Highlights from the Lowland Catchment Research programme (LOCAR)

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Science to help manage our lowland rivers, now and in the future
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Definitions

A river **catchment** is the area of land whose water drains into that river. A **permeable catchment** lies on porous rock, such as chalk or sandstone.

**Groundwater** is underground water in the cracks and pores of the saturated permeable rocks.

**Aquifers** are porous rocks (such as chalk) or loose material (such as sand and gravel) that are a major source of groundwater. Springs and rivers form where aquifers meet the surface.

The **water table** is the depth below which the soil or rock is saturated with water.

**Hydrology** is the study of the movement, distribution and quality of water. **Hydrogeology** is the part of hydrology that studies groundwater in particular.

A **dry valley** is a valley without a surface stream – water may move under the surface instead, through the permeable soils or rocks.
Overview
Alan Thorpe, Chief Executive of NERC

Although there is a perception that water is plentiful in Britain, it is a scarce resource in some parts of the country. While water is a renewable resource, it is also finite. A growing population, with more households and greater wealth, means growing demand for water.

We must manage our water resources sustainably, so that the needs of people, industry and agriculture are balanced with the needs of the environment. The EU Water Framework Directive requires the UK to maintain our rivers as healthy aquatic habitats. To meet this challenge the whole landscape needs to be managed in an integrated way – acknowledging that what happens in one part of a catchment will affect another.

Good water management must be based on the best information. This is where LOCAR comes in. The programme has allowed scientists to unravel the complexities of how water and the material it carries move through permeable catchments. Catchments like these provide much of the drinking water for England, but both ecosystems and our drinking water are under threat from rising demand for water, a changing climate and a pollution ‘time bomb’ from agricultural chemicals and other pollutants already in the ground.

Monitoring the movement of water through a permeable catchment requires significant resources. Our £10 million LOCAR programme invested £5 million in installing and running field research facilities in three river catchments: a measurement network which is the envy of hydrologists and aquatic ecologists throughout the world.

To exploit this infrastructure NERC brought together a multi-disciplinary team of around 75 scientists and students, who studied different components of the complex path that water takes through permeable catchments and have taken on the challenging task of bringing these components together to give a unique picture of how the system functions as a whole.

The results are relevant to government, regulators, fishermen, farmers, conservation groups, land and water managers, and local authorities. This booklet presents a fascinating review of what we have learned: what happens to our water from rainfall to river. I hope you will enjoy reading it.
Introduction
Ian Douglas, programme coordinator

Large parts of England depend on underground water for human use and for agriculture. Winter rainfall percolating through permeable rocks like chalk and sandstone normally tops up aquifers and maintains the low flows of streams in summer, but in recent years some of these streams have occasionally dried up. Changes in land use and agricultural practices have altered the patterns of movement of sediments and chemicals in the water, affecting fish, plants and other life in the rivers.

To understand how and why these changes are happening and to work out better ways of managing the interactions between land and water, the LOCAR programme has examined the workings of five lowland rivers, particularly the interactions between surface and groundwater and the interplay of plant and animal life with stream chemicals and sediments.

LOCAR investigated how water enters, is stored in, and is discharged from rivers in three contrasting permeable catchments on chalk or sandstone: the Frome and Piddle in Dorset, the Pang and Lambourn in Berkshire and the Tern in Shropshire.

The work involved the largest programme of drilling boreholes for research ever undertaken in Britain. Along with new geological mapping, this revealed in more detail than before that chalk groundwater moves along different routes at different speeds. We have found that chemicals move from the land into streams in hours or days in some areas, yet take a decade or more in other parts of the same catchment. In some places, water moves down sinkholes, through openings in the rock to emerge at springs a day or two later. Elsewhere it flows through tiny cracks in the uppermost part of a zone where all the spaces in the chalk are filled with water. But we found that much of the water moves extremely slowly at greater depths, is influenced by large-scale geological structures and does not always follow the direction of surface valleys. LOCAR research found that this water may stay for many years (40 or more in some places) in the rocks before it emerges in springs or seeps into rivers. This means that even if we stop applying agricultural chemicals today, it may be decades before they no longer enter rivers fed by groundwater.

Within each catchment there are pressure points that respond quickly and dramatically to change. One of these is in the active upper layer of the stream bed where biological and chemical changes regulate stream chemistry.

In valley bottoms on chalk, groundwater returns to the surface in springs, seepages and upwellings. We shed light on the complex biological and chemical changes that occur in this zone, where groundwater and stream water mix. The nitrogen and phosphorus compounds from fertilisers and sewage effluent are transformed into new compounds, particularly within the top 20cm of sediments on the stream bed. Some of the nitrogen and phosphorus is temporarily stored in these sediments and may be released gradually or in bursts after storms. But some of the nitrogen and phosphorus, which otherwise would have affected life in the river further downstream, is fixed almost permanently to particles of sediment in the river. The greenhouse gases nitrous oxide and methane are also released to the atmosphere from the stream bed. LOCAR found that these streams may not be as healthy as conventional ecological assessments lead us to think.

In lowland streams, plants can alter the water flow and trap sediments, changing the habitats of plants, animals and insects, altering fish movements and influencing biodiversity. LOCAR has made us realise how important river plants are in determining the chemical and ecological status of rivers. Biodiversity, habitat and water quality are affected by channel maintenance for flood and fisheries management. LOCAR results cast doubt on the existing models that are being used to manage catchments.

Thanks to LOCAR, we now have a good understanding of what controls groundwater movement in these catchments. Detecting the sources of water will allow managers to plan water-quality-control measures more precisely.
Science highlights

How to recognise a healthy river

Most conventional biological assessments of the LOCAR rivers, based on the diversity and type of the animals and plants that live in them, would conclude that they are ecologically healthy. But LOCAR scientists identified significant changes taking place in stream beds which suggest that these rivers may not be as healthy as previously thought. Salmon and trout eggs survive poorly, the rivers contain too many nutrients and their clogged-up beds emit significant quantities of gases such as methane and nitrous oxide – not features of high quality river ecosystems. The river function and conventional assessments seem to be telling different stories and suggest we might need a new ecosystem-based approach to ecological assessment (see page 13).

The significance of plants

LOCAR scientists showed that plants are the engineers of a healthy river. Plants influence the speed of the current, where sediments are deposited and eroded, where nutrients are recycled and where the animals of the river live. Faster currents between dense patches of water weeds can clean silt from river bed gravels. Where plants slow the current down, plant debris, organic and mineral particles are deposited. As a result, new bed and bank forms develop, new plants germinate and grow, and hotspots for processing organic matter are created. Sensitive management of vegetation in the river and on its banks is therefore critical for a complex and healthy habitat in lowland rivers (see page 12). Land plants are also important for rivers. LOCAR research showed that different types of plant cover in the catchment have a big effect on the amount of rainfall reaching a river. Using new methods developed by LOCAR (combining direct local measurements with satellite data), we found that much more rainwater evaporates from fields of grass and clover than from fields of wheat, for instance. Hedges, especially hawthorn, intercept and evaporate more than half of the rain that falls on them, and woodlands and wetlands also affect the amount of rain that gets into the rivers and the ground. This information will be important in estimating how much rainfall is needed to recharge groundwater.

Agricultural chemicals will pollute rivers for years to come

A new LOCAR catchment model shows how river pollution will respond to changes in the application of agricultural chemicals. Unless there are drastic reductions to the amount of chemicals applied, LOCAR found that some rivers will routinely exceed safe drinking water limits by 2020 and groundwater nitrate will continue to increase for the next 70-80 years. And even if there are reductions now, agricultural and other chemicals already in the groundwater will continue to leach into rivers for several decades (see page 10).
Where does the water go?

In the Pang catchment, LOCAR researchers found that the flow of water underground can’t always be predicted by the slope of the land surface, because groundwater flow is controlled by the complex network of large and small cracks in the porous rock which developed over millions of years. Using data from the dense network of boreholes on the Pang catchment, LOCAR scientists discovered that much of the water below the surface of the catchment flows directly into the Thames, not into the Pang as expected. Water managers need to know where the groundwater is going so that they can make the best decisions about how much water can be extracted and how these sensitive catchments will respond to rainfall and pollution (see page 9).

An invisible water supply

Dry valleys, which are a feature of permeable catchments, were formed by meltwater at the end of the ice age when the land was frozen. LOCAR research in the Tern catchment found that water from aquifers flows through the layers of sand and gravel on the floor of dry valleys, feeding a considerable volume of water into the main rivers. This invisible underground flow helps to sustain aquatic environments during droughts, but also channels agricultural chemicals into rivers (see page 11).

Tracing the source of silt

Eroded soil can damage aquatic life by silting up river channels. For example, salmon don’t breed well when their gravel spawning beds are silted up. And silt can carry pesticides and nutrients into the water from fields. River managers need to know where the eroded sediment comes from so that it can be controlled. LOCAR has used innovative ‘fingerprinting’ methods to investigate the source of the fine sediment moving through the study catchments. The detailed field measurements clearly showed that the shift from pasture to cultivation in southern England affects rivers. For the first time we have a complete picture of where eroded soil particles come from and go to. LOCAR discovered that bank erosion is only a minor source of sediments in most of the study catchments: much of it comes from agricultural land and particularly from ploughed fields. Very little silt comes from unploughed pasture. This important new information can be used by environmentally sensitive farming initiatives to reduce silt in rivers.

Side channels are important for fish

It is not just the main channels of rivers which need looking after: LOCAR research showed that side channels are very important for biodiversity and have different flow, sediment, vegetation and temperature characteristics. LOCAR scientists found that different fish use different types of channel as refuges and for spawning, moving from one type of channel to another at different times of year and as water levels and flow rates change (see page 12).
Perspectives: is this research useful?

LOCAR research has many applications – for water and land managers, farmers, fishing clubs, wildlife and countryside organisations, local authorities, parish councils, planners, agricultural advisors, regulators and policy-makers. Here are some views on LOCAR research from the people and organisations that will use it.

Water for life
Mike Bonell is the former Chief of Section: Hydrological Processes and Climate within UNESCO’s International Hydrological Programme (IHP). As the chair of LOCAR’s steering committee he has been active in promoting LOCAR within the IHP as an example of a new integrated approach to catchment research. This approach is needed to tackle the global problem of supplying an increasing world population with clean, fresh water.

Mike said, ‘Water is crucial for sustainable development, and 2005 to 2015 is the UN International Decade for Action Water for Life. The decade recognises the need for integrated water resource management and balancing the preservation of our natural environment with the alleviation of poverty and hunger. LOCAR is a model programme – it has shown how scientists can work together to provide water managers throughout the world with the knowledge they need. In that regard, LOCAR has a pivotal role in contributing to HELP, the IHP Hydrology for the Environment, Life and Policy Programme, and the associated IHP integrated science project.’

Sustainable farming
Sheepdrove Organic Farm is on the Pang-Lambourn catchment studied by LOCAR. Measurements of evaporation, groundwater and soil moisture were made on the farm. Lois Philipps (who works with Sheepdrove at the Elm Farm Research Centre) said, ‘We were pleased to work with the LOCAR scientists. At Sheepdrove we appreciate that action on one part of a catchment may create impacts elsewhere. We need to know the connection between rain falling on the ground, and water in the underground aquifers and in the rivers. Only when we know how the catchment functions as a whole will we be able to manage it to create a healthy environment: sustainable farm management and sustainable water management go together.’

Regulating the environment
The Environment Agency regulates how catchments are managed in England and Wales. The Agency’s Bob Harris has been following LOCAR research to ensure that they make full use of the results as soon as they appear. Bob said, ‘Our objective is sustainable water use and healthy aquatic ecosystems. LOCAR is changing the way we perceive lowland catchments – the processes controlling water and pollutant movement are far more dynamic than we had thought. LOCAR is providing us with a new appreciation of how permeable, lowland catchments function and with invaluable scientific underpinning to help us develop the regulatory framework we need.’

The water industry
Thames Water is responsible for supplying water to some eight million customers in the south-east of England. The company is investing heavily to meet the increasing demands on the limited water resources available in the region. Brian Connorton of Thames Water said, ‘The low rainfall in the winter 2005-2006 has demonstrated the vulnerability of water resources in southern England to drought conditions. In planning for the future, water companies need to continue with the progress being made in using water more efficiently, while at the same time identifying and developing new environmentally sustainable yet cost-effective water sources. LOCAR results are helping us to make these investment decisions based on sound science.’

Local communities
Councillor Jeff Hopkins of Market Drayton has welcomed the way the LOCAR projects in the Tern catchment have given the local community a new understanding of the significance of their local river. Jeff said, ‘Having such high-level research going on in the community provides new information for all, from farmers to schoolchildren. If it helps them to use the land and water more sustainably, it is a good thing.’

Sheepdrove Organic Farm.
The Lowland Catchment Research programme (LOCAR)

Thames Water, which is responsible for delivering water to London and much of south-east England, expects the number of households in its area to increase by 200,000 over the next ten years, with the population increasing by 800,000. Added to this, on average, each customer is also steadily using more water, creating a further new demand. Increasing demand for water puts pressure on the environment. Water companies could meet the demand by extracting more from rivers, but then the rivers would dry up – damaging the local ecology and environment.

How will this demand be met? The south-east of England has a relatively low rainfall and probably 70 per cent of this is lost to evaporation by the crops and woods which cover the landscape. The remaining 30 per cent has to replenish our reservoirs and aquifers, and sustain our rivers and wetlands.

The region is quite resilient to summer droughts because of the water stored underground, but water supply during the summer is vulnerable to dry winters. If winter rainfall is not sufficient to refill the aquifers and reservoirs, the water supply is at risk the following summer. The drought orders imposed on the south-east of England during the summer of 2006 are a case in point. The area relies heavily on groundwater but because of the dry winter of 2005-2006 groundwater levels are at record lows and all non-essential water use has been banned.

This combination of increasing demand and limited supply will inevitably lead to water shortages. To avoid a crisis in the future requires action now: new policies, based on sound science, are needed for planning, regulating and managing the region’s water resources.

Backdrop: the water crisis in southern England

A rising population, more households and greater wealth have led to an ever greater demand for water, putting the limited supply in the south of England under stress.

Household water use. Each person in England and Wales uses an average of 154 litres of water a day - a figure which continues to rise.

Source: Ofwat - Office of Water Services.

Low winter rainfall in 2005-2006 caused the headwaters of the River Pang to dry up completely.

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The LOCAR approach

A permeable chalk or sandstone catchment is a complex, dynamic system with a multitude of interacting components. LOCAR was designed to unravel these interactions through a coordinated programme of long-term monitoring and 12 studies focusing on a part of the hydrogeology or ecology of one or more of three study catchments. Taken together these studies produce, for the first time, the ‘big picture’: a unique understanding of how the catchments behave as complete systems.

To understand how a permeable catchment works, LOCAR researchers needed to measure how much water falls on the catchment, how much is taken up and evaporated by plants, how much enters an aquifer and how it then moves through pores and cracks in the rock into the river.

European law has changed the way that water resources are regulated by the Environment Agency. The European Water Framework Directive places a new emphasis on creating and maintaining rivers as healthy ecological habitats. To help the UK meet its requirements under this directive, LOCAR has investigated how sediments and chemicals (dissolved in the water or attached to sediment) move from fields into rivers. Identifying the key physical, chemical and biological processes operating within a river valley has allowed the impact of land and river management on the ecology of the river to be assessed, one of the requirements of the directive.

Infrastructure worth £5m was used in this research. At each of the three LOCAR catchments, the teams put in equipment to measure the rainfall and how much of it evaporates, refills the aquifers or is stored in the soil. Measuring the chemical composition of the water revealed the water quality at each stage in the path from rain to river. A network of deep boreholes was drilled to allow the LOCAR scientists to map the flow of water as it finds its way through the complex chalk geology into the rivers.

A computer model that maps how water moves across and through a catchment is the best method of combining the results from all the diverse studies from the LOCAR programme. LOCAR is developing models which will be able to make useful predictions of how changes in one component of the catchment system will affect the quantity and quality of water in another (see page 14).
The concept of a stream catchment is apparently straightforward – it is the area of land whose water drains into the stream. From any given point on a stream, the divide between the land that slopes towards the stream and that sloping away from it can be easily picked out on a map. But for chalk streams, which depend upon groundwater flow, things aren’t so simple. LOCAR discovered that in the River Pang catchment, much of the underground water moves directly to the adjacent River Thames and not to the Pang.

The water quality in chalk-fed streams and rivers depends in part on where the water comes from. If it runs rapidly through cracks in the rock straight into streams it will carry chemicals and sediments from the surrounding fields. If it takes the slower path percolating through pores in the rock, the impact of the chemicals will be delayed so water quality will be better (but some of the pollutants will emerge into rivers much later).

Tracers (harmless, inert chemicals used to label a small volume of water) were used by LOCAR scientists to show how fast the water moves through the rocks. In some cases, when tracers were injected in places where streams disappear into the ground, they reappeared in springs a day or two later. In other places the water did not emerge at all. High up in the Pang catchment on the chalk downs, any new water sinking into the ground pushes down the water that entered the catchment earlier. This ‘piston flow’ process means that a given litre of water entering the ground today might take many decades before actually emerging in a stream.

LOCAR has recognised four important types of groundwater movement:

- shallow but fast flow within a few tens of metres of the water table;
- deeper slower flow which transmits water to a main river like the Thames;
- very rapid flow where water runs through major cracks which channel rainfall directly to springs that in dry weather provide the major part of the flow of the surface stream (such as the Blue Pool spring which sustains the Pang in dry summers);
- river valley flow where the water moves through the sands and gravels beneath the valley floor and stream channel (under dry valley tributaries, for example).

Shallow flow generally contains water that fell as rain in the last few days or weeks whereas the deeper system may contain much older water that takes ten years or more to work its way through the rocks to the stream. These waters tend to mix in the valley bottoms where the rapidly flowing young water feeds the larger springs and upwellings and the older water emerges at the base of valley sides and in seepages along the channel.

In the valleys, surface streams often disappear into porous rock, but LOCAR work confirmed that beneath these dry valleys water is often moving through the gravels that partially fill the floor. These gravels formed during cold periods in the last two million years when ice covered areas further north in Britain. Today they are an area of concentrated, relatively rapid groundwater flow, influencing where water reaches the flowing rivers and also acting as a store of water beneath the rivers. It is helpful to think of the river not merely as the channel we can see, but as a large part of the valley floor underlain by gravels and sands all carrying water downstream.

LOCAR research has reinterpreted the groundwater catchment and groundwater flows around the Pang, showing that much of the rain falling onto the catchment flows directly to the Thames. This is helping to improve the computer models used in forecasting available groundwater.
As rainwater moves through the soil it becomes contaminated with agricultural chemicals, and this polluted water eventually works its way into rivers and the water supply. Predicting the rate of water movement through aquifers is thus important for estimating both water quantity and quality.

In the chalk downs of southern England the water table may typically be up to 70 metres below the surface. Some of the rain falling on the surface diffuses through the pores of unsaturated chalk slowly, taking many years to reach the water table. On the other hand, rain which flows through cracks in the rock may reach the groundwater almost immediately.

LOCAR scientists have found that up to 30 per cent of the water takes the rapid route through cracks, with the rest diffusing slowly through the chalk.

**The trouble with phosphorus**

Phosphorous compounds are a problem for river water quality and ecology because too much of these nutrients causes excessive growth of river plants. As plants die and decay, oxygen levels drop, which can kill fish in extreme cases. Phosphorous compounds enter rivers from agricultural runoff and sewage effluent. At times of greatest ecological sensitivity (usually dry periods in spring and summer, when river flows are low), the major source of phosphorus entering rivers is sewage effluent. LOCAR research has shown that phosphorus is taken up by river sediments and that this is an important ‘self-cleansing’ mechanism for reducing river water phosphorous concentrations downstream of sewage effluent discharges. When water companies reduce phosphorus in sewage effluent, phosphorus stored in the river bed sediments can be re-released into the river water, but, over time, the levels diminish and the river water quality gradually improves.

As the use of agricultural chemicals has increased over the last 50 years, the amount of chemicals in the chalk has built up, creating a time bomb of pollution waiting to find its way into the rivers which supply our drinking water. These findings have been incorporated into a model which predicts when this pollution will reach the rivers. The model will help catchment managers to draw up a timetable for taking remedial action.

The main problem for water quality and ecosystem health is with plant nutrients such as nitrates and phosphates. In many areas, fertiliser applications have led to nitrate levels in rivers and groundwater that already exceed drinking water limits for part of the time. LOCAR research suggests that if existing agricultural applications continue, groundwater nitrate will continue to increase for the next 70-80 years, and by 2020 some rivers will routinely exceed drinking water limits. Even if tight restrictions are put in place now, it will take several decades for nitrate concentrations to reduce.

Not all the chemicals applied in agriculture are used by the crops, much is washed from the soil into the groundwater. LOCAR models can now predict when polluted waters will enter our water supplies.
The ecological health of a river and adjoining areas depends on the regular supply of appropriate amounts of water and nutrients under specific conditions (such as temperature and oxygen levels). Interfering with these conditions—by abstracting water (from wells or from the river), changing the quality of water entering the river or changing recharge to the groundwater—can have devastating impacts on the ecology in and along the river.

The headwaters of rivers in permeable catchments are particularly vulnerable to exploitation of water resources because they have a high, natural variability in their flow. This variability is caused by seasonal fluctuations in groundwater levels. The use of water resources in these vulnerable areas must therefore be carefully managed to reduce the potential risk of both summer drought and winter flooding.

LOCAR scientists have been looking at the similarities and differences in the way aquifers and rivers interact in different catchments. This has allowed them to work out what is influencing the delivery of water to a river and how that water (and the associated chemicals) continues its journey to the river mouth. Relevant factors might include where the groundwater comes from locally, the type of rocks, the soils, the form and use of the land, and the plants, animals, insects and microorganisms present.

About 75 LOCAR researchers have been involved in intensive fieldwork programmes for over three years to analyse changes in river flow and water quality along the lengths of the five rivers in the three LOCAR catchments. Broader scale studies have involved examining some 350km of river, with highly detailed investigations over 45km of channel.

Isotopes (the heavy and light variants of a given element) of naturally occurring chemical elements have been shown to be particularly useful in understanding these environments—water that has travelled through different geologies or has been in the ground for different lengths of time emerges into the river with a particular isotope ‘fingerprint’. Scientists then have a measure of how water, which initially fell on the catchment as rain, enters the river days or years later. Other tracers—deliberately injected or, like CFCs and radon, already present—were also used to trace routes and age water.

These data provide new evidence of how dry valleys can act as subterranean pathways allowing water to move into and out of the river. Some stretches of a river may lose water to the groundwater, while in other places the groundwater may re-emerge to add water to the river. LOCAR discovered that this natural exchange between aquifer and river is extremely variable within a catchment and can also change over time. For example, under low river flows fine sediments may be deposited on the river bed which can lead to a kind of hydraulic sealing of the river. Then, during periods of higher flow this ‘lining’ of the river may be stripped away, allowing connection again with the aquifer.

These findings are important for managing the quality of the river. If pollutants are to be eliminated we need to know where they come from and how and where they enter the river. LOCAR’s work provides the understanding and detailed theories that help managers to know what to look for and where they might find it. It has also produced knowledge that will form the basis of new models required for estimating the impact of changing climate, land-management practice and water use on the ecological environment in and close to the river.
Rivers continually change as they erode and deposit sediment, and plants play a crucial role in engineering their ever-changing form. River bank trees such as willow and alder, water edge plants such as reedmace, and submerged plants such as water crowfoot are all common along lowland rivers. When inundated, these plants slow the current causing sand, silt and organic material to settle out of the water. Sediment accumulations create new landforms, new seed banks, a seed bed for the growth of new plants and sites for decomposition. Winter floods are vital for dispersing seeds from aquatic and riverside plants. Twice as many species are deposited across river banks by winter floods than during the low flows of summer.

Trees and other rigid plants on the river margins help to drive progressive changes in rivers by trapping and reinforcing sediment. Working in the Rivers Frome and Tern LOCAR scientists found that flexible water plants, such as water crowfoot, cause annual cycles of sediment trapping as they grow in the spring and decay in the winter. Water crowfoot also provides habitat for the larvae of filter-feeding insects and a settling area for their waste. As a result, sediment accumulations around these plants are hotspots for processing organic matter. During summer, aquatic plants are also very important for raising river levels, shading cool patches of slow-flowing water and inducing faster currents between plants which clean river bed gravels.

These processes are important in both the main river and in side channels such as natural tributaries, mill streams or drainage ditches. Contrasts in local habitat conditions along and between side channels are crucial in maintaining fish populations and their diversity. Using electronic tags, LOCAR researchers found that movements between the main river and side channels are an important part of life for many river fish. Mill streams and small tributaries provide important spawning sites for dace, while the slow-flowing drainage ditches are preferred by pike. In the high flows of winter, many types of fish use side channels as refuges from the main channel.

These results are important for river managers. The diversity of river land-forms, flow velocities, patches of sediment and plant communities along lowland rivers and streams is heavily dependent upon engineering by plants. Sensitive vegetation management is critical for habitat complexity, biodiversity and organic matter processing within lowland rivers. Managers need to give space for riverbank plant communities and to maintain a balance between plant growth and channel choking where supplies of fine sediment and nutrients are high. Moreover, it is not just the main channel which needs sensitive management. Careful vegetation removal and desilting at the mouths of side channels can make them more accessible to fish and their food sources; but highly engineered, heavily dredged ditches and other side channels are of very low value to fish.
How do we judge the health of rivers?

It is no longer sufficient to maintain rivers free from pollution. River managers are now trying to maintain their rivers in an ecological state that is as close to pristine as possible.

Rivers reflect the environments that they drain. They are sensitive to all human activities in their catchments, to introductions of new plant and animal species, and to the impacts of climate change. For a long time the quality of rivers has been assessed by measuring a few chemical factors or by counting the numbers of key types of fish, invertebrates or plants in the rivers. Assessed on such criteria, the LOCAR rivers would seem to be of good quality. However, LOCAR scientists have identified significant changes taking place in stream beds which suggest that these rivers may be less healthy than previously thought.

Stream beds are highly variable. The bed is a mosaic of patches: some muddy, some sandy and some gravelly. Some patches support dense stands of plants which trap silt and support abundant insect life, particularly the larvae of simulid blackflies, whose wastes contribute to the chemical exchanges in the bed. The patches differ in the way they allow water to penetrate into the bed or, at low flows, to emerge from the bed into the stream. These contrasts affect the mixing of surface water and groundwater, the time that water is held between the grains of material in the bed, and the rate of chemical exchanges.

In the River Lambourn, LOCAR research found that most of the important chemical and biological interactions between surface and groundwater take place in a thin layer rich in organic matter, just 10 to 20cm thick, at the top of the river bed sediments. In the flowing water column above this layer, and in the rising groundwater below, nitrate is abundant. But in the thin active layer nitrate is chemically reduced, with the oxygen atoms being replaced by hydrogen. The ammonium which is produced is actively taken up by growing aquatic plants, and gases such as nitrous oxide and methane are generated by microbes.

Such processes also occur in the River Frome, where it has also been shown that methane finds its way from the poorly oxygenated sediments below plant beds to the atmosphere via the stems of the plants. Evidence from the conventional biological assessment of these rivers suggests they are of good quality, but it seems unlikely that the production of nitrous oxide and methane is really characteristic of ‘good ecological status’. Farming practices leave these rivers rich in sediments and nutrients, creating the conditions in which such gases are produced and leading to low birth and survival rates among fish species of importance to anglers, including salmon and trout.
Models of catchments are an important way of bringing together all the information about a river system to help to inform management decisions, develop policies and draw up new regulations. Researchers create sets of equations, solved by computer, which represent the timing and routing of water and its contaminants, and the chemical and biological changes taking place as the water moves through the catchment. These models can predict how change in one part of the catchment will affect the quality and quantity of water in another: for example, how reducing fertiliser applications or increasing groundwater abstractions may affect the wetland habitat around a river.

LOCAR data have also shown some limitations of conventional groundwater models. How groundwater interacts with the rivers is more complicated than was previously thought. Better models are needed for managing water to protect river habitats, which often include rare and protected species.

LOCAR researchers have produced a new model to show how water and pollutants move through the deep unsaturated zone – the layer between the surface and the water table. The model successfully predicts the movement of pollutants from the soil to the river. The effects of future climate change and agricultural fertiliser application can now be predicted.

A promising model of evaporation across an entire catchment has been developed. This model incorporates the effects of different types of land cover by combining field results with satellite measurements. This work gives a useful insight into the water use of common agricultural crops and will improve our ability to estimate how much rain reaches the groundwater. Other computer models produced by LOCAR include models of slope erosion, bank erosion, movement of fine sediments (and hence their associated chemicals), and movement of nitrogen and phosphorus.

Contours showing the variation of annual evaporation from the Pang and Lambourn catchments.
Students’ work

This section highlights the work of four of the students who took part in LOCAR.

Helen Moggridge, a PhD student at King’s College London, is studying the regeneration of willow trees on the banks of the River Frome.

Helen found that the survival of willows depends on spring flooding – information which will help river restoration projects. ‘Working in a LOCAR catchment has really helped my research as there is so much data available on the river,’ said Helen. ‘There are also many other LOCAR researchers working on the Frome who have all been really supportive – and it’s much more fun working in a team! The annual meetings have provided an opportunity to publicise my research and meet other scientists in the field. Being part of LOCAR has been a very positive experience, principally because it has given me the opportunity to join a large, diverse research community.’

Nathan Callaghan is studying the water use of woodland growing on saturated soils.

I have been measuring the amount of water used by wetland trees growing on sites with different species composition, structure and hydrology,’ Nathan explained. ‘I’ve learnt to use a number of techniques, working at the leaf, tree and landscape scale. The work is a collaboration between CEH and the Open University, but LOCAR provides a much larger framework of research which has made me realise the relevance of my work and how it fits into the bigger picture.’

Ben Thomas, a student at Exeter University, has been using computer simulation to assess climate change impacts on catchment hydrology and soil erosion.

Ben said, ‘The dynamics of river flow and eroded soil have major implications for the sustainability of river and riparian ecosystems, and my computational contribution to the broader environmental issue is immensely satisfying. My participation in the LOCAR project has given me a solid grounding in conceptualising problems and writing computer programs to solve them. Together with an advanced knowledge of managing and analysing vast quantities of data, my research has afforded me a skill base that is more diverse and transferable than one traditionally associates with PhD study.’

David Hussey is a PhD student at the University of East Anglia studying what happens to pharmaceutical drugs administered to animals.

David said, ‘Antibiotics are widely used in veterinary medicine and large amounts find their way into the soil. But how long do they remain in the soil before being degraded and will they reach the rivers? Are they a danger to humans and are new regulations needed? My research is concerned with an antibiotic used in pig farming in the Pang catchment and seeks to assess the quantities of it in soil and surface waters to inform answers to these questions. LOCAR has given me the opportunity to research an important environmental problem and to make a real contribution.’
LOCAR, the Lowland Catchment Research programme, is a £10 million research programme which ran from 2000 to 2006, funded by NERC with additional funding from Defra, the Environment Agency and the Joint Infrastructure Fund. It involves researchers from 14 institutions in 12 major interdisciplinary projects to study and model the hydrology, geology and ecology in three river catchments on porous rock (chalk and sandstone). It aims to provide the science required to support current and future management needs for permeable lowland catchments through an integrated and multidisciplinary experimental and modelling programme. The programme provided a £5m infrastructure for research: £2m for the basic data-collection systems, the management of the data and coordination of the project, and £3m for 12 research grants and 3 research studentships. Another 16 research students joined the programme using funds from other sources.

Further reading

A detailed summary of the technical results from LOCAR is given in ‘An Integrated View of the LOCAR Programme Research Outcomes’, by Ian Douglas published by NERC, Swindon (available from www.nerc.ac.uk/funding/thematics/locar/)


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Further information

Details on LOCAR, and a pdf version of this brochure, can be found at www.nerc.ac.uk/funding/thematics/locar/

LOCAR Programme Administrator – Dr Sally Palmer
Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU.
Tel: 01793 41170, email: sapal@nerc.ac.uk
www.nerc.ac.uk

For access to LOCAR data contact the LOCAR Data Centre at www.nwl.ac.uk/locar/main.htm