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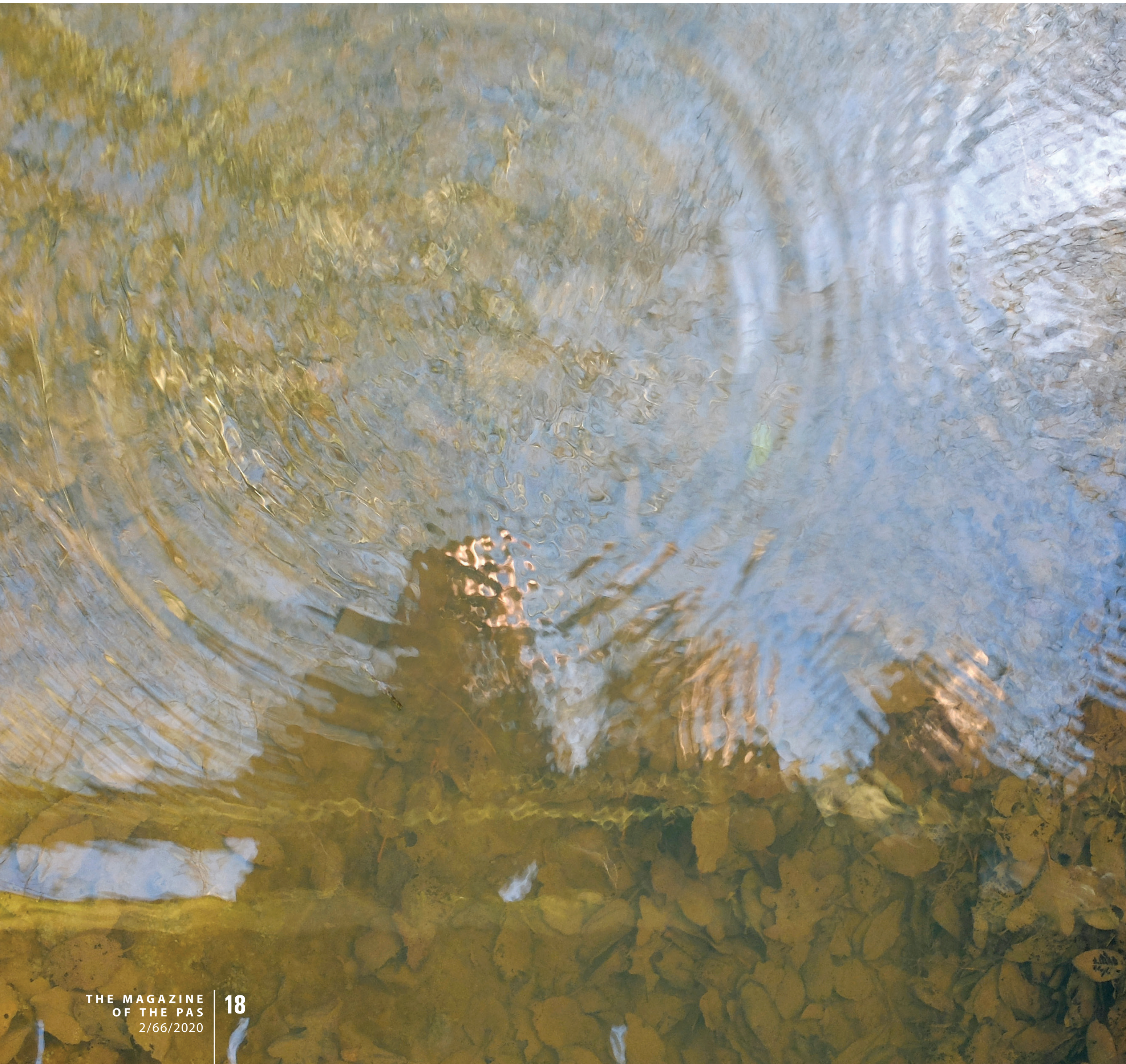
# Modelling Mixing Mechanisms



**If we throw something into a river, how long will it take to reach a certain location downstream? We talk to Prof. Ian Guymer from the University of Sheffield about our increasingly complex models of this deceptively simple problem.**

**Prof. Ian Guymer, PhD**

is Professor of Civil Engineering and EPSRC Established Career Research Fellow at the University of Sheffield. He is a Chartered Engineer, member of the Chartered Institution of Water and Environmental Management.

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**Why is water an important research subject?**

IAN GUYMER: Water is essential for life! When most people think of issues in the water environment, they usually think about when there is too much water, i.e. floods, or too little, i.e. droughts. Both these conditions present major challenges to human life, security, and safety and are highly visible. In the news, we regularly see images of barren, dried land, or areas of the country totally submerged in flood waters. Protecting against such disasters is certainly one role of water engineers, often in collaboration with hydrologists. Nevertheless, in addition to these challenges posed by the volume or quantity of water, there are also many, often unseen, pollution-related problems, involving the quality of water.

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Pollution, caused by contaminants in water, is becoming an increasing issue in protecting the natural environment and delivering clean sustainable water supplies. These contaminants range from increased levels of nutrients due to the overuse of fertilizers, through chemicals used in pesticides, herbicides and pharmaceutical products, to dissolved heavy metals and micro-plastic particles. My area of research aims to provide ways in which engineers and environmental managers can improve their predictions about where these contaminants will go, how long it will take for them to arrive at a downstream location and for how long they will remain present there, at what concentrations.

**What is the main focus of your work?**

My research is mainly experimental, and is undertaken either in a laboratory or in full-scale fieldwork. It can simply be thought of as an extension to playing Pooh Sticks. Pooh Sticks is a game first mentioned in *The House at Pooh Corner*, a Winnie-the-Pooh book written by A.A. Milne in 1928. It is a very simple game which can be played on any bridge over running water. Each player drops a stick on the upstream side of a bridge and the one whose stick first appears on the downstream side is the winner. Playing the game involves very little skill and a great deal of luck!

Just observing a single stick gives us an idea of the direction that the stick travels, and so what path it takes. If we record how long the stick takes to travel the distance under the bridge, then we know its velocity. If we make lots of assumptions and many simplifications, we could use this to estimate when something within the water may arrive at a certain location downstream. For instance if there has been an accidental spill of chemicals in a river. However, this is a very crude estimate, with lots of possible errors, so we need to do better.

A Cambodian woman taking water from a public source

IAN GUYMER

### What methods can be used to improve such measurements?

Whilst knowing the flow direction and route is useful, it is also important to understand that not all the water travels at the same velocity. Hence the challenge in the game is to drop your stick into the fastest flowing region. If multiple sticks are input at the same time, they will all arrive at the downstream side of the bridge at different times. This illustrates the spreading of individual particles as they travel downstream, each experiencing different routes and different velocities. It is this spread, or more technically the dispersion, that my research aims to quantify.

To do this, instead of inputting a vast number of sticks, we use a liquid tracer that has certain unique properties, making its concentration easy to accurately measure in the field. In most applications, we use a bright red fluorescent dye, Rhodamine WT, which is harmless to the ecology, but is highly visible when initially input. As this tracer flows downstream, we record its concentration when it passes points of interest. Once the concentration is diluted by 1,000,000 times it becomes invisible to the naked eye. However, the instruments we use in the field, fluorometers, can measure concentrations down to as little as 1 particle of dye in 1,000,000,000,000 (one trillion) particles of water! This is far below what the eye can see.

### Could you provide an example of how this works in practice?

Using this approach, a large-scale river study was undertaken in collaboration with the Institute of Geophysics, Polish Academy of Sciences on the Upper Narew River between Siemianówka Reservoir and Narew National Park. It was used to investigate the transport of blue-green algae from the reservoir. The study reach was about 90 km long and 24 litres of Rhodamine WT dye were poured into the river from two buckets at the same time. Measurements were taken at several sites along the river and the first dye arrived at the entrance to the National Park after about 65 hours. The highest concentration of tracer, about 300 parts per billion, occurred after 75 hours. Concentrations of the tracer were still measureable at this site up to 130 hours after the dye was released! From these measurements an average speed of around 0.3 m/s was obtained, but perhaps more surprisingly, the time difference between the fastest and slowest particles arriving at the National Park, the spread, was about 65 hours! This is just one example of how we need to better understand travel times and the mixing of material in water bodies.

### How can such experiments be used in the practice?

Unfortunately, many accidents occur both in Europe and around the world, where untreated contamination enters a river. In my teaching at the University of Sheffield, I use an example from an industrial accident that occurred in China in 2005 and threatened the water supply to Harbin, a city of 3.8 million population. An industrial explosion, 380 km upstream of the city, allowed 100 tonnes of benzene to enter the river Songhua. Ten days later Harbin's drinking water abstraction was shut off as the concentration of benzene was over 100 times above the National Safety Levels. The length of this contamination cloud in the river was around 80 km and the water supply was stopped for over 5 days, as the cloud passed the city. Water supplies were restored to Harbin, but the river Songhua eventually flows into the river Amur in Russia. This highlights the potential international impact and man's reliance on having a clean, secure water supply.

### What else can be done to protect water from contamination?

Since 1990, I have developed a research program to measure the longitudinal dispersion created by different urban drainage structures. This initially focused on the effect of manholes (diameter; step changes; changes in direction) together with looking at combined sewer overflows, storage tanks and dynamic separators. After showing the limitations of the conventional approach to describing dispersion in manhole structures, which assumes a random distribution about a mean travel time, our research has shown that for surcharged manholes two non-dimensional residence time distributions (RTDs) could accurately describe all the effects of manhole size, surcharge height and discharge on longitudinal mixing.

**What do you plan to focus on in the following years?**

Since 2018, I have been fortunate to be awarded an Established Career Fellowship from the Engineering and Physical Sciences Research Council (EP/P012027/1), part of UK Research and Innovation. This funding allows me to focus on the aspects of mixing in the management of water quality in rivers, urban drainage and water supply networks, all of which are essential for ecological and human well-being. Predicting the effects of different management strategies requires knowledge of the hydrodynamic processes covering spatial scales of a few millimeters (turbulence) up to several hundred kilometers (catchments), with a similarly large range of timescales from milliseconds to weeks. The work aims to advance the predictive capability of one-dimensional (1D) time-dependent models, which are critical for economic, fast, easy-to-use applications within highly complex situations in river catchments, water supply and urban drainage systems. In the majority of water systems, the standard 1D model predictions fall short because of knowledge gaps associated with low turbulence, 3D shapes and unsteady flows. The main benefits of the research will be that the representation of transport and mixing of soluble pollutants and microscopic particulates in rivers, urban drainage and water supply networks will be significantly improved. This understanding is essential to predict concentrations for risk assessment and ecological impact, especially under dynamic conditions, such as spill events or storm flows that create rapid concentration changes.

These issues of water quality transcend local, national and even continental boundaries and amplify the challenges created by climate change; increased urbanization; reduced food security and increasing water scarcity. The demand on water resources is becoming ever more unsustainable in relation to supply. Risk reduction measures for the EU Water Framework Directive priority pollutants can be expensive. However, providing refined information on their fate, through engineered and natural systems, can help in the design optimal resilient solutions. The security of water resources and water ecosystems is one of the cornerstones of environmental protection in Europe and the world. As stated in the UN Sustainable Development Goals, it is essential to "ensure availability and sustainable management of water and sanitation for all."

IAN GUYMER

River confluence mixing