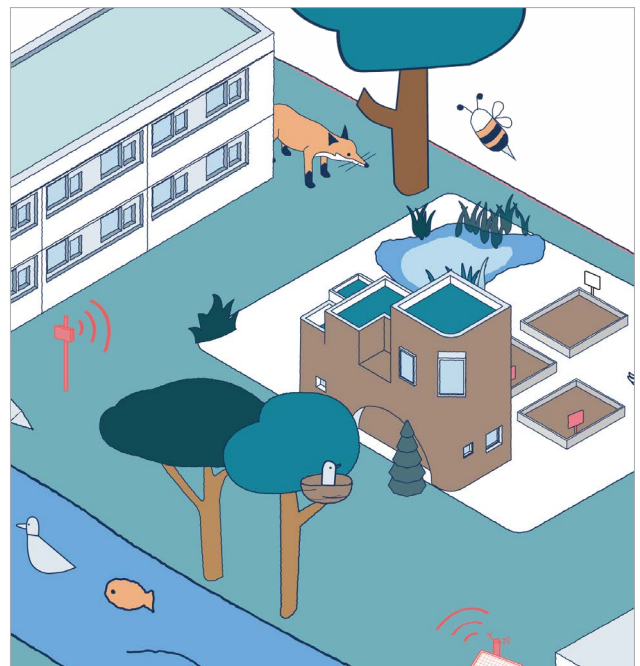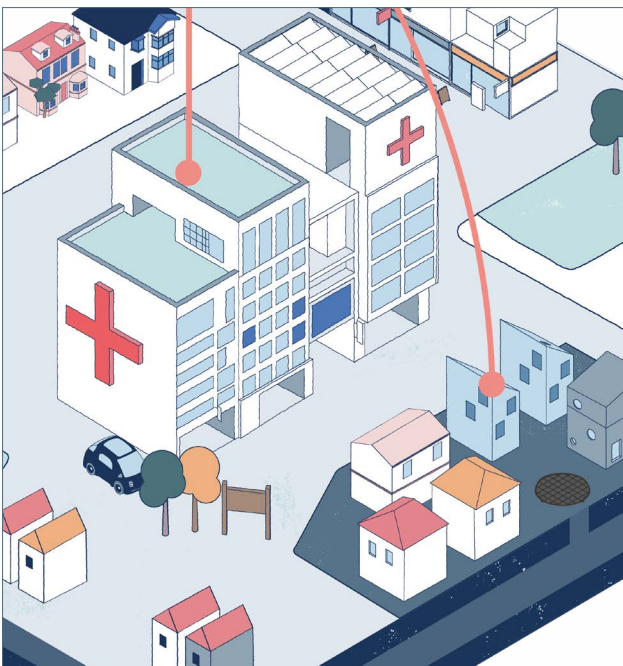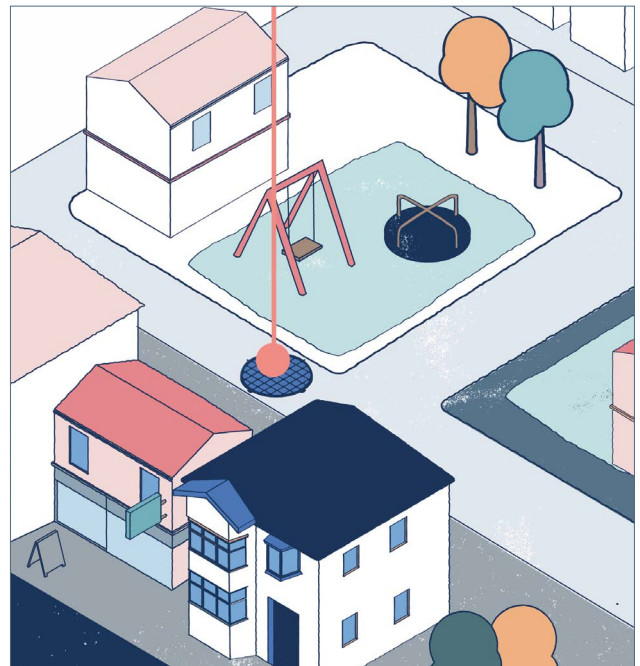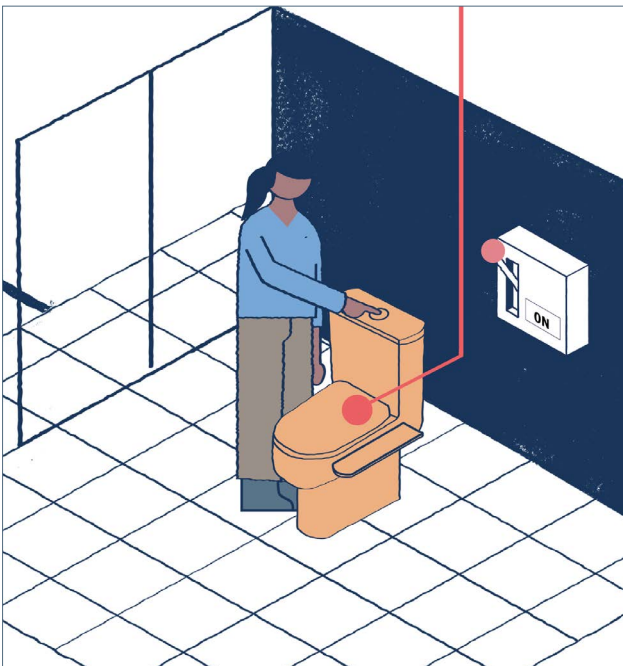# Wastewater: a reflection of our health

A look at the future of wastewater-based epidemiology

Executive summary

The COVID-19 pandemic has reminded us of the importance and impact of public health. In these unprecedented times, governments across the world have been looking to a new source of health data to track the viral spread: wastewater.

Through monitoring biomarkers, found in sewage, wastewater-based epidemiology (WBE) can give an indication of human health. Since humans can begin secreting biomarkers into sewage days before COVID-19 symptoms develop, WBE has been used, throughout the pandemic, as an early warning system to identify viral hotspots before this was visible in clinical data. This is therefore a very honest data source that is not dependent on who came forward for clinical testing or got an appointment with the general practitioner (GP), allowing healthcare services to proactively respond in a timely manner.

While data captured from WBE can be incredibly valuable in understanding attributes of societal health, less clear is what to do with this data. What kind of health-related responses might WBE data support in the future? How could it help us make more informed decisions about our personal and collective health? What new services, spaces and urban infrastructure could be developed to respond to rapid health shocks, or enable preventative health measures? If WBE has the potential to hold up a mirror to the health of society, how can we use this to better community and environmental health?

This report uses four future scenarios to unpack these questions and explore the potential that WBE holds into the future and how gaining health insights in this way can create healthier environments. Exploring these scenarios allows us to consider whom we are designing for and why, articulate the benefits to users and communities, and discuss the potential implications that may arise. What are the implications of gathering WBE data at varying scales? Who are the key actors in these future systems, and what potential pitfalls exist around issues such as data privacy? These are not just technical hurdles, but strategic, organisational and ultimately human challenges.

Our aim is to create the space to explore these challenges to help shape tomorrow's solutions and start a conversation about how we might shape WBE and use data to achieve beneficial outcomes. Developing speculative scenarios is not about predicting the future, but about developing a vision for how WBE can support our broader health and wellbeing in the future.

What's inside?

Arup team

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Key contributors
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Chris Green, Rebecca Chau, Sophie Liu.

"Looking in the sewer is like looking in the mirror of society."

Dr. Gertjan Medema
KWR Water Research Institute

Introduction

What is wastewater-based epidemiology?

Wastewater-based epidemiology (WBE) is the process of monitoring biomarkers, found in wastewater, to give an indication of human health. As humans, we excrete an abundance of biomarkers into the toilet everyday which indicate how healthy we are. By inspecting these biomarkers for a large population, e.g. at a wastewater treatment plant, we can gather anonymised, honest data on the health of society, including factors such as disease prominence, lifestyle choices and drug use.

Humans can begin secreting biomarkers into sewage even before we develop symptoms. This is therefore a very honest data source that is not dependent on who came forward for clinical testing or got an appointment to be seen by a general practitioner (GP).

At Arup, we've been exploring the potential this holds into the future and how gaining health insights in this way can create healthier environments. If wastewater-based epidemiology has the potential to hold up a mirror to the health of society, how can we use this to improve community and environmental health?

In this report

The following report explores what the future for WBE might hold, through a series of speculative scenarios outlining potential use cases for WBE data and their ramifications. These scenarios do not set out to predict the future, but are intended to start a discussion about the potential applications and benefits of WBE, the kinds of reactions it might elicit, and the pitfalls that may lie ahead.

Furthermore, WBE is not a silver bullet to creating healthier futures. While it can provide rich insight, its value lies in the ability to augment other existing health-related datasets. This document should be read in this context, recognising WBE as a promising technology within a wider toolkit of approaches which, seen together, can help us achieve health-led outcomes in the future.
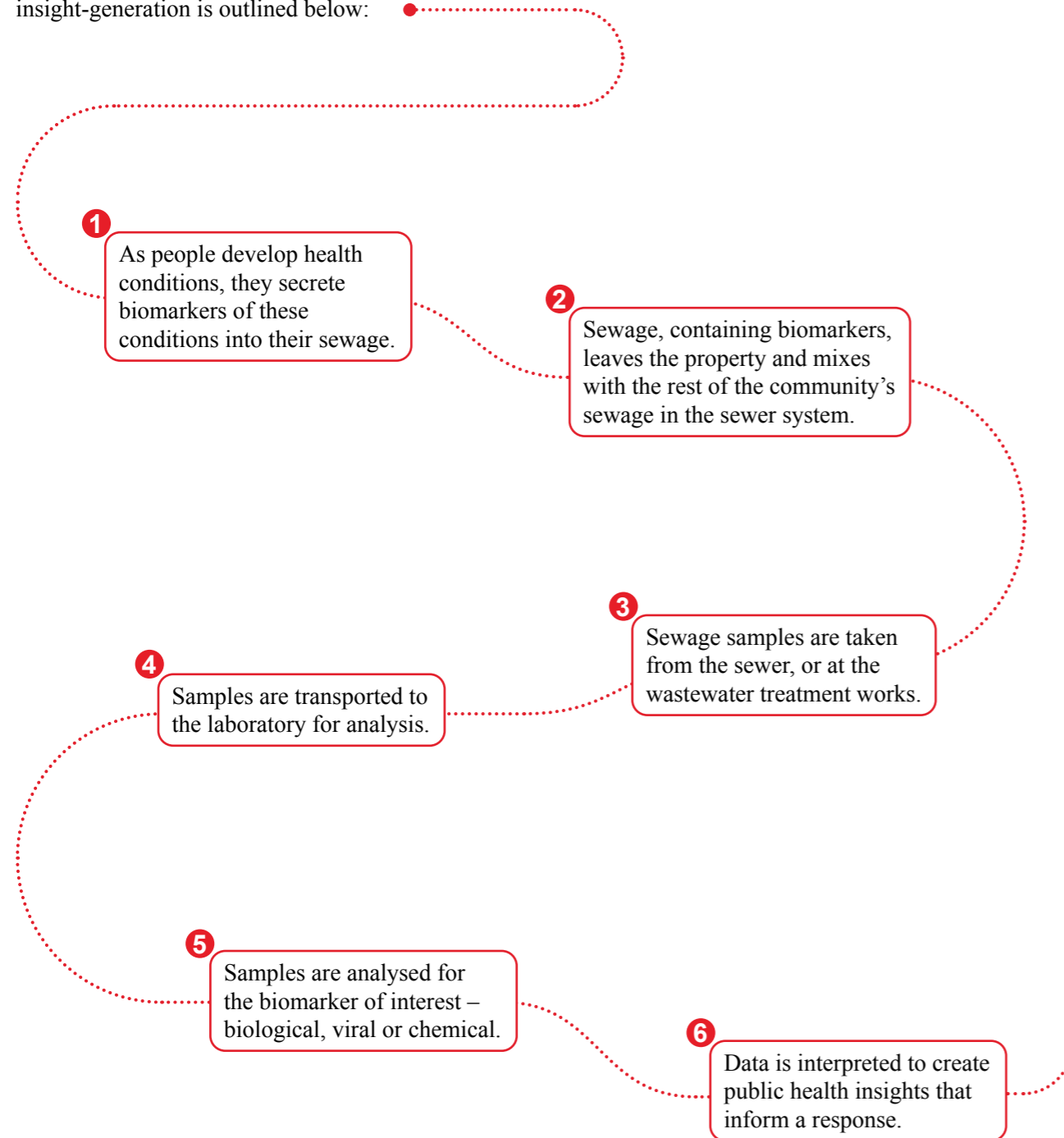
Figure 1. Arup and University of Sheffield conducting WBE experiment
(In collaboration with Bangor University and University of Bath), Bangor, February 2022.

# From wastewater to public health insights

The typical WBE process today

While WBE technology continues to evolve, the high-level process of data-collection and insight-generation is outlined below:

1 As people develop health conditions, they secrete biomarkers of these conditions into their sewage.

2 Sewage, containing biomarkers, leaves the property and mixes with the rest of the community's sewage in the sewer system.

3 Sewage samples are taken from the sewer, or at the wastewater treatment works.

4 Samples are transported to the laboratory for analysis.

5 Samples are analysed for the biomarker of interest – biological, viral or chemical.

6 Data is interpreted to create public health insights that inform a response.
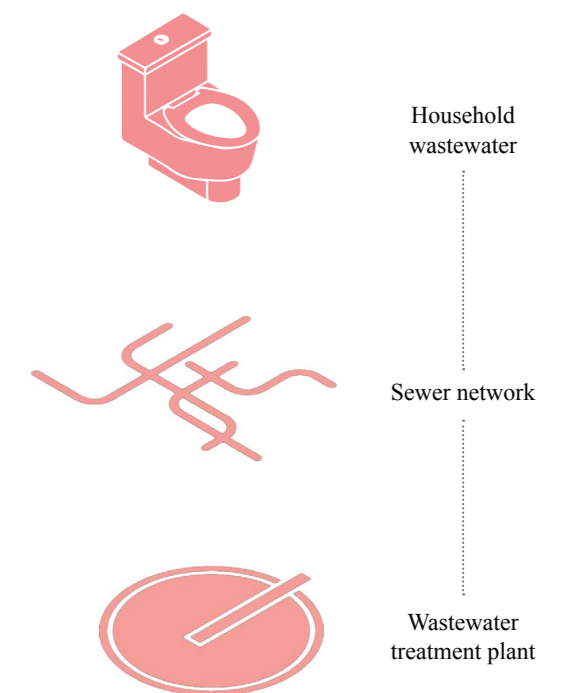
Data from wastewater

Wastewater-based epidemiology can offer quantitative data on a huge range of health markers, allowing actual, observed data from communities on factors such as pharmaceutical consumption, disease prevalence, antimicrobial resistance and environmental pollution.

Other public health datasets are often obtained through surveys, focus groups or at point of use which offer valuable insights not attainable through WBE but can miss the wider visible consequences when viewing public health data from the population as a whole. WBE offers a new dataset that public health practitioners could utilise, alongside current datasets to monitor impacts of healthcare practices or predict future trends.

QUANTITATIVE

WBE data

Other public health datasets

REPORTED — OBSERVED

QUALITATIVE
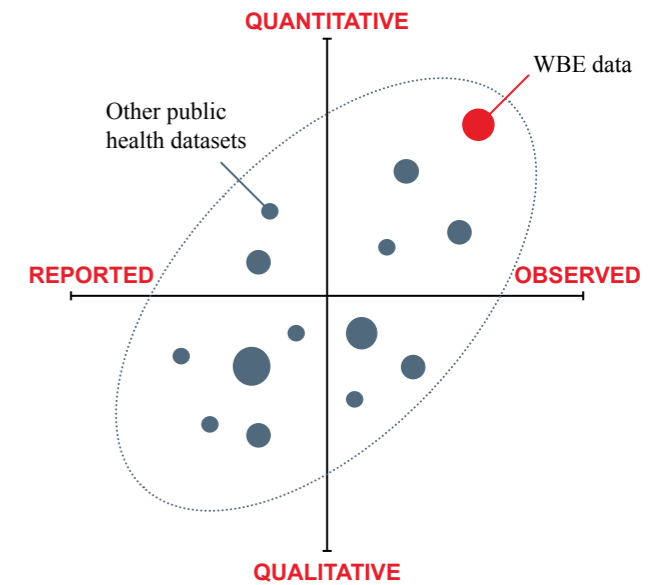
Collecting data at different scales

Wastewater data can be collected and analysed at various points throughout the sewerage system depending on the information you wish to capture. The various scales range from an individual household (harvesting household wastewater), to community scale (collection from the sewer network), to city or regional scale (collection at the wastewater treatment plant). Each scale reveals different insights and carry specific benefits or challenges depending on the healthcare scenario it is utilised for.

Household wastewater

Sewer network

Wastewater treatment plant

What can WBE tell us?

Data collected from wastewater can provide us with rich insight into the current state of population health, surfacing information around a range of potential factors and indicators.

WBE data start to tell us stories about our health, such as:

A current snapshot

WBE can provide us with a picture of current conditions in this moment, based on levels of observed markers.

Changes over time

Gathering data over time, WBE can start to build up an image of how our health is changing, whether it is to indicate sudden issues and shocks, or monitor slow changes over longer periods.

Health inequalities

Combined with other data sources, WBE can begin to tell contextual and comparative stories about our health across different geographies and demographics.


Physical health

We could better understand a community's physical health by observing factors such as diet (vitamins, minerals and meat/fish/vegetable consumption), obesity levels and pharmaceutical consumption linked to specific health conditions.


Mental health

Understanding of community mental health status could be achieved through the monitoring of stress hormones, uses of antidepressants or other pharmaceuticals linked to mental health.
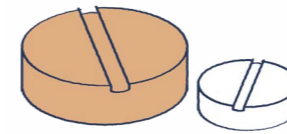
Addictions and crises

Raise awareness to what services or targeted help might be required in communities through monitoring lifestyle chemical such as tobacco use, alcohol consumption, use of prescription and recreational drugs.
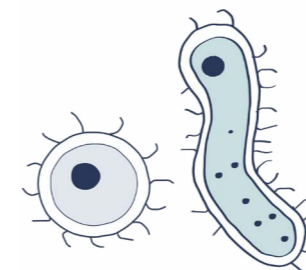

Infectious diseases

Detection of disease prevalence and spread within the community of diseases such as COVID-19, norovirus, influenza, hepatitis, Zika, HIV, polio and dengue fever.

Life stages

Gain insight into what might be important to communities by understanding life stages represented through monitoring substances such as pregnancy hormones and dementia medication.
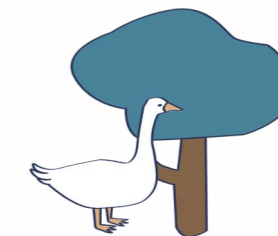
Environmental health

Gain understanding of environmental pollution from wastewater and impact on ecosystems through monitoring substances such as chemical pollution (originating from pharmaceutical use and household cleaning products), biological pollution (faecal matter and nutrient loading) and environmental DNA (eDNA) i.e. the presence of specific species.

Embracing health and wellbeing assets

Enabling health-led responses

A wide range of social, economic and environmental factors – or assets – influence human health and wellbeing. These are often referred to as the 'wider determinants of health'. The framework below, developed by Arup, maps health and wellbeing assets across six dimensions. It is a whole-systems model that can be used to inform health-led approaches to policy, planning and design.

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, WBE can help to inform priorities for enhancing health and wellbeing assets. There is potential for WBE to extend its role and impact as part of longer-term cross-sector approaches to urban health and wellbeing.
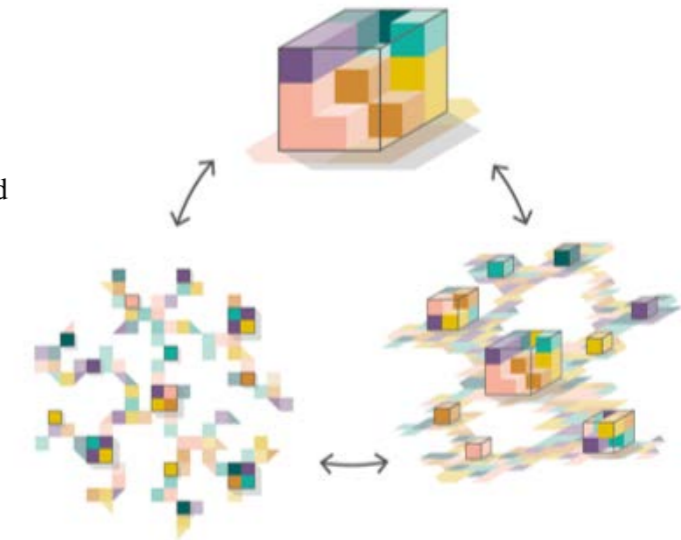

Health-led planning and investment

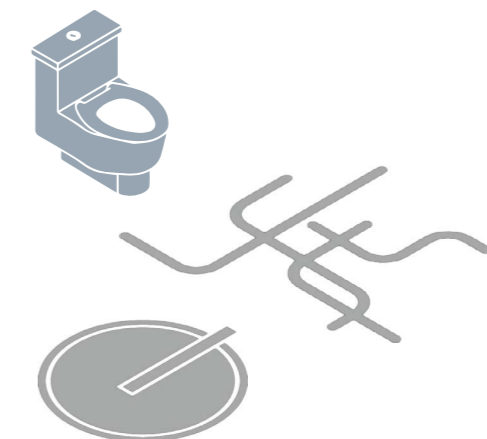Planning, policy, design and shared investment in place-based health and wellbeing assets.

Health and wellbeing assets

Understanding the wider determinants of health and wellbeing, and working with stakeholders to set shared priorities.

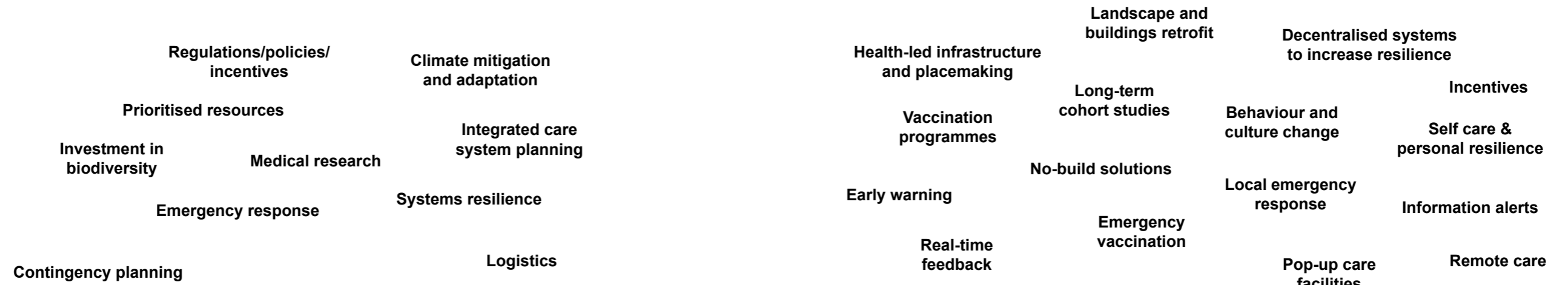### Health challenges and opportunities

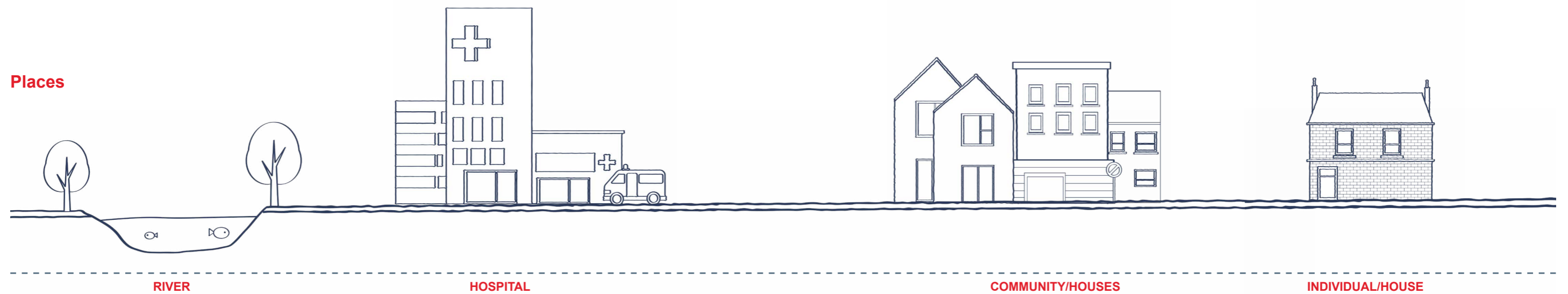Insight from WBE data, combined with population health and demographic data.

Evaluating health and wellbeing schemes

Taken together, we can begin to connect health
measurements with the context of local places,
and ultimately start to inform health-led responses.

Responses

Regulations/policies/ incentives

Climate mitigation and adaptation

Landscape and buildings retrofit

Decentralised systems to increase resilience

Health-led infrastructure and placemaking

Prioritised resources

Long-term cohort studies

Incentives

Investment in biodiversity

Medical research

Integrated care system planning

Vaccination programmes

Behaviour and culture change

Self care & personal resilience

No-build solutions

Emergency response

Systems resilience

Early warning

Local emergency response

Information alerts

Emergency vaccination

Contingency planning

Logistics

Real-time feedback

Pop-up care facilities

Remote care

Places

RIVER

HOSPITAL

COMMUNITY/HOUSES

INDIVIDUAL/HOUSE

Measurements

Wastewater treatment works

Network

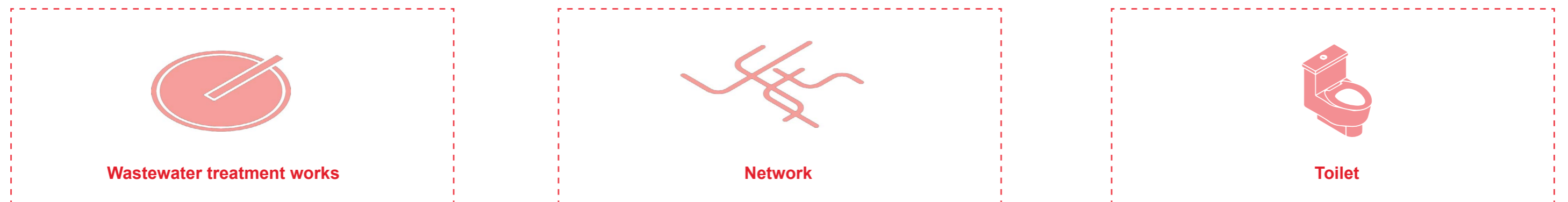**Toilet**

How might WBE improve our health in the future?

Developing future scenarios

While data captured from WBE can be incredibly valuable in understanding attributes of societal health, less clear is what to do with the data once we have it. What kind of health-related responses might WBE data support in the future? How could it help us make more informed decisions about our personal and collective health? What new kinds of services, spaces and urban infrastructure could be developed to respond to rapid health shocks, or enable preventative health measures?

Exploring future scenarios allows us to unpack these questions and develop a vision for how WBE can support our broader health and wellbeing in the future. These scenarios are not about predicting the future, rather about starting a conversation about how we might shape the technology and use data to achieve beneficial outcomes. They allow us to explore whom we are designing for and why, articulate the benefits to users and communities, and discuss the potential implications that may arise. What are the implications of gathering WBE data at varying scales? Who are the key actors in these future systems, and what potential pitfalls exist around issues such as data privacy? These are not just technical hurdles, but strategic, organisational and ultimately human challenges; developing speculative scenarios creates the space to explore these challenges in order to shape tomorrow's solutions.

Key questions

The following scenarios explore a number of key questions and attributes around how WBE might be implemented in the future, including:

Type of health issues

What kinds of health issues might WBE help us detect? Might we use it to detect slow changes to our health, or sudden shocks?

Scale at which data is collected

What are the implications of collecting data at different scales, from the individual to the wider population?

Reactive vs preventative responses

What kinds of health-led responses might WBE data inform? Will it enable us to respond more efficiently to health shocks, or put in place more preventative solutions to improve population health in the future?

Actors involved

Who are the key users and stakeholders in these future scenarios? Who needs access to the data, and who's involved in implementing responses?

Open vs closed data

What are the implications around access to WBE data? Is it open to the public, or specifically for use by authorised institutions and third parties? What are the implications around data privacy and ethics?
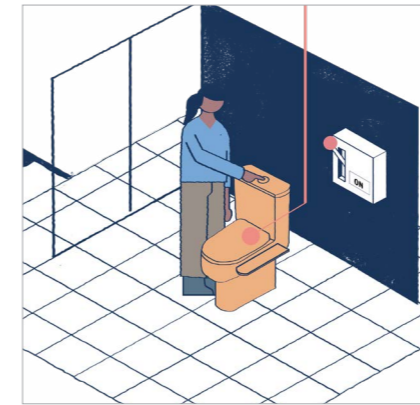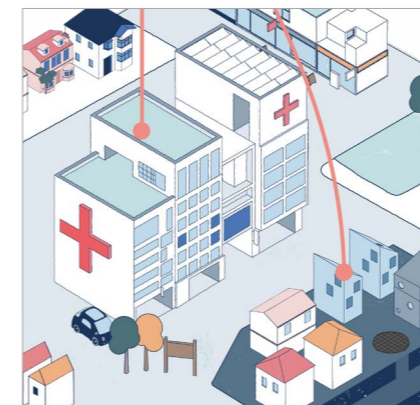

What if your toilet could tell you how healthy you are?

Monitoring capabilities at the household scale could enable new insights into personalised health and connect to tailored, preventative health solutions, should you choose to opt in.


What if your waste could improve the health of your community?

Monitoring capabilities at the community scale could enable new insights into the health and wellbeing of an area and inform local urban responses that improve health and address health inequity.

What if wastewater could improve our integrated health systems?

Monitoring capabilities at the healthcare scale could enable new insights into demand for health services, and inform the short- and long-term planning of healthcare responses.
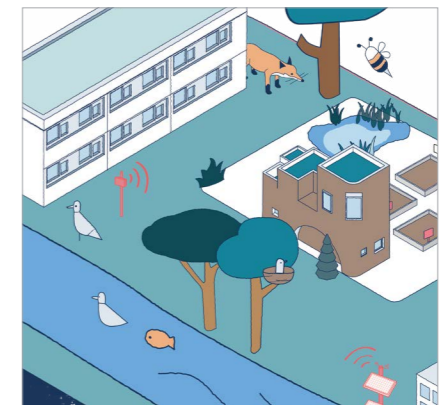
What if you knew all the species that lived in your area?

Monitoring of streets, parks and cities can reveal the hidden species we live among, from night-time dwellers to underwater friends, and encourage citizen engagement with biodiversity.

1

What if your toilet could tell you how healthy you are?

Monitoring capabilities at the household scale could enable new insights into personalised health and connect to tailored, preventative health solutions, should you choose to opt in.

Monitoring method: Household wastewater from the shower, toilet and sink.

Data collected: Lifestyle chemicals (e.g. monitoring diet, nutrition, stress levels, tobacco, caffeine or alcohol use); viral DNA (e.g. influenza, COVID-19 and norovirus); bacterial DNA (e.g. infections, antimicrobial resistance and obesity); fungal DNA (e.g. asthma, allergies and thrush); chemical exposure (e.g. pesticides, parabens and mycotoxins); and chemicals associated with pharmaceutical consumption (e.g. painkillers, antibiotics and antivirals).

Potential responses:

- GPs can use WBE data to enrich other diagnostic methods
- Behaviours to support healthier lifestyles.

Personalised in-home monitoring speaks to its residents about their health. Whether providing gentle reminders about eating or sleeping trends in individual health markers, residents are empowered with granular and real-time information to make informed personal health choices and are encouraged to seek medical support. Intelligent analytics learn about the household, identifying what their 'normal' looks like, enhancing early detection of abnormalities.

With greater visibility of household health, new conversations are prompted about how to take care of ourselves and the people we live with.
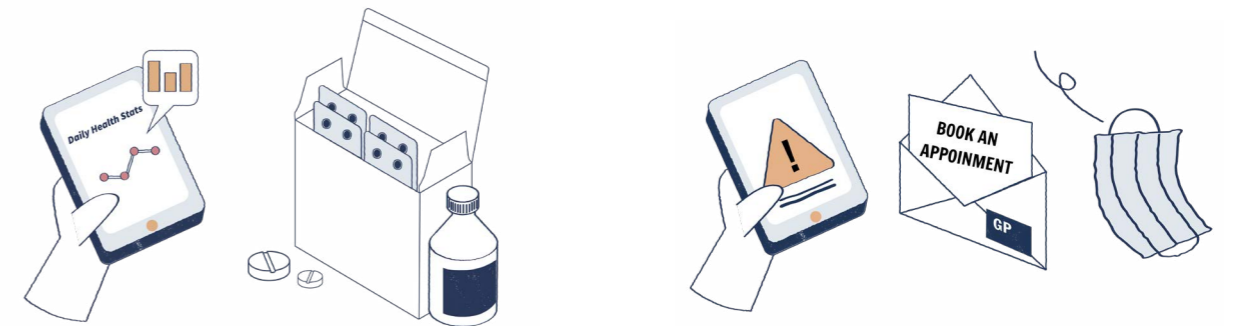
Data could enable monitoring of slow changes over time

Powered by personalised and real-time data, people can keep and eye on their health. For example, by tracking trends in vitamin and mineral levels, people can adjust their diet or lifestyles to stay well, seek supplements when needed. People are informed to act quickly rather than leaving conditions, like iron deficiencies, untreated. It can automatically prescribe 'social prescriptions', without the need for seeing a doctor. With a focus on your body you are encouraged to tune into your health. This technology-enabled home device helps to promote body awareness and shift mindsets from reactive to preventative health care.

Data could alert us to sudden changes and 'health shocks'

With early detection essential for treating many serious health conditions, from ingesting contaminants to acute diseases, this personalised health monitor sends the signals you need to seek medical help. Working to support routine check-ups and other health care practices, your personalised data could be shared with your GP together with referrals to enrich their view of your health. Alongside conditions requiring urgent care, households can be alerted of the detection of contagious viruses, without a test or symptoms. With greater awareness, they can proactively take steps to keep their community safe.

What if...

| People who don't share their data had to pay higher insurance? | You had someone come and stay at your house? | Decisions were made collaboratively with communities? |

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| These toilets were in offices or in public spaces? | People stopped visiting the doctor? | People chose to share data among friends? |

2

What if your waste could improve the health of your community?

Monitoring capabilities at the community scale could enable new insights into the health and wellbeing of an area and inform local urban responses that improve health and address health inequity.

Monitoring method: Measured at sewer point locations that represent closed systems serving specific neighbourhoods or towns.

Data collected: Chemical exposure (e.g. pesticides, parabens and mycotoxins); chemicals associated with pharmaceutical consumption (e.g. painkillers, antibiotics and antivirals); recreational drug use.

Potential responses:

• Cycling infrastructure

• Gym membership schemes

• New healthy food retailers

• Local food growing initiatives.

A whole neighbourhood view provides insight into population health without relying on people to interact formally with the health service. Expressed as a series of health indices, neighbourhood data can be compared, and high need areas invested in. Augmented with other data sources, this evidence makes the case for urban health-related policy and initiatives like cycling infrastructure, exercise programmes or healthy and local food schemes.

Like much evidence-based policy-making, data can be acted upon by public health authorities to make population-level decisions, like fluoridation of water. And if made open, communities are empowered with new data to advocate for equitable health investment.
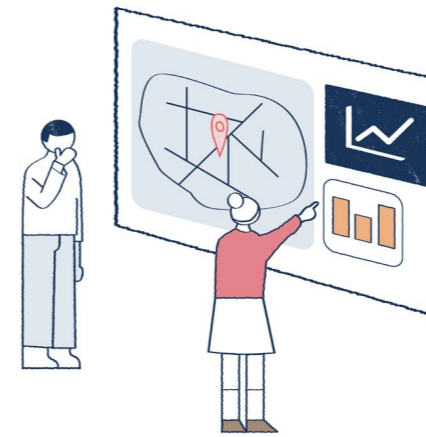
Collecting community health data to inform policy

Informed by community health data, public health authorities and other municipal partners can take action to improve urban places and systems to increase health outcomes for a given area. Stitching together data sources like areas of food deprivation with nutrition markers from the sewers can prompt local food growing schemes, diet education and support local healthy food businesses. Comparing across streets, neighbourhood and regions, investment can be targeted to close the health inequity gap.
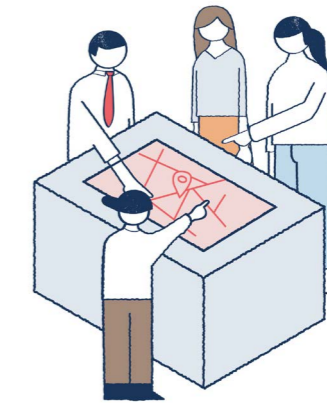
Making local data available to empower community decision-making

If made available, community-scale data can empower people to self-organise and advocate for community-related health initiatives. Strengthened by data, community voices can also demand healthy environments and water, particularly those who are currently underserved or whose complaints have been ignored. With transparent data, communities can convene through deliberative processes to set local priorities. A neighbourhood that is engaged around health is more aware of how to foster healthy communities.

What if...

People disagree with water treatment or other top-down decisions?

Communities were empowered to advocate for health investment?

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Some communities were stigmatised?

Neighbourhood data was made available?

3

What if wastewater could improve our integrated health systems?

Monitoring capabilities at the healthcare scale could enable new insights into demand for health services, and inform the short- and long-term planning of healthcare responses.

Monitoring method: Measured at the wastewater treatment plant and at sewer point locations serving the hospital system.

Data collected: Biomarkers indicating health conditions, exposure and substance abuse: viral DNA (e.g. influenza and COVID-19), bacterial DNA (e.g. infections, antimicrobial resistance and obesity); fungal DNA (e.g. allergies and thrush); chemicals associated with pharmaceutical consumption (e.g. painkillers and antibiotics); addictive substances (e.g. tobacco and recreational drug use).

Potential responses:

- On-street pop-up clinics
- New beds, ICU units or other equipment
- Containment areas across the health network
- Adaptive prescribing practices
- Enhanced social support services for high-need areas.

Dynamic populations, require a dynamic care systems. Data at the population scale, measured within the neighbourhood and at the hospital site can inform projections for health service needs. From fast detection of novel viruses, to long-term trends in substance levels, data can inform how health services plan, prepare and deliver care. Expanding to meet demand, carparks, street and clinics can play host to pop-up testing sites, vaccination clinics and more. Monitoring at the hospital outlet can also spot outbreaks within, or see indicators of community resistance to treatments like antibiotics, informing space management and prescribing practices.

Ongoing monitoring of substance levels within the community

With a granular view of health trends, substance levels can be tracked across the population. The presence of addictive substances might prompt local social support programmes, or resistance to medication could inform new prescribing policies or investment in medical research. Not only can concerning upward trends be identified, but also the effectiveness of interventions measured. Where interventions cannot prevent population health concerns worsening, they can inform future planning of integrated care systems.
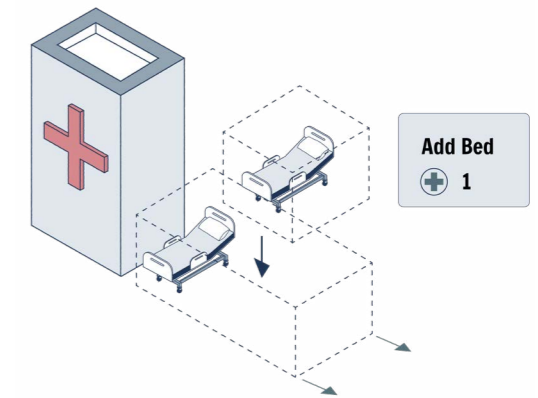
Enabling the early detection of new threats

With a picture of community health that does not rely on symptomatic cases or formal engagement with healthcare services, faster emergency resilience planning is possible. Advanced warning affords services precious time to react, responding rapidly to localised outbreaks, targeting responses, sourcing equipment or personal protective equipment (PPE), and delivering on-demand hospital capacity through a distributed health network, making full use of adaptable spaces – from GPs to carparks, and streets. Data bypasses existing biases, many of which can only represent those who are willing and able to trust and access testing or care.

What if...

Public surveillance of illicit drug use was increased by the police?

New animals strains could be detected early in humans?

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The future demand for medical supplies could be predicted?

Staff capacity could be shared between neighbouring health trusts?

4 What if you knew all the species that lived in your area?

Monitoring of streets, parks and cities can reveal the hidden species we live among, from night-time dwellers to underwater friends, and encourage citizen engagement with biodiversity.
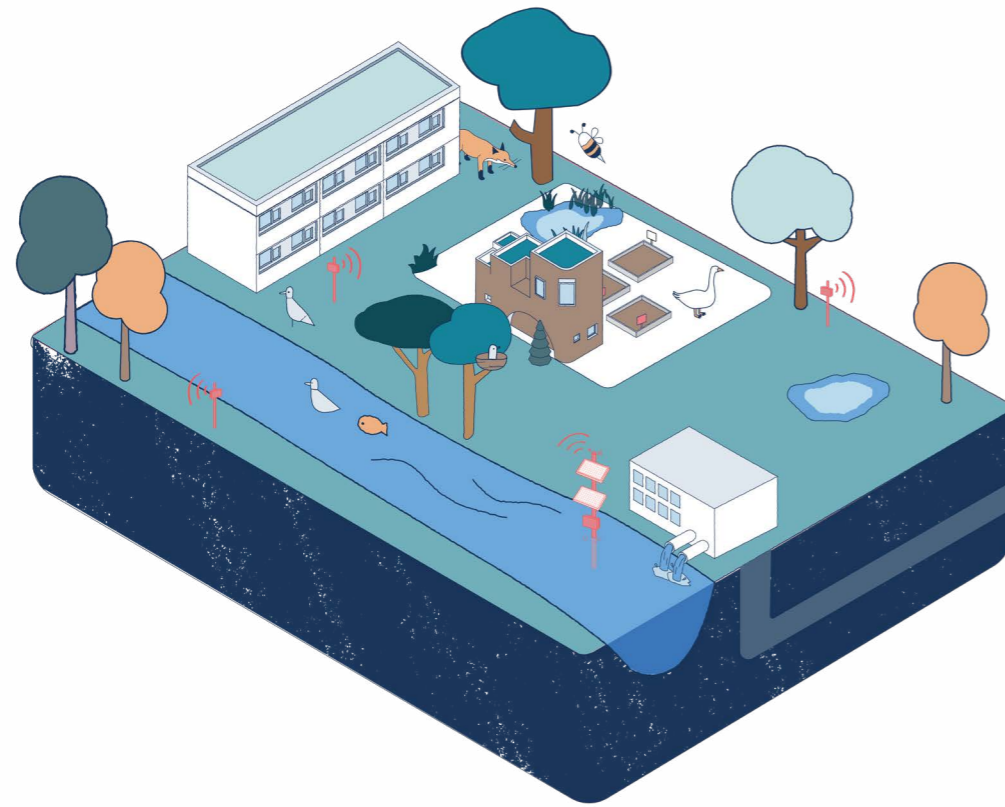

Monitoring method: In waterways and at the wastewater treatment plant.

Data collected: eDNA (e.g. animal DNA); pathogens (e.g. viruses, parasites and fungi); nutrients (e.g. nitrogen and phosphorous); synthetic organic compounds (e.g. polymers and medicines); inorganic chemicals (e.g. salts, acids and bases); other pollution (e.g. microplastics, oil and heat).

Potential responses:
- Nature notice boards
- Biodiversity tracker apps
- Educational moments
- Ecosystem health investment schemes and marketplaces.

Thriving cities, are shared by diverse wildlife. eDNA data can reveal the species living alongside a city's human inhabitants. Making their presence, or absence, visible through data, can spark curiosity in ecosystem health. New conversations about biodiversity and the importance of plants, trees, birds, insects and aquatic life can foster new relationships between human and their biological neighbours. Enhanced awareness and education about urban nature, can accelerate public care and financial investment in biodiversity gains and ecosystem health and wellbeing. With the ability to measure improvement in particular areas, communities can come together to invest, creating the potential for new value exchanges between communities and the public and private sector.
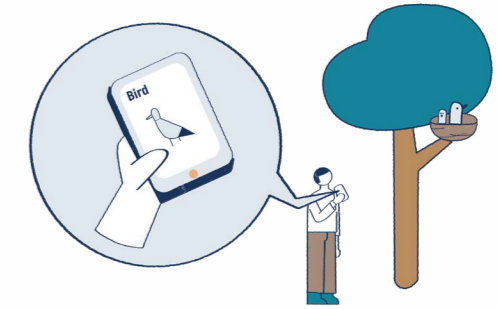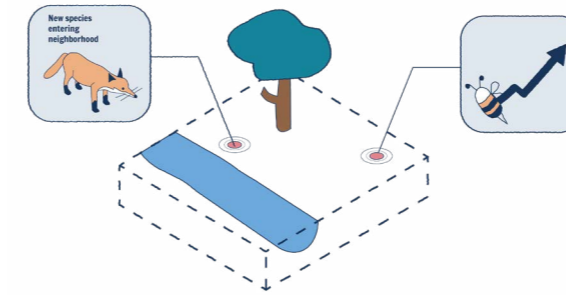
eDNA data could enable investments in ecosystem health

With an ability to monitor ecosystem health at all scales, communities can come together to invest in improving their areas. From streets, to allotment holders and whole neighbourhoods, biodiversity net gain can enable new collective incomes. As both the public and private sector hold liabilities associated with poor ecosystem health, they can reward groups who contribute to reducing the risks by increasing environmental wellbeing. With a new incentive to self-organise and the power to generate local wealth, communities are encouraged to further engage in addressing the climate crisis.

eDNA data could help raise awareness around ecosystem health

Revealing the hidden neighbours living alongside us can create learning moments about nature. 'Species of the day' message boards in parks, and inviting people to explore their green spaces through a new lens provides a channel for people to learn about their needs and respectful ways to engage. With a deeper understanding of the needs of their surroundings, people are encouraged to think not only of human health and wellbeing, but also of ecosystem health and wellbeing. Alongside thriving environments, polluted areas and the absence of life can encourage behaviour that supports restoring habitat to invite wildlife back.

What if...

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Too many people flocked to see species that need to be left alone?

Parks became an extension of the classroom?

Communities were empowered to reduce pollution in their area?

Not everyone had the initial capital to invest in improving biodiversity?

Action to address climate change accelerated?

ARUP

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arup.com