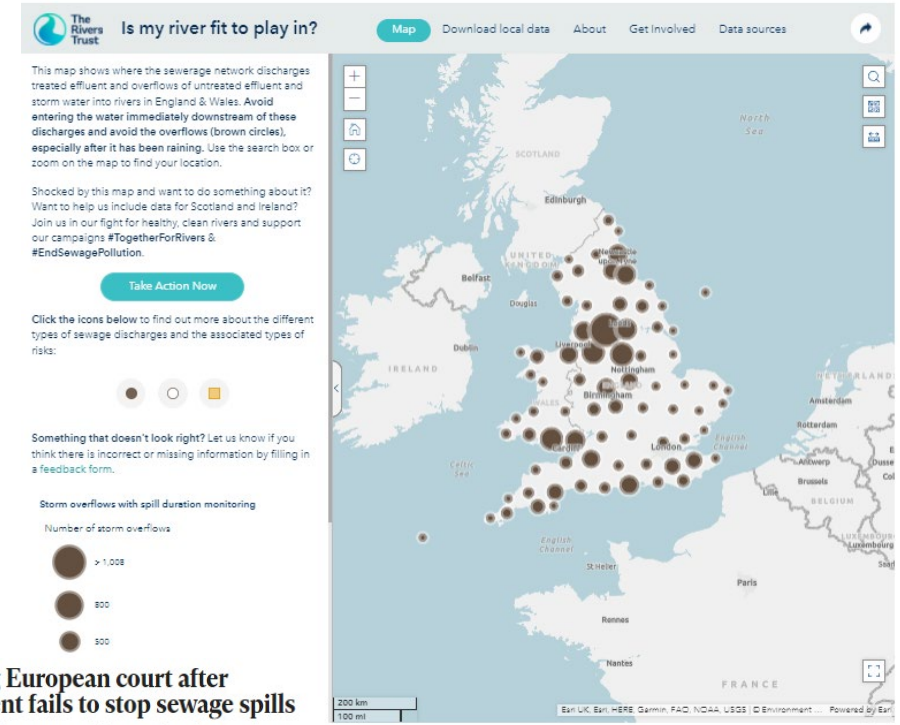
Britain's rivers are suffocating to death

George Monbiot

Water that should be crystal clear has become a green-brown slop of microscopic algae because of industrial farm waste

'The River Wye is covered by every possible conservation law, but in just a few years it has spiralled towards complete ecological collapse.' Photograph: Pepkats Images/Alamy Stock Photo

There's more below the surface than we thought – something even worse than the water companies' disgusting habit of filling our rivers with raw sewage. After a deep dive into the data, the team that made Rivercide last week discovered that while sewage now



The Rivers Trust — Is my river fit to play in?

Map | Download local data | About | Get Involved | Data sources

This map shows where the sewerage network discharges treated effluent and overflows of untreated effluent and storm water into rivers in England & Wales. **Avoid entering the water immediately downstream of these discharges and avoid the overflows (brown circles), especially after it has been raining.** Use the search box or zoom on the map to find your location.

Shocked by this map and want to do something about it? Want to help us include data for Scotland and Ireland? Join us in our fight for healthy, clean rivers and support our campaigns **#TogetherForRivers** & **#EndSewagePollution**.

Take Action Now

Click the icons below to find out more about the different types of sewage discharges and the associated types of risks:

Something that doesn't look right? Let us know if you think there is incorrect or missing information by filling in a feedback form.

Storm overflows with spill duration monitoring

Number of storm overflows

> 1,000

800

500

Environment Agency launches major investigation into sewage

EA and Ofwat begin inquiry after water companies admit possible illegal discharges into rivers

Companies admitted that they could be releasing unpermitted sewage into watercourses. Photograph: Maureen McLean/Rex/Shutterstock

Water companies are at the centre of a major investigation by the financial and environmental watchdogs after they admitted they may have illegally released untreated sewage into rivers and waterways.

The Environment Agency and Ofwat said they had begun an investigation

UK facing European court after government fails to stop sewage spills

London MEP says it is 'clear the government cannot be left to its own devices when it comes to keeping our water sources safe'

Josh Gabbatiss Science Correspondent • Sunday 03 February 2019 14:10 • Comments

RIVERCIDE

IN 60 ACTION-PACKED MINUTES, THE WORLD'S FIRST LIVE INVESTIGATIVE DOCUMENTARY WILL ATTEMPT TO FIND OUT **WHO IS POLLUTING OUR RIVERS** AND **WHY WE'RE NOT STOPPING THEM**

ARUP

Analyse CSO frequency

Identify high frequency spill time

Track source

Use source tracking to identify probable catchment contributing and time probable wastewater left catchment

Analyse domestic wastewater quality

Identify probable water quality of the high frequency spill

Target interventions

Prioritise interventions based on spill frequency and quality

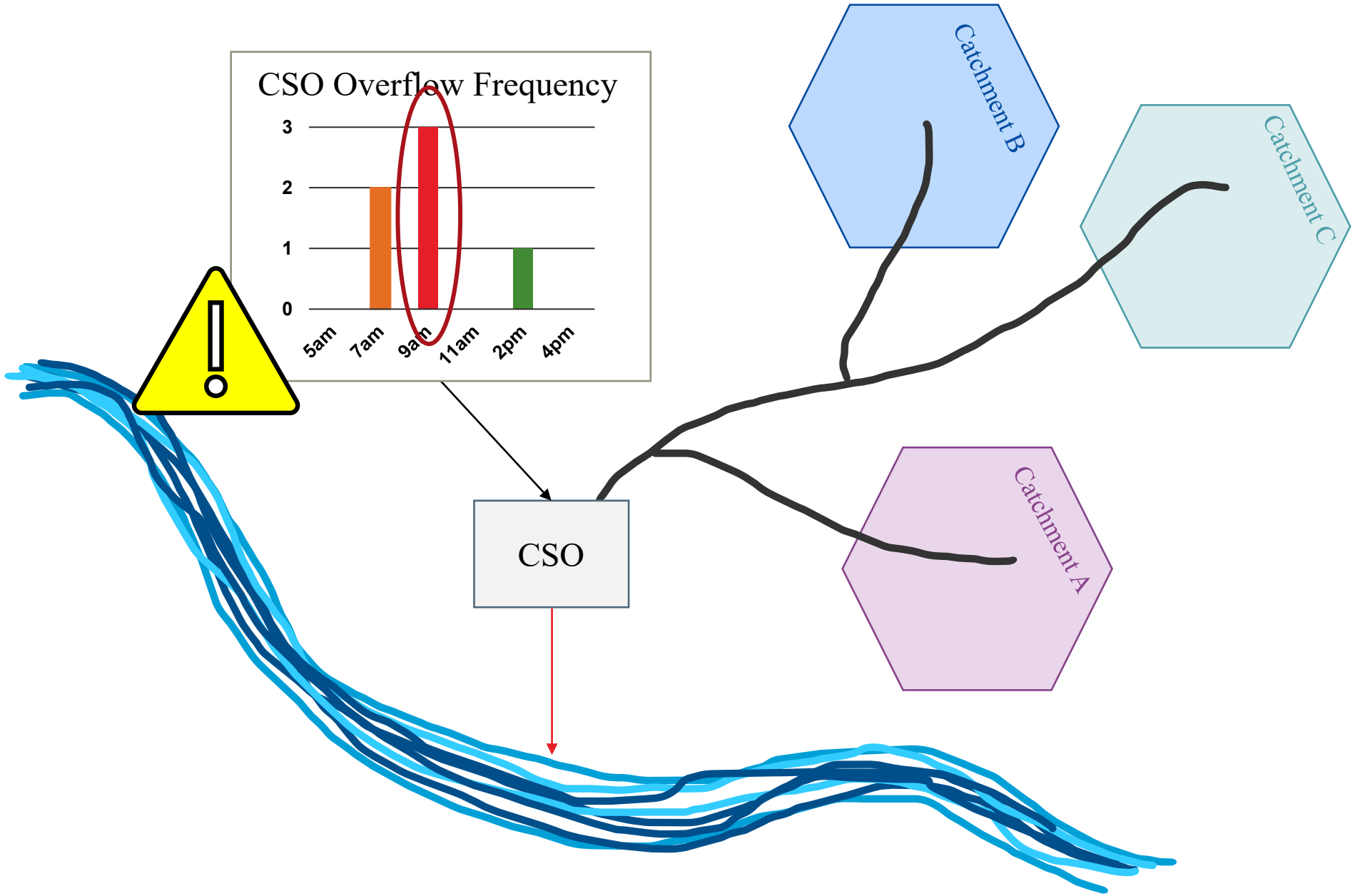
Interventions include:

- Stormwater removal
- Incentivise water-saving technology
- Targeted communications
- Infrastructure upgrade

When is the sewer overflowing?

ARUP

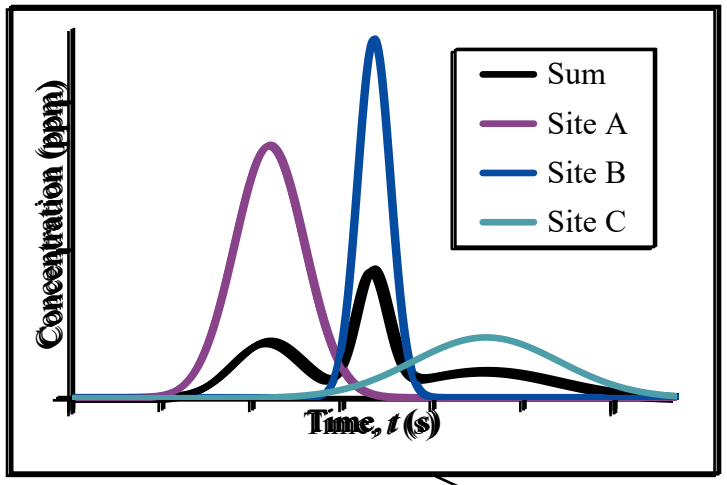
1. CSO frequency
2. Track source
3. Wastewater quality
4. Target interventions
5. Select intervention

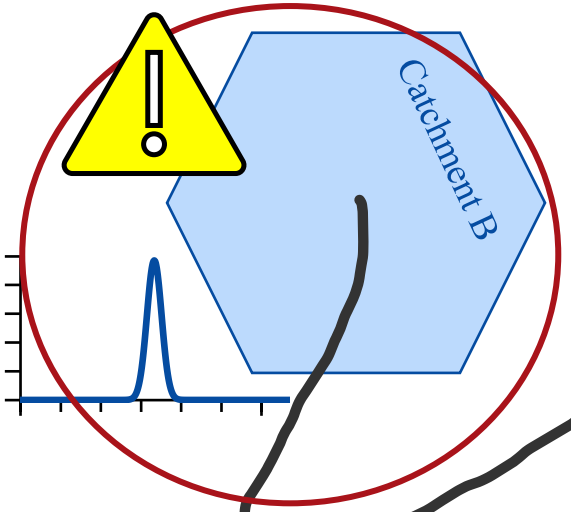


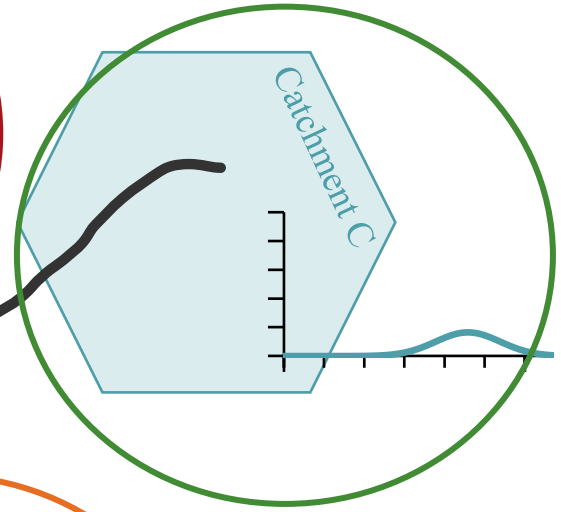
Disaggregate signals to track source

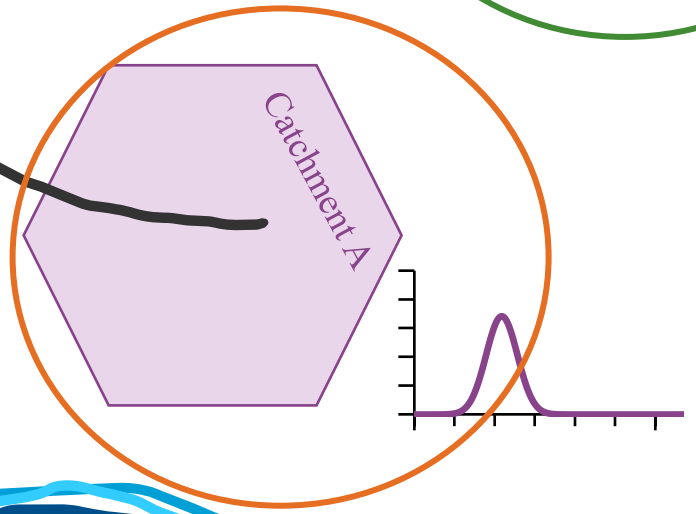
ARUP

1. CSO frequency
2. Track source
3. Wastewater quality
4. Target interventions
5. Select intervention







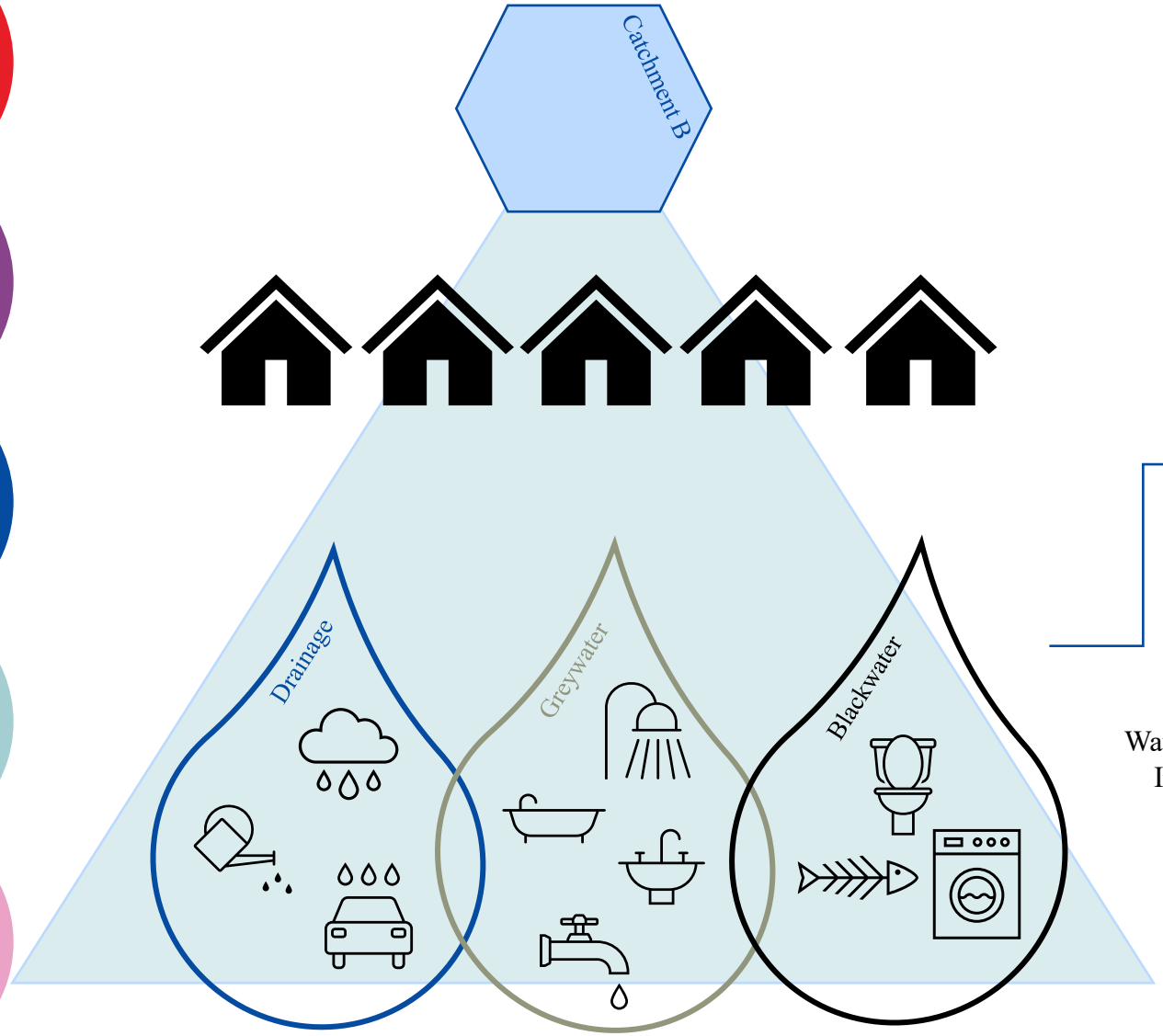


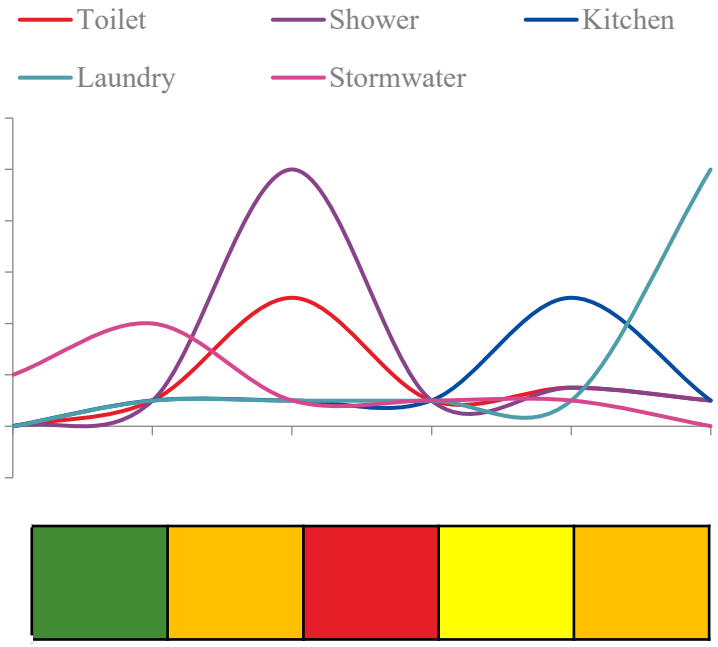
CSO

Explore catchment water source

ARUP

1. CSO frequency
2. Track source
3. Wastewater quality
4. Target interventions
5. Select intervention



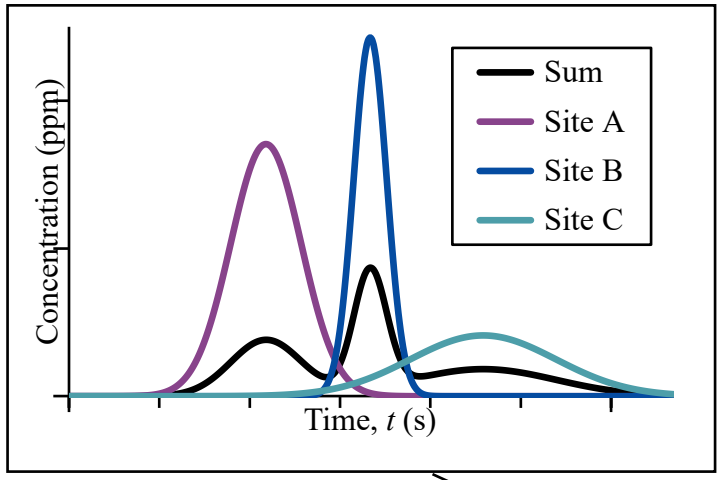


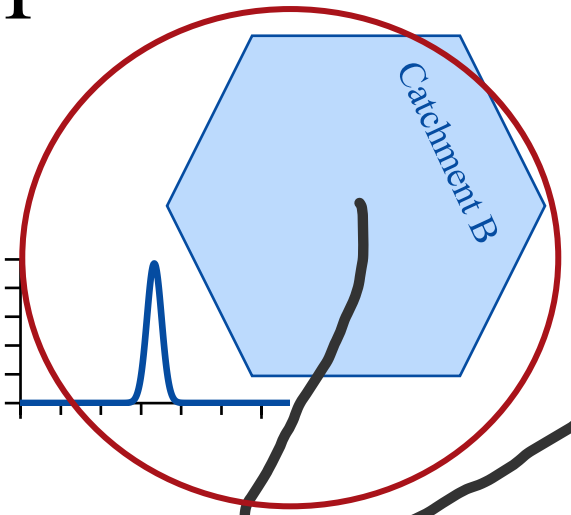
Water Quality Indicator

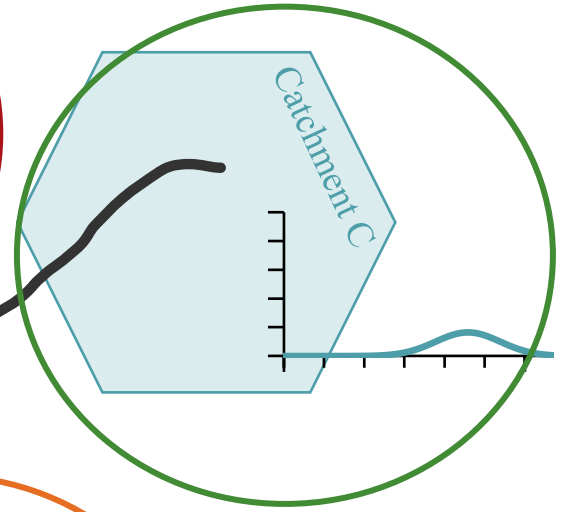
Target interventions to problem areas

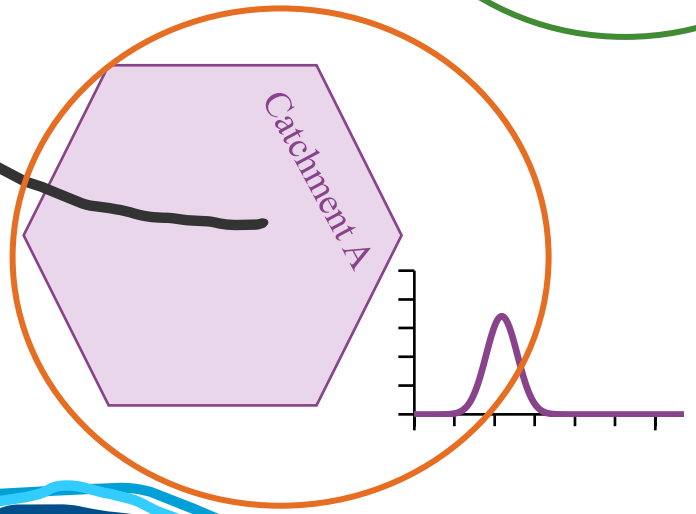
ARUP

1. CSO frequency
2. Track source
3. Wastewater quality
4. Target interventions
5. Select intervention





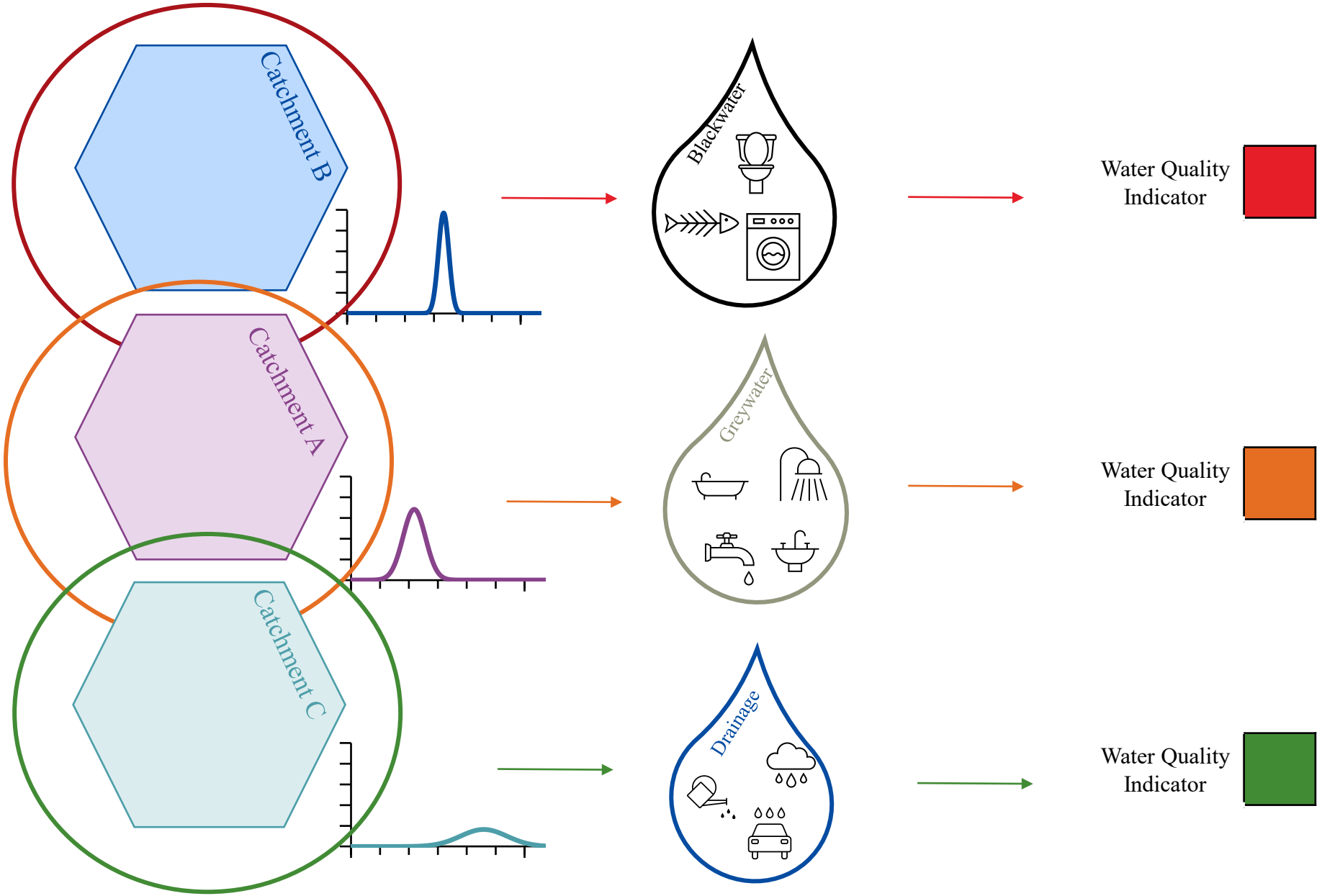




CSO

Target interventions to problem areas

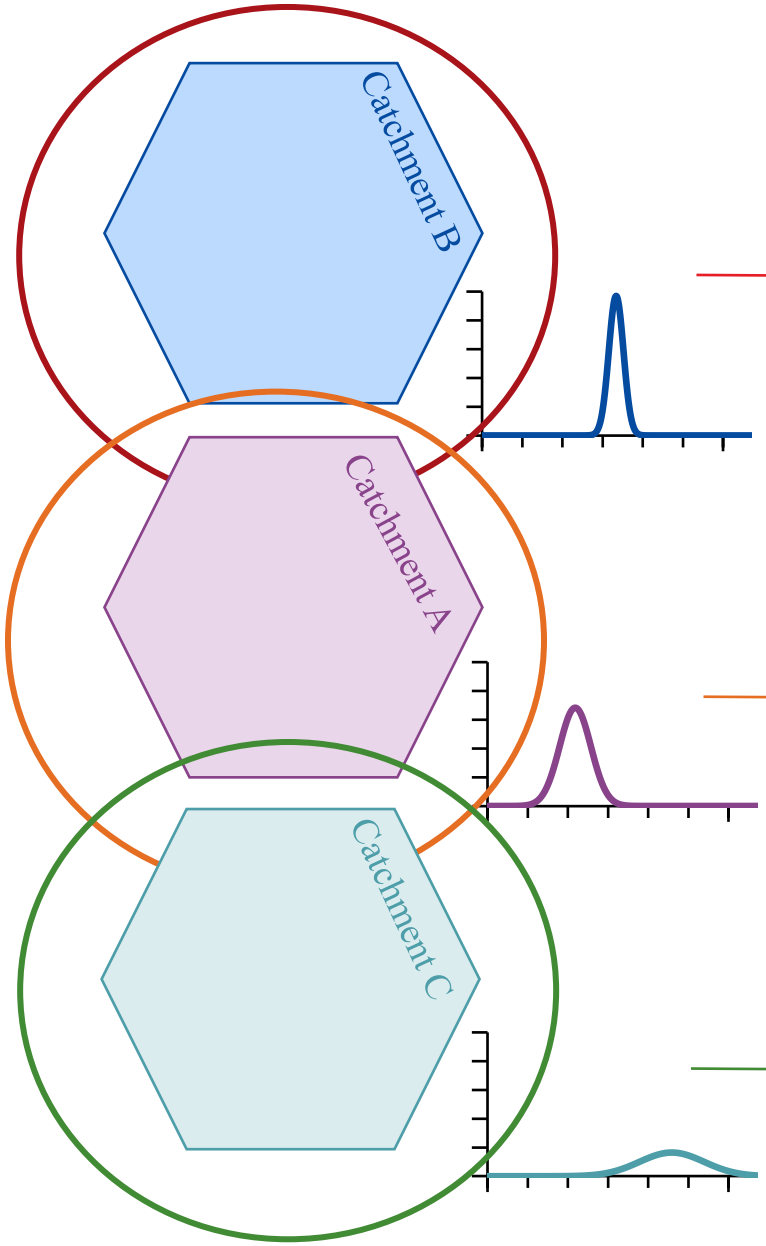
ARUP



Select appropriate intervention

ARUP

1. CSO frequency
2. Track source
3. Wastewater quality
4. Target interventions
5. Select intervention



- Incentivised technology schemes
- Targeted public engagement
- Infrastructure upgrade

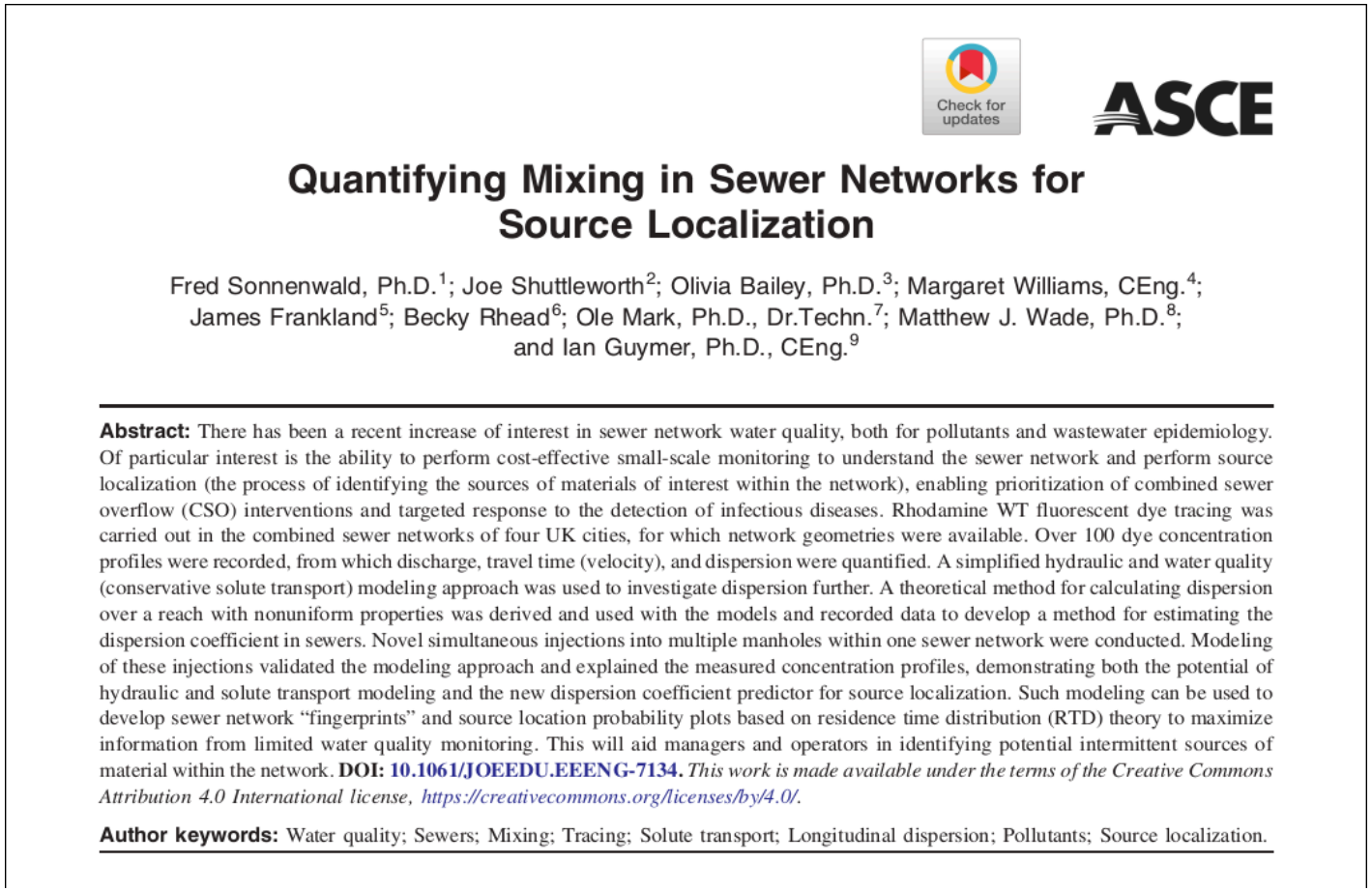
- Incentivised technology schemes/ SMART tariffs
- Greywater reuse
- Targeted public engagement
- Infrastructure upgrade

- Incentivised rainwater harvesting
- Sustainable Urban Drainage

Want to Read More?

4

Outputs



Check for updates

ASCE

Quantifying Mixing in Sewer Networks for Source Localization

Fred Sonnenwald, Ph.D.[1]; Joe Shuttleworth[2]; Olivia Bailey, Ph.D.[3]; Margaret Williams, CEng.[4]; James Frankland[5]; Becky Rhead[6]; Ole Mark, Ph.D., Dr.Techn.[7]; Matthew J. Wade, Ph.D.[8]; and Ian Guymer, Ph.D., CEng.[9]

Abstract: There has been a recent increase of interest in sewer network water quality, both for pollutants and wastewater epidemiology. Of particular interest is the ability to perform cost-effective small-scale monitoring to understand the sewer network and perform source localization (the process of identifying the sources of materials of interest within the network), enabling prioritization of combined sewer overflow (CSO) interventions and targeted response to the detection of infectious diseases. Rhodamine WT fluorescent dye tracing was carried out in the combined sewer networks of four UK cities, for which network geometries were available. Over 100 dye concentration profiles were recorded, from which discharge, travel time (velocity), and dispersion were quantified. A simplified hydraulic and water quality (conservative solute transport) modeling approach was used to investigate dispersion further. A theoretical method for calculating dispersion over a reach with nonuniform properties was derived and used with the models and recorded data to develop a method for estimating the dispersion coefficient in sewers. Novel simultaneous injections into multiple manholes within one sewer network were conducted. Modeling of these injections validated the modeling approach and explained the measured concentration profiles, demonstrating both the potential of hydraulic and solute transport modeling and the new dispersion coefficient predictor for source localization. Such modeling can be used to develop sewer network "fingerprints" and source location probability plots based on residence time distribution (RTD) theory to maximize information from limited water quality monitoring. This will aid managers and operators in identifying potential intermittent sources of material within the network. **DOI: 10.1061/JOEEDU.EEENG-7134.**

Author keywords: Water quality; Sewers; Mixing; Tracing; Solute transport; Longitudinal dispersion; Pollutants; Source localization.

Paper

Sonnenwald, F., Shuttleworth, J., Bailey, O., Williams, M., Frankland, J., Rhead, B., Mark, O., Wade, M.J., Guymer, I. (2023). *Quantifying mixing in sewer networks for source localization*, ASCE Journal of Environmental Engineering. 10.1061/JOEEDU.EEENG-7134.

Dataset

Guymer, I., Shuttleworth, J., Bailey, O., Williams, M., Frankland, J., Rhead, B., Mark, O., Wade, M.J., Sonnenwald, F., (2022). *Fluorescent dye traces in four UK sewer networks*. The University of Sheffield. 10.15131/shef.data.20480241

ARUP