Booklet production

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Copies of this booklet can also be downloaded from the UK Irrigation Association website www.ukia.org

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Smart agricultural water resources management

Using advanced wireless sensor technologies to better manage high and low flows for agriculture

Living with ‘high’ and ‘low’ flows

Water resources are under intense pressure and a major challenge to manage, especially during dry summers when there are competing abstraction demands from multiple sectors. But increased climate variability will exacerbate the situation with a greater frequency of both extreme ‘high’ and ‘low’ flows

Climate, regulatory and water-related risks

Climate change will result in more frequent flood and drought events with high and low river flows creating both risks and opportunities for agriculture. At the same time, farmers must contend with new regulations on water abstraction that will reduce their licensed allocations and their ‘headroom’ limiting when and how much water they can abstract. Developing both strategic longer-term solutions and short-term operational plans to cope with high and low flows will be critical. So how can advanced wireless sensor technologies help farmers make better decisions in managing their water resources?

A need for ‘smarter’ water management

In the face of growing competition for water resources across different sectors, coupled with escalating pressures of climate change and regulatory reforms, efficient irrigation is becoming increasingly vital for agricultural sustainability. The need for smarter water management is an urgent priority particularly in water-stressed catchments where irrigated agriculture underpins rural livelihoods.

This booklet...

Describes a pilot study undertaken in the River Strine catchment area in Shropshire to assess the implementation challenges and value of advanced wireless sensor technologies for monitoring local water resources and how the data collected can help farmers pre-empt risks and reduce their vulnerability to high and low flows passing through their catchment. The pilot has also investigated how sensors can improve local knowledge of agricultural water resources by supporting stronger multi-sector collaboration among farmers, the Internal Drainage Board (IDB), Environmental Agency (EA), Water Resources West (WRW) and local environmental stakeholders.

Sensor technology benefits

Through practical demonstration, the pilot study has shown how wireless sensors can provide valuable near real-time data streams to support integrated approaches to agricultural water resources management, focusing on abstraction control and reservoir storage.

Sensors have long been used to measure river flows, changes in soil moisture, and reservoir levels, but they were historically expensive, often unreliable and not widely used within the agricultural sector. But that situation has changed over the last decade as the costs have declined and the choice of applications has increased. Today, sensor technology is more affordable, practical, and within the reach of many farming businesses. The combination of modern low-cost sensors with wireless connectivity using telemetry systems to stream data in near real-time provides a significant opportunity for the agritech sector to develop and implement a range of tools and decision support services to improve water resources management.

Sensors installed in the Strine IDB to monitor drainage channel and river water levels. Both sites also fitted with automatic rain gauges and telemetry for remote connectivity.

Supporting strategic long-term planning

Over time, these datastreams will provide farmers and land managers with a better understanding of their local catchment hydrology and water resources. This will help them to:

- Understand how water flows and levels fluctuate through the year and their impacts on summer and winter abstractions
- Plan for future droughts or abstraction restrictions, including ‘Hands-off Flow’ constraints
- Design better integrated systems to capture and store excess water (“scalping”) during ‘high-flow’ periods
- Reduce farm exposure to increased climate and regulatory water-related risks
- Develop collaborative opportunities for water-sharing with other farm businesses in your catchment
- Exploit opportunities to build more resilient farm businesses that can adapt to changing regulations and climate risks.

Near real-time on-farm decision-making

Farmers can now obtain up-to-date information on their local river water levels, changes in soil moisture conditions, and how much water their crops have used in near real-time, meaning they receive the information almost as it happens to facilitate data-driven decision-making. With these data from land and local watercourses, farm businesses can:

- Know precisely when water is available and when it’s not
- Use weather data to forecast changes in river flows
- Decide on the best time to irrigate based on crop water needs and soil conditions
- Monitor their water use in relation to licence allocations and allowable peak rates of abstraction, and respond quickly to Hands-off Flows or Section 57 restrictions
- Use stored water more efficiently by tracking changes in reservoir levels and available capacity
- Work with neighbouring farms to move and share water between businesses when drought conditions are constraining direct summer abstraction (pooling resources).

Sensor applications

Sensors can support dynamic near real-time water management, helping to implement precision irrigation practices and optimising farm inputs. They can also support farm businesses in minimising the environmental impacts, both in terms of both water quantity (abstractions) and quality (nutrients and diffuse pollution). The key is in understanding which sensors are appropriate for different applications and operating scales.

In short, sensors are no longer a luxury; they are essential assets for enabling efficient, sustainable agricultural water management in a water-constrained future.

“If you can’t measure it, you can’t manage it.”

Without data, it is difficult to understand a situation, identify problems, and measure progress. Advanced wireless sensor technologies can provide data to support more dynamic and better decision-making.

Sensors for catchment and farm-scale agricultural water resources management

Digital technologies including advanced wireless sensors and telemetry systems are becoming an essential component in water resources management and planning for agriculture

Scale and application

Sensors have a crucial role in modern agricultural water management at both catchment and farm scales. They offer potential to provide near real-time data to monitor changes in soil moisture, changing weather conditions (including rainfall and evapotranspiration, ET), and crop health, enabling more efficient and sustainable water use. Sensors can either be in-situ, for example, devices installed in the field to monitor changes soil moisture through the rootzone, which operate at a very localised scale, or they can be remote-sensing based technologies using satellites to provide data at a much larger scale (field to catchment to region). Remote-sensing technologies can provide valuable assessments of crop stress, the extent of drought (large area) and flooding risks (localised).

Two examples of catchment (river) and local (field) scale sensor installations for agriculture are shown below.

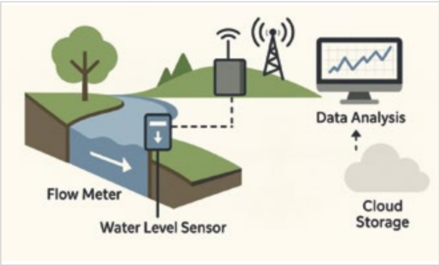
Water-level sensor installed in Strine catchment in 2024. (a) suitable site identified with access and unobstructed water flow, (b) trenching for sensor pipework (c) wireless sensor installed within access pipe.

In-situ soil moisture sensors installed in lettuces in 2024. (a) trench to match maximum rootzone depth, (b) sensor installation linked to datalogger, (c) datalogger connected to GPRS modem to enable remote monitoring.

Sensor communication

Sensors are often installed in remote locations, while end-users need quick and reliable access to the data being collected. Telemetry systems using mobile phone networks are the most common method for data communication. This technology involves the remote collection and transmission of data from in-field sensors to a central location for analysis. There are five main elements to a telemetered sensor system:

1. **Sensor installation:** Flow meters, level sensors, rain gauges, and other hydrological instruments are installed at key locations across the catchment (e.g., rivers, channels, weirs) where new data are needed
2. **Data collection:** Sensors measure and store information using data loggers on water levels, flow rates, weather (rainfall and evapotranspiration), crop status and soil moisture conditions either in real-time or at set intervals
3. **Data transmission:** Sensors transmit their data from loggers via telemetry systems to central servers or cloud platforms using cellular, radio, wifi or satellite networks
4. **Data processing:** Transmitted data are stored, processed, and visualised using software, allowing farmers and land managers to monitor changing conditions, detect trends, and make informed decisions
5. **Alerts and control:** Some systems include automated alerts or can trigger remote controlled actions (e.g., opening a sluice gate or turning off a pump) in response to management or environmental triggers

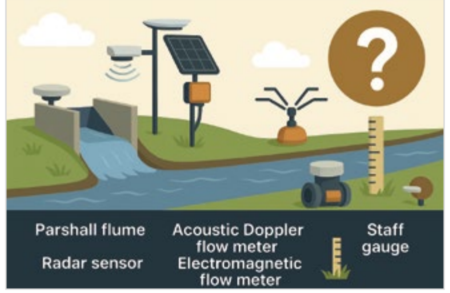


Catchment sensors

Various sensors are available for measuring river flows and water levels, many of which are compatible with telemetry systems for real-time monitoring. Here are the main types:

Water level sensors

- **Pressure transducers:** Measures the weight exerted by the water column above the sensor
- **Ultrasonic sensors:** Uses sound waves to measure the distance to the water surface from a fixed point above
- **Radar sensors:** Similar to ultrasonic sensors, they use radar waves and are often more accurate in turbulent conditions



Flow measurement

These measure the rate of water movement (discharge) through a channel or river.

- **Area-velocity flow meters:** These measure the rate of water movement (discharge) through a channel or flow by directly or indirectly measuring water velocity and water level
- **Doppler flow meters:** Uses acoustic Doppler technology to measure water velocity at various depths
- **Weirs and flumes (with level sensors):** Structures for monitoring channel flow so discharge can be calculated based on the water level
- **Electromagnetic flow meters:** Measure flow velocity in open or closed channels using magnetic fields

Sensor flow monitoring

An example of data collected remotely via telemetry from an insteam flow sensor and automatic rainguage is shown below.

These data relate to the Pipe Strine, a small water channel near Harper Adams University, which is part of the Strine IDB. It is frequently prone to overtopping and flooding of adjacent agricultural land. Flow (red line) and rainfall (blue columns) data are collected at a high (15 min) frequency. The data clearly shows how short duration high intensity rainfall events result in peaks in stream flow. The flood recession is quite quick as the flow returns to normal levels. These types of data can be visualised on platforms or ingested into decision support models to provide farmers with access to better information.

Demonstrating sensor benefits – a catchment case study in the Strine Internal Drainage Board area

Located north of Telford and on an east-west axis between Newport and Crudgington, the Strine Internal Drainage Board covers 2092 hectares. It includes areas of productive agricultural land, as well as important environmental sites and peatland

Strine Internal Drainage Board

The Strine Internal Drainage Board (SIDB) was set up in 1952 and has two main arterial channels (River Strine and Commission Drain). All channels then discharge into the River Tern near Crudgington. For a small area the open channel system is relatively complicated, due in part to the reclamation works undertaken by the Dukes of Sutherland in the 18th and 19th centuries.

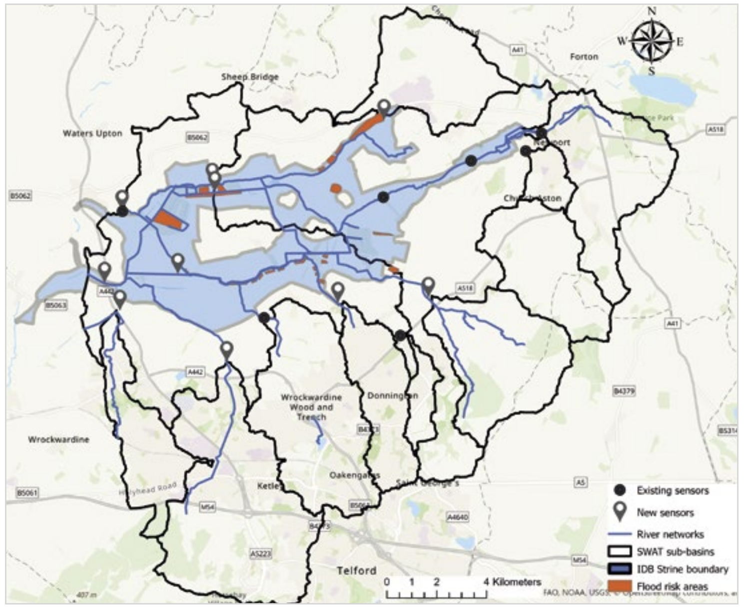
In 2024, with funding from the Department of Science and Technology (DSIT), the area was selected as a case study to demonstrate the business and environmental benefits of wireless sensors to improve catchment scale agricultural water resources management.

A key element in managing water flows and storages across the area relates to open channel maintenance. In the SIDB, the Environment Agency are responsible for the main river, the SIDB maintain the arterial channels and local land owners are responsible for field ditches. The SIDB undertakes annual maintenance on all its channels to remove silt which has accumulated due to the shallow channel gradients.

Catchment hydrology and water resources interactions

Although modest in scale, the SIDB plays a vital role for local drainage and water management in an area shaped by farming and flood risk. Many farms grow high-value crops and rely on irrigation with direct abstraction from the Strine. Water demand is high, but summer water availability is limited, especially during dry years.

Spatial extent of the Strine IDB in relation to the surrounding sub catchments. Location of existing and new sensors installed in 2024 are shown. →



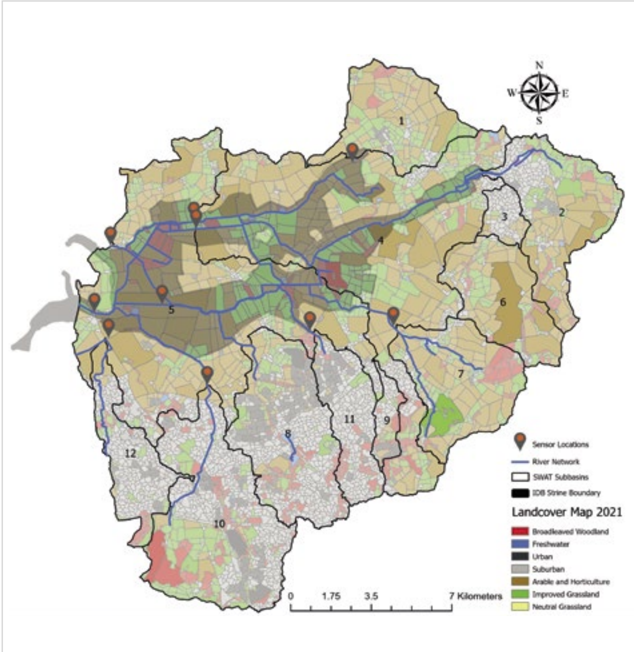
The SIDB work reflects a broader shift in drainage practice from simply moving water away to using it more wisely and sustainably within the catchment with increasing emphasis on managing water for multiple benefits: for irrigation, biodiversity and climate resilience. The SIDB supports agriculture and environmental needs by holding back water in the landscape during wetter periods and managing its release in drier times. In short, the focus of this pilot case study was to provide new information needed for the IDB to act now and plan for the future. It's a practical way to make better use of water, save costs, and help farmers stay ahead of the changes coming to farming.

Agricultural land use and irrigation abstractions

The composition of land use across the Strine IDB and surrounding sub catchments is shown in the map opposite.

Land use across the area represents a mosaic with arable and horticultural cropping (45%) and suburban areas (21%) constituting the dominant land uses. Winter wheat is the most widespread arable crop (c30%) with grassland representing c32% of the total area.

In terms of abstraction, there are 35 abstraction licences with 66 abstraction points. Of these, 13 licences and 34 points are within the Strine IDB boundary". Four are dedicated to water supply and the remaining 30 are for agricultural purposes (spray irrigation and general agriculture). Abstraction for irrigation is split almost equally between groundwater (55%) and surface water (45%).



Managing water risks and working together

"This is the big issue now, how we adapt to climate change. It's something we're starting to think about more and more. We shall go for engineered solutions, deeper ditches, higher banks and try to solve it that way – but it's not that easy"

Bruce Udale Strine IDB farmer

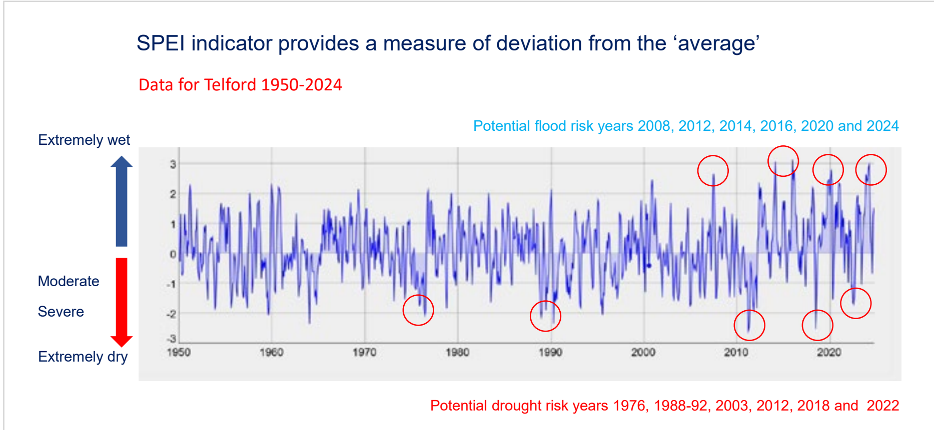
"Water doesn't naturally respect boundaries so it's become a fundamental need that we work with other farmers around water, whether its about abstraction licensing in the future, or around flood issues that we're trying to deal with at the moment"

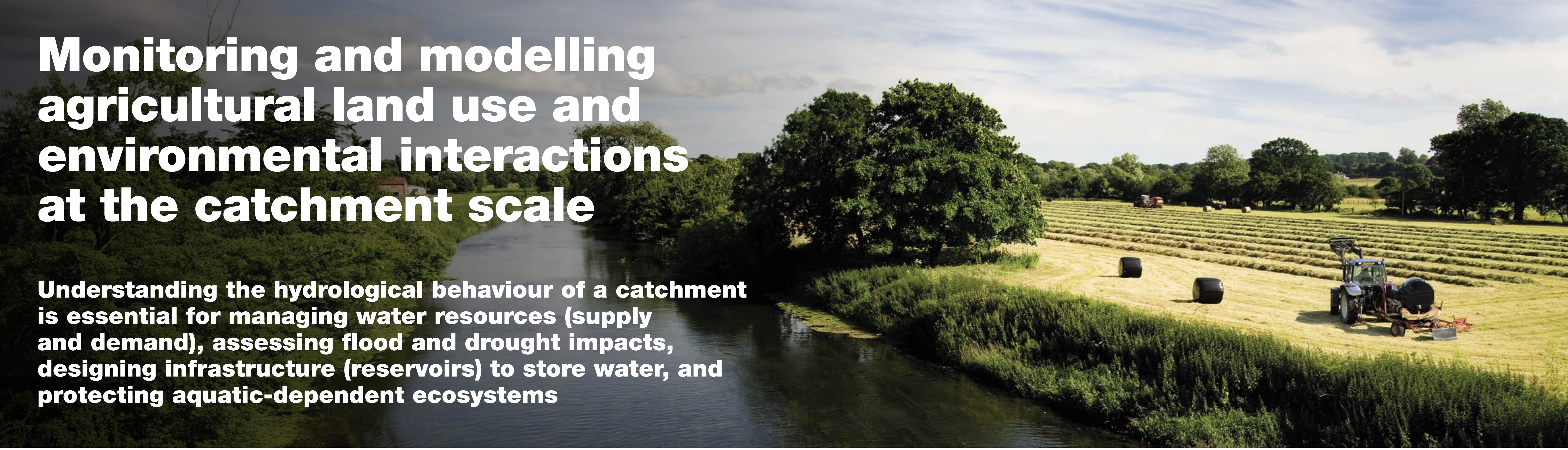
Kate Mayne Strine IDB Clerk

For more information, watch this video **Strine IDB Smart Abstraction**
https://www.youtube.com/watch?v=mrnkqvuimlI

Coping with recurrent flood and drought risks

Like many other lowland rural catchments where agriculture is important, the Strine IDB is subject to an increasing frequency and magnitude of both flooding and drought risks. The figure to the right shows the Standardised Precipitation and Evaporation index (SPEI) between 1950 and 2024. This indicator is useful for assessing climate risks facing agriculture, ecology and water resource management. The SPEI provides a measure of deviation from the 'average'. The data highlights a series of both extreme wet and dry recent years in the timeline, emphasising the need to cope with 'high and low' flows.





Monitoring and modelling agricultural land use and environmental interactions at the catchment scale

Understanding the hydrological behaviour of a catchment is essential for managing water resources (supply and demand), assessing flood and drought impacts, designing infrastructure (reservoirs) to store water, and protecting aquatic-dependent ecosystems

Modelling agricultural and environmental catchment interactions

Assessing the impacts of current and future land and water management interventions requires detailed knowledge of the study area including its hydrological catchment boundaries, river and drainage networks, locations where water levels and flow gauging are being monitored, availability of long-term agroclimate and hydrological data, water withdrawals (abstractions) as well as catchment characteristics including topography, soils variation, land use and land cover, underlying geology and presence of aquifers. These data help to understand the hydrological processes such as rainfall-runoff relationships, soil evaporation, losses due to crop and natural vegetation transpiration, infiltration, surface runoff and pathways to the surface and groundwater sources.

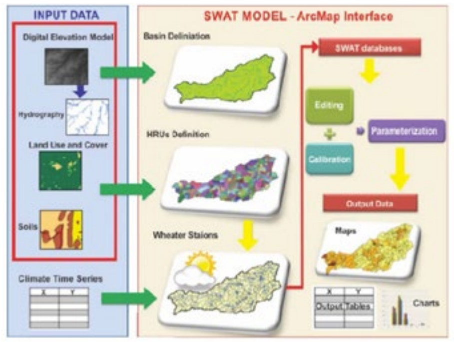
Soil Water Assessment Tool (SWAT)

In this study, the Soil and Water Assessment Tool (SWAT) was used to simulate the agricultural land use and environmental interactions in the Strine IDB and surround sub-catchments.

The SWAT model was developed by the USDA Agricultural Research Service and is designed to predict the impacts of land management practices on water, sediment, and agricultural yields in complex watersheds with varying soils, land use, and management conditions. SWAT divides a catchment into multiple water bodies (sub-catchments), which are further subdivided into Hydrologic Response Units based on unique combinations of land use, soil type, and topography.

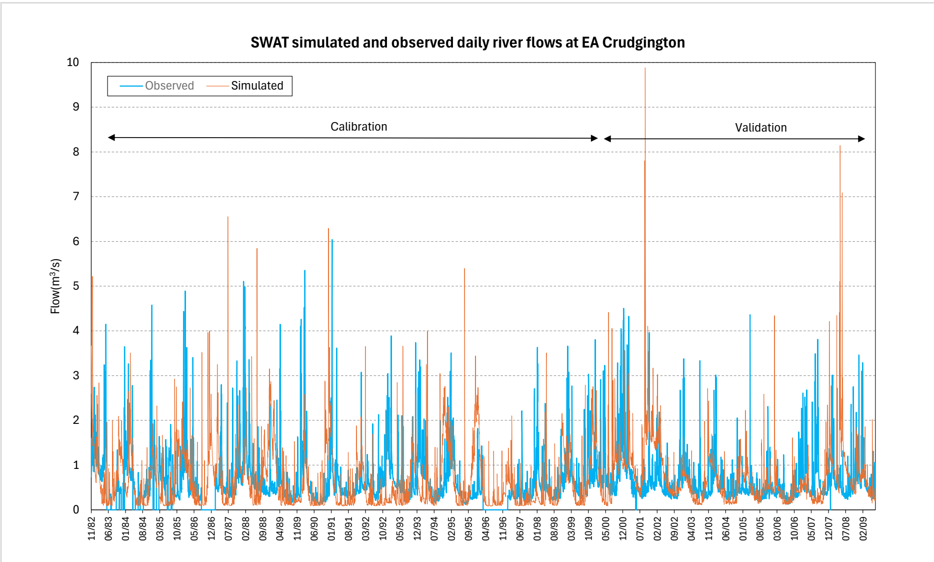
This allows users to simulate water movement, crop growth, nutrient cycling, erosion, and pollutant transport across space and time.

With a focus on sustainable water resources and environmental protection, the SWAT model enables users and stakeholders to understand the potential long-term changes in a catchment including impacts and trade offs by defining and evaluating a series of 'what if' scenarios.



Source: da Silva et al (2018)

The SWAT model was parameterised using local data and then calibrated and validated against observed river flows (1983-2009) at the EA Crudgington gauging station, which represents the main outlet for the catchment area. Statistics are then used to assess the confidence in the model representation of the catchment system



Following calibration and validation, two scenarios were then evaluated:

Scenario 1: Impacts of land use change on flood risk. Significant areas of urban expansion north of Telford are proposed, requiring conversion of existing agricultural land for development.

But how will these changes in land use influence local hydrology and downstream agricultural land flooding risks?

Scenario 2: Identifying opportunities to 'scalp' peak flows or flood events into storage

Identifying opportunities to 'scalp' peak flows (floods) into storage. A combination of upstream development and high intensity rainfall events results in peak flows passing through the catchment.

These overtop IDB channels and cause localised flooding. Some farmers no longer cultivate on areas prone to frequent flooding. But where and how much water could potentially be harvested during these 'high flow' events that could be diverted into storage for alternate uses?

These include summer irrigation, water for peatland restoration and augmenting summer low flows for environmental benefit.

SWAT modelling outputs and implications

Scenario 1: Land use change and flood risk

Figure (a) compares the SWAT modelled peak flow (m^3/s) against the return period (years) for the baseline (blue) and for the planned suburban expansion north of Telford (red).

Figure (b) shows the SWAT modelled daily discharge (m^3/s) for the suburban expansion (red) scenario. This has much higher peaks and reduced baseflows compared to baseline (blue).

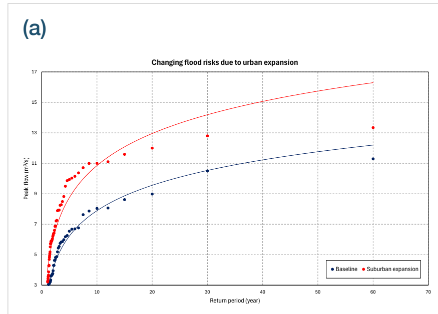
The implication of this scenario is that urban expansion increases peak flows across all return periods, indicating higher flood risks. The effect is especially pronounced for shorter return periods, suggesting that more frequent, smaller storms may cause more flooding due to reduced infiltration rates and increased runoff.

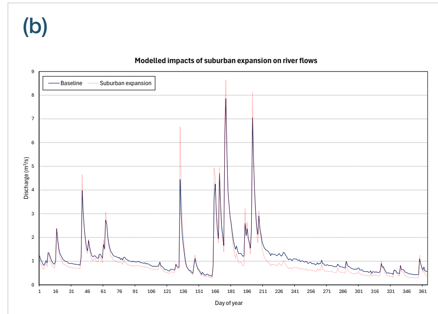
This emphasises the importance of installing effective sustainable drainage systems (SuDS) to help attenuate peak flows from newly developed areas.

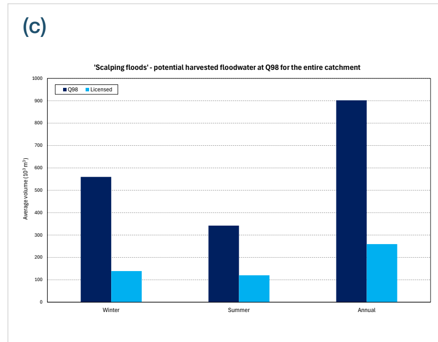
Scenario 2: 'Scalping peak flows'

Figure (c) shows the total volume of water ('000 m^3) that could potentially be 'scalped' or harvested from high flows passing through the catchment above the 98th percentile (Q98) during winter, summer and annually (dark blue).

These volumes can be compared against the total licensed volume for irrigation (light blue). This highlights the significant potential for storing peak flows which could provide additional new summer water to support multiple uses.







Managing high and low flows at the farm scale

High and low flows passing through a catchment are part of the natural hydrology of a river or stream. But they do create challenges for farmers and land managers if their frequency and magnitude become too extreme. So how can sensors help to pre-empt when these events might occur to mitigate their economic and environmental impacts?

‘Line of sight’ for managing water abstractions

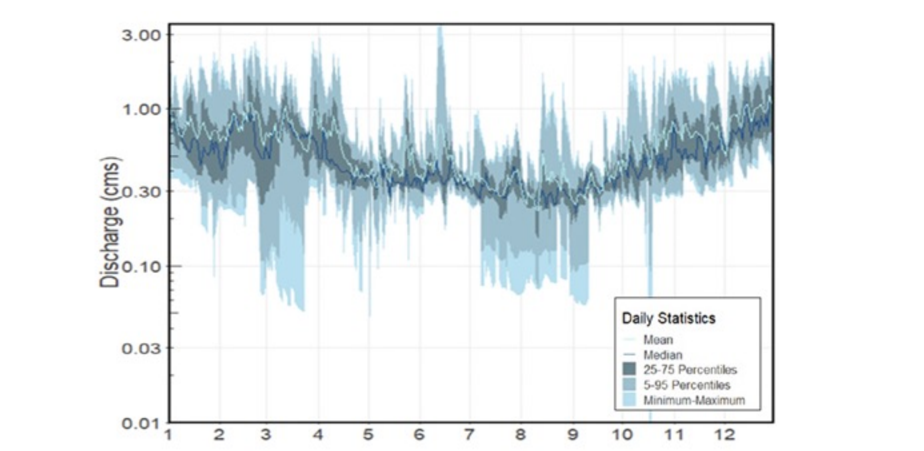
Many farmers that rely on direct abstraction from local water courses for irrigation have no ‘line of sight’ on how the flow or water level at their point of abstraction might change in the near future. This uncertainty makes it difficult to plan for the onset of either high or low flows. Since farmers cannot rely on reliable access to water supplies, this uncertainty creates inefficiency, often forcing them to irrigate when water is available rather than when their crops need water.

Uncertainty happens because our changeable weather and the local catchment characteristics influence river flows. Regulations including licence conditions and Hands-off Flow also determine how much and when a farmer can abstract at any one time.

Collectively, this makes it extremely difficult to plan irrigation schedules to minimise crop yield and quality losses. To mitigate the impacts, many farmers are exploring alternatives such as increasing their on-farm water storage capacity, switching to high flow (winter) abstraction into storage for summer use, joining a local water abstractors group, and implementing precision irrigation technologies to increase water productivity.

An additional problem is that our national network of gauging stations to monitor river flows is quite limited (usually concentrated on the larger river systems). Farmers do not have easy access to these data and interpret what they mean for their local situation.

Understanding the statistical properties of river flow



This figure shows the monthly range in flows (discharge measured in cumecs) recorded at the EA gauging station at Crudgington between 1980-2023. The mean discharge is shown, together with the extremes (at the 5th and 95th percentiles) which highlight the occurrence of low and high flows. Low flows are more common in March and May and between July and October. Conversely, high flows occur between January and April, July and October to December.

“High-flow low-flow” tool for farmers

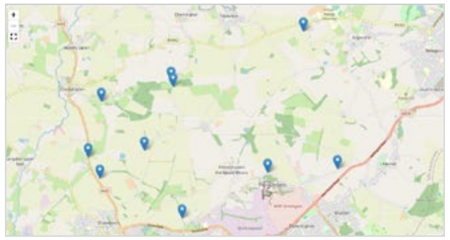
The application of artificial intelligence (AI) and machine learning techniques are also being used to develop solutions to help farmers know when high or low flows are might be coming through their catchment. This provides an invaluable ‘line of sight’ so they have advance notice of low flows and the increased probability of their Hands-off Flow being triggered. It also offers a major opportunity to capture or ‘scalp’ flood flows which could be diverted into nearby storage. Of course, the key is knowing when these high flows might occur and having available capacity to store the flood water. In the near future it is likely that small groups of farmers may work together to increase the connectivity across their distribution networks so that surplus water can be moved around and between farms more easily, and reservoir levels can be monitored to balance the available capacity against the volumes of water that can be ‘scalped’.

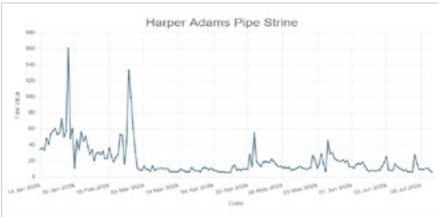
In summary, the benefits of using sensors to record changes in flow and models to then predict near term changes include:

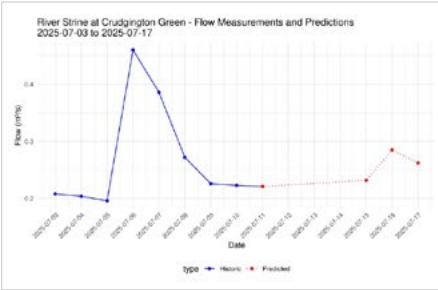
- Developing a better understanding of local hydrology and how rainfall impacts on changes in flow and/or level (known as the hydrograph)
- Helping to predict if and when river flows will drop below or rise above defined HoF thresholds
- Assisting decision-making on whether to irrigate or postpone in response to licence conditions or imminent HoF triggers
- Helping to optimise the timing and abstraction of water for irrigation from multiple abstractors, reducing risks of abstraction constraints
- Enabling real-time river flow alerts by linking sensors via telemetry systems to farm management applications or directly to pumpsets to avoid cavitation
- Providing valuable evidence to support abstraction licence compliance

Mobile application to predict short-term flows based on rainfall forecasts

As part of this project, a prototype web and mobile based application has been developed to help farmers in the Strine area monitor their local stream flows.







Using a machine learning based approach, these daily variables (river flow, rainfall and date) were integrated within a Long Short-Term Memory (LSTM) model. This is designed to ‘identify, learn and remember’ observed patterns within the long-term historical data. Using the Hydromaster forecast rainfall data, the change in flow was then forecast. This has a reasonably high level of confidence for days 1 to 3, but then like any weather forecast, its accuracy declines over time (days 4 to 9). It does, however, provide an indication of the likely probability of rainfall over the next few days, and the impact on stream flows. This can be invaluable for planning irrigation planning, for low flow (HoF) management and for flood (high flow) early warning.

Sensor locations: The application provides a user friendly interface with a map showing the location of nine individual water level (or flow) sensors which were installed in 2024 across the catchment. The site locations were agreed between the IDB and local farmers as being important reference points for monitoring.

Flow trends: Recent historical data can be viewed for any site. The sensors record data at a high frequency, typically 15 minute intervals, to help visualise the recent trend in level or flow and to identify any recent changes. Some sites also have automatic rain gauges.

Flow forecasting: Local rainfall strongly impacts on the hydrograph for a river or stream, so the “High Flow Low flow” application integrates short term (3 day) radar based rainfall forecast data via an API from the Kisters Hydromaster system. The other important element is the time of year (date), as we know that high and low flows can be seasonal (as shown on page 10 opposite for Crudgington).

The prototype tool is free and available online at: https://www.highlow-flows.co.uk/shropshire

Future developments

The prototype tool is in its early stages of development and its performance is being evaluated by comparing predicted to observed flows. Future developments will also include incorporating local rainfall trends into the tool for each site and adding local HoF triggers so that users can compare current water levels (or flows) against Hands-off Flow thresholds. The tool could also be readily transferred to other catchments but would need local calibration.