**A Review of Current Knowledge**

# Community Involvement in UK Catchment Management

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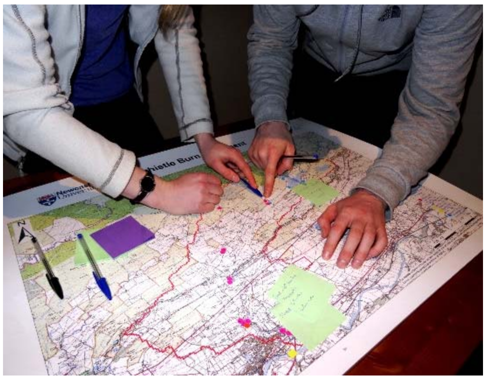
# Review of Current Knowledge

**This review is one of a series of Reviews Of Current Knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion about them.**

# Review of Current Knowledge

# Community Involvement in UK Catchment Management



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# Review of Current Knowledge

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## ABBREVIATIONS and ACRONYMS

| | |
|---|---|
| CaBA | Catchment Based Approach |
| CIWEM | Chartered Institution of Water and Environmental Management |
| Defra | Department for Environment Food and Rural Affairs |
| DTC | Demonstration Test Catchment |
| EEA | European Environment Agency |
| EU | European Union |
| IPCC | Intergovernmental Panel on Climate Change |
| NFM | Natural Flood Management |
| NRFA | National River Flow Archive |
| RAF | Runoff Attenuation Feature |
| SEPA | Scottish Environment Protection Agency |
| WFD | Water Framework Directive |
| WwNP | Working with Natural Processes |

# Review of Current Knowledge

## 1 Overview

River catchments, also known as watersheds or drainage basins, are naturally complex systems. The water environment is also heavily relied upon and modified by human activities. Catchment managers therefore encounter multiple issues relating to flooding, drought, poor water quality, sedimentation, erosion and habitat degradation, along with climate change projections. These recurring catchment issues have led to various policies and frameworks within the context of European legislation to support the management of catchments across the UK, and have triggered changes in the way catchments are now managed and the level of involvement on a local scale.

Long term observations are required to characterise catchment behaviour, implement effective mitigation measures and meet policy targets. Monitoring equipment such as automatic rain and river level gauges are well-established within the hydrological community, offering reliable datasets. However, largely due to cost constraints, traditional monitoring networks still provide limited spatial coverage, particularly within rural catchments. Catchment managers, scientists and engineers have often worked independently from the people that they serve, making it difficult for communities to truly understand their local catchment, share their own knowledge and understand catchment data produced by 'professionals'.

Defra's Catchment Based Approach (CaBA) policy framework provides an example of how the UK is now encouraging a more integrated, evidence based and bottom-up approach, allowing for greater partnership for communities to be involved on a local level. Community Flood Plans also demonstrate how local people are becoming more actively involved in flood risk management. Natural Flood Management has also emerged over recent years as an innovative way of managing multiple catchment issues. Pilot sites, such as Belford in Northumberland, are influencing how catchments are, and will be, managed in the future. Long term evidence of individual catchment behaviour and stakeholder engagement will therefore be required.

Citizen science projects are becoming increasingly popular across a range of disciplines to expand our knowledge about the natural environment, and are relatively well developed in some areas, for example in wildlife observation. These projects rely on volunteers to contribute to the knowledge production process by actively collecting, processing and sharing information. Similar approaches are developing in hydrological science, but are not yet well organised nationally. Existing approaches used in the UK and internationally are described, and examples are given from several innovative projects, including the Haltwhistle Burn catchment (Northumberland), where low-cost and simple monitoring techniques are being used by local people to make spatially-detailed observations about their local water environment. This approach to catchment monitoring offers various social and educational benefits, including bridging the gap between professionals and stakeholders, increasing locals' awareness and understanding of catchment connectivity, and empowering and supporting decision making on a local level. There are a wide range of end users for this type of data, including catchment modellers who require evidence to support their outputs, which should also be conveyed back to the citizen scientists in a meaningful way.

This Review of Current Knowledge (ROCK) highlights issues related to monitoring and understanding the complexity of river catchments which are subject to multiple pressures. It details how countries, such as the UK, are beginning to manage catchments on a local level with involvement of local people. Case studies are also presented to emphasise how we are now within exciting times due to the rapid growth in technology and communication facilities, which can and should be utilised in innovative ways (and to our advantage) to support the management of river systems.

## 2 Catchments: understanding the water environment

### 2.1 Defining the term ‘catchment’

Water and its surrounding environment is a fundamental resource to humans, plants and wildlife. On land, this commonly includes ditches, streams, rivers, lakes and water which is stored or travels underground through soils and rocks (groundwater). In order to understand the water environment, scientists and engineers divide the land up into hydrological (water) parcels known as catchment, river basin or drainage basin systems. Despite variations in terminology, ‘catchment’ is used widely in the UK today by professionals and it is a term used to describe ‘the land area which collects all surface runoff flowing in a network of channels to exit at a particular point on the river’ under the influence of gravity (Downs and Gregory, 2004). This means that their boundary, thus size and shape are purely as a result of the surrounding topography. Catchments can therefore vary significantly in scale (size), from thousands of kilometres squared, to less than one kilometre squared. Smaller catchments are often referred to as ‘sub-catchments’ and several of these are typically nested within a larger catchment. This concept can be illustrated by the Thames catchment which covers an area of over 12,000km$^2$ and has 18 major sub-catchments flowing into the River Thames itself (Thames Rivers Trust, 2014).

Naturally, catchments are composed of several components, such as the river and stream network itself, valley sides, floodplains, confluences, sediment, habitats and wildlife. However, most modern day catchments are extensively modified by humans and have experienced urbanisation and/or rural activities. Simple schematics of river catchment networks and a river catchment landscape can be found in Figure 2.1. In reality, river networks are far more complex that those shown in Figure 2.1. A useful example is the Eden catchment (North West England) which covers an area of 2300km$^2$. The River Eden itself is only 130km long, yet all 98 water bodies in this catchment have a combined length of more than 2490km (Eden Rivers Trust, 2013), as illustrated in Figure 2.2.

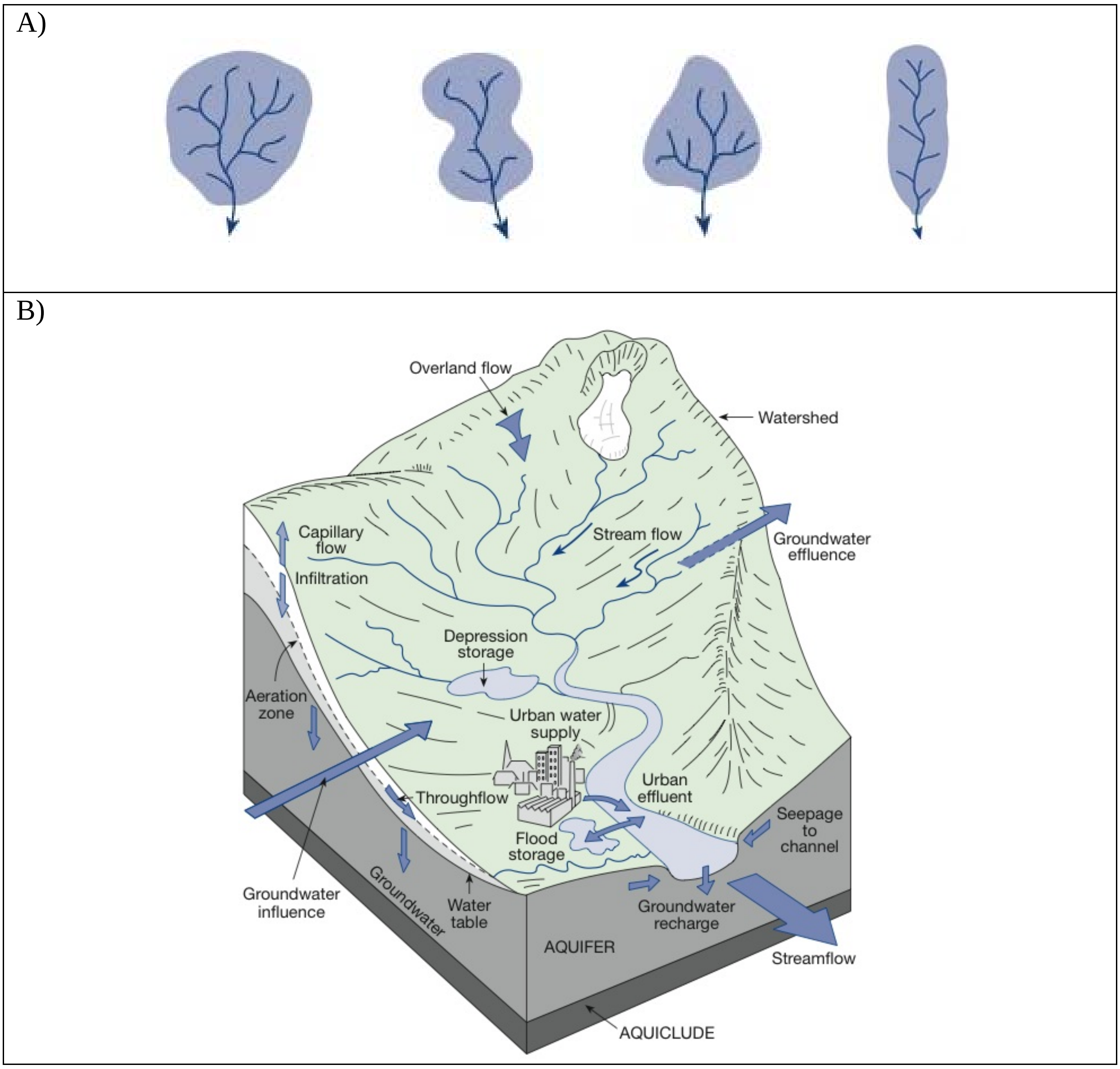



***Figure 2.1 –*** *Schematics of (A) generic river catchment networks and (B) a typical river catchment landscape*
*(Source: Smithson et al., 2008)*

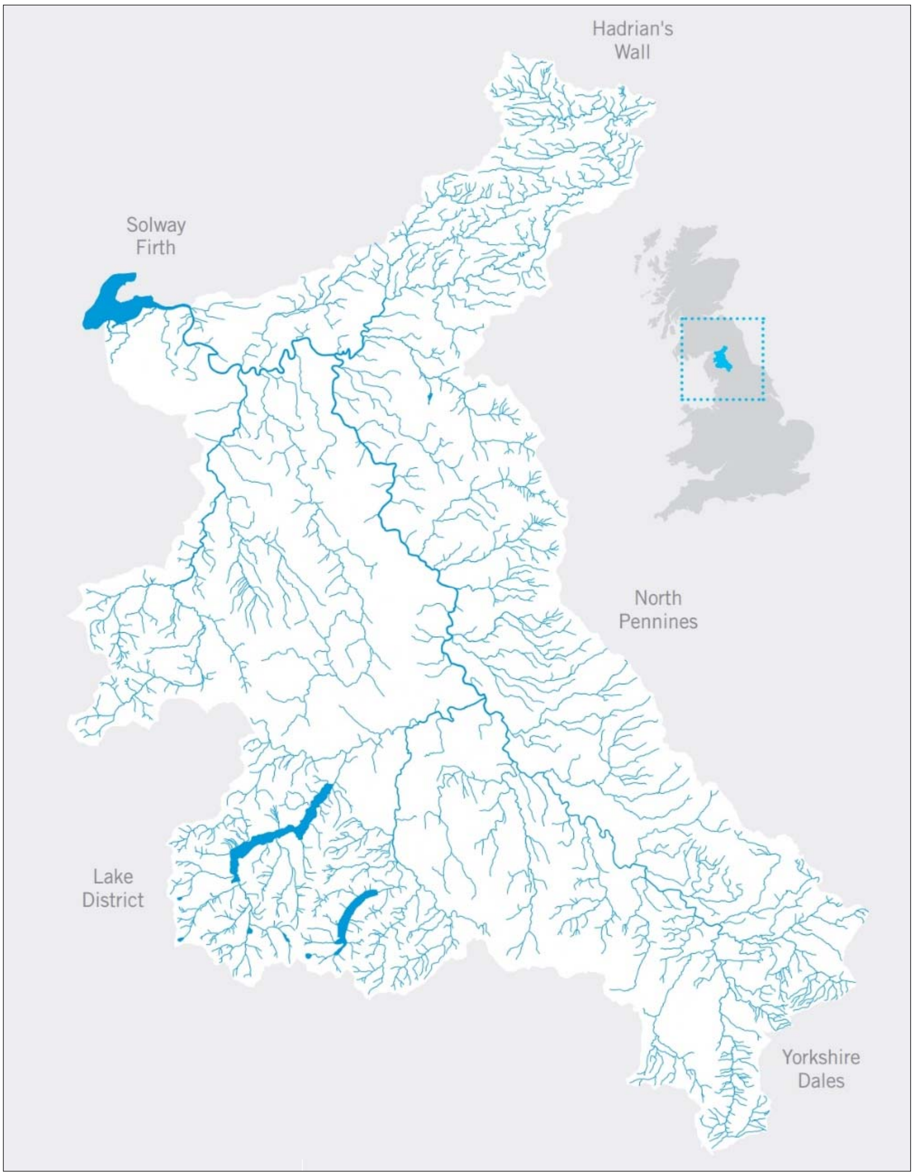



***Figure 2.2*** *– The river network draining the Eden catchment in North West England (Source: Eden Rivers Trust, 2013).*

Catchments also play an important role in the Earth's hydrological cycle, providing pathways and storage areas for water once it has fallen as precipitation. They are responsible for transporting water from mountains to the sea. Despite their importance, surface water only accounts for less than 0.01% of the global water balance, with just 0.3% of this being as rivers and lakes (Smithson *et al*., 2008).

### 2.2 Catchment connectivity: land, water and humans

As the term 'network' suggests, streams and rivers are linked from source to outlet, and because they pass over and drain an entire catchment area there are various land and water interactions occurring. Newson (1997) describes a catchment as an 'interconnected transport system' which transfers both water and sediment downstream. The quantity and quality of the water and the diversity of aquatic species at the catchment outlet are therefore a signature of an integrated response to everything occurring upstream of that point. This is why ‘catchment connectivity’ is used in hydrology and catchment science (e.g. Downs and Gregory, 2004; Barron *et al*., 2009; Newson, 2010). The behaviour of an individual catchment therefore varies significantly both spatially (across the catchment area) and temporally (though time). Spatial scales range from the full catchment or sub-catchment scale, right through to individual reaches, plots or points of interest. For example, the velocity of water between river bed pebbles and reeds or other vegetation is important for habitat suitability on a point scale. Behavioural timescales can vary from millions of years (geological processes) down to annual, monthly, weekly, daily, hourly and sub-hourly, with sub-hourly to annual timescales being of most interest and concern to catchment scientists and engineers.

Often without fully realising and appreciating it individually, humans also live and work within unique catchment systems. This means that human activities also influence the characteristics and subsequent behaviour of catchments. Human activities are often seen as having a negative impact on a catchments response, for example land cover change (land use), channel modification, water abstraction and waste release.  A significant amount of research has shown that modern land use changes have considerable impacts on the quantity, quality and morphology of the river environment (see O’Connell *et al*., 2007; Ewen *et al.*, 2010; Norton *et al*., 2012; McIntyre *et al*., 2013). Although rivers have been of high importance since agricultural communities began and modification of catchment landscapes is long established, Downs and Gregory (2004) emphasise that since the 1960s it has been more widely appreciated that direct changes to the river system can have a profound effect downstream. Most modern-day catchments are affected by a combination of natural processes and human activities. It is therefore fair to say that no two catchments or sub-catchments are alike because their behaviours are shaped and controlled by a number of factors (see Table 2.1). This makes it very difficult for catchment scientists and engineers to make sense of the complexity of catchments, even on a local level.

| Factor | Influence on a catchment |
|---|---|
| **Topography** | The relief of the land will control where water is stored and where it flows, therefore total land area contributing to a particular catchment. A steep catchment will encourage water to run off much more rapidly as opposed to a gently inclined catchment. Hills and mountains also affect the amount of rainfall by creating 'orographic' lifts or shadows. |
| **Weather/ Climate** | Weather variables, including precipitation (water falling as rain, hail or snow), temperature and evaporation are major factors controlling a catchment's water balance. The rate and duration of precipitation is a dominant factor in the UK as it is so variable, in both space and time. Climate is a term used to describe the general weather conditions over a much longer time period which can also influence factors such as vegetation cover. |
| **Soils and Geology** | Soil is generally regarded as a permeable material which allows water to infiltrate through, or store, between soil particles. Soil thickness and type can vary significantly, affecting the amount of water it can hold. If the soil structure becomes saturated, water will begin to flow overland under the influence of gravity. If water continues to infiltrate through the soils, it may also percolate into rock pores, fractures and fissures. This depends on the geological properties of the catchment.<br><br>Soils and geology play an important role in connecting the land with water and regulating groundwater storage. They also influence the physical, chemical and biological properties of a river network. |
| **Land cover & vegetation** | Like soils and geology, permeable land cover types will allow water to infiltrate into the subsurface and at different rates. Impermeable man-made surfaces, such as roads and pavements, significantly limit infiltration, generating overland flow. Agricultural activities such as ploughing patterns, drainage and choice of crops also affect how quickly water runs off the landscape. Vegetation type and density influences how much water is intercepted (thus evaporated) and/or taken up by their root structure. |
| **Human activities** | Most catchments are now heavily modified and used for a variety of activities, all of which place pressures on the land-water interactions and the subsequent quantity, quality and morphology of water bodies. Examples include urbanisation, industrialisation, building of dams, water abstraction, waste release, deforestation, loss of wetlands, farming and irrigation, building of storm water drains, channel straightening, construction of bridges and culverts, dredging, building of flood defences and river bank stabilisation. Population growth adds further pressures on catchments. It is argued that human activities are changing how rainfall turns into river flow. |

***Table 2.1*** *– Common factors affecting the behaviour and response of individual catchments, including the quantity and quality of water within a river network*
*(list compiled from Newson (1997), Ward and Robinson (2000), Downs & Gregory (2004), Boon (2012), Holden (2012) & McIntyre et al.* (2013)

It is important to remember that although there are various ways in which land and human activities can affect the water environment, the river system also plays a significant role in shaping the surrounding landscape and human activities too. This means that river networks are by no means closed systems and a multidisciplinary approach is required in order to manage them.

### 2.3 Common catchment issues and climate change

Owing to the large number of factors affecting the quantity, quality and morphology of a catchment and its river network, catchment managers and engineers are inevitably faced with a number of catchment issues. Common UK catchment issues (also applicable to most catchments worldwide) include:

**Flooding:** There are various sources of flooding including river, surface water, groundwater, tidal, coastal, sewer and reservoir flooding (Environment Agency, 2009). River and surface water flooding are most common on land and are associated with periods of heavy or prolonged rainfall, often causing ‘flash floods’. The European Commission highlights that Europe experienced over 213 major flood events between 1998 and 2009 (European Commission, 2014a). UK-based case studies are provided in Section 2.4.

**Drought:** Prolonged periods where precipitation is absent can leave catchments parched, causing river and groundwater levels to drop significantly. River networks can even dry up completely. This affects water supplies and aquatic species, particularly fish. The UK’s vulnerability has been highlighted following events such as the spring 1995 to summer 1997 drought (Marsh *et al*., 2007).

**Poor water quality:** High levels of pollution can cause the physical and chemical properties of the water environment to change and reach levels which are unusual or unnatural to the water body of interest. Although pollution incidents can be triggered naturally, it is known to exacerbate as a result of human activities such as agricultural intensification (Withers *et al*., 2014).

**Rapidly changing (morphologically active) rivers:** Rapid rates of erosion and transportation of material, usually sediment or soil during storm events, can knock a river system out of equilibrium, alter the channel geometry and leave them extremely unstable (Newson, 1997; Downs and Gregory, 2004). This provides a source of sediment for downstream locations and can (for example) damage man-made structures, block up culverts and increase flood risk.

**Degradation of habitats and species:** The UK’s river corridors contain a diverse range of aquatic habitats and species. Many of these are extremely sensitive and require optimum conditions in order to survive, grow and reproduce. Dramatic changes to the quantity, quality and morphology of a particular river network or reach will affect population rates. White-clawed crayfish, freshwater pearl mussels and salmon are examples of sensitive aquatic species indigenous to the UK. Capable of living for over 100 years, the freshwater pearl mussels for instance were abundant across Scotland during the 19$^{th}$ century. They are now extinct or diminishing rapidly in two-thirds of the original locations found (Cosgrove *et al*., 2012).

**Invasion of non-native species**: Various invasive non-native plant and animal species have been introduced into the UK water environment which are damaging the environment, causing a threat to native species and creating significant economic impacts (The Rivers Trust, 2014a). River Trusts representing catchments across England and Wales are promoting and acting on a campaign to stop the spread of invasive non-native aquatic species, for instance the killer shrimp, American mink, signal crayfish, giant hogweed, Himalayan balsam and Japanese knotweed (see Figure 2.3).


***Figure 2.3** – Invasive non-native aquatic species campaign promoted by the River Trusts (Source: The Rivers Trust, 2014a)*

**Climate change**: The UK is expected to experience an intensification of precipitation extremes, including heavier summer downpours and wetter winters (Pitt, 2008; IPCC, 2014; Kendon *et al*., 2014), affecting catchment response. This could lead to an increased frequency of flood events. Boon (2012) stresses that '*the influence of climate change on rivers will undoubtedly be near the top of the list of threats over the next few years*'.

Due to potential loss of life, damage to properties, businesses and infrastructure, as well as the number of recent events experienced, flooding constantly remains a concern to the UK and much of Europe. Local communities also experience direct impacts from flooding, meaning that they are much more aware of this type of catchment issue. In fact, according to the Environment Agency's National Assessment of Flood Risk (2009), around 5.2 million (one in six) properties are at risk of flooding in England alone (Figure 2.4). The Scottish Environment Protection Agency (SEPA) has confirmed that around 125,000 properties are at risk from flooding in Scotland and they estimate the average annual cost of flood damage to be as much as £850 million (SEPA, 2011).

Each of the catchment issues listed above are often linked to and exacerbated during a flood event. This is mainly because flood waters exert such power, causing sediment and pollution entrainment upstream, sudden changes and possibly widespread destruction downstream. During the peak of a flood event the connectivity of a catchment is also at its maximum, so the lower catchment system is heavily affected by the upper catchment system.

There are a number of UK and European policies, frameworks and plans in place, as well as responsible and regulating bodies to ensure catchment issues are sustainable (see Section 3.1). Monitoring of hydrological- and catchment-related parameters (refer to Section 3.3) is one way of understanding catchment behaviour, providing evidence to support the management of the above catchment issues. Although various negative impacts induced on the natural environment have been highlighted, catchments and their ecosystems are also a vital resource to humans. They provide 'ecosystem services' which are the multiple benefits provided by ecosystems that contribute to human life, such as food and water (Everard, 2012). Different stakeholders therefore have different perspectives and perceptions which can be challenging to manage sustainably (Taylor *et al.*, 2014; Withers *et al*., 2014).

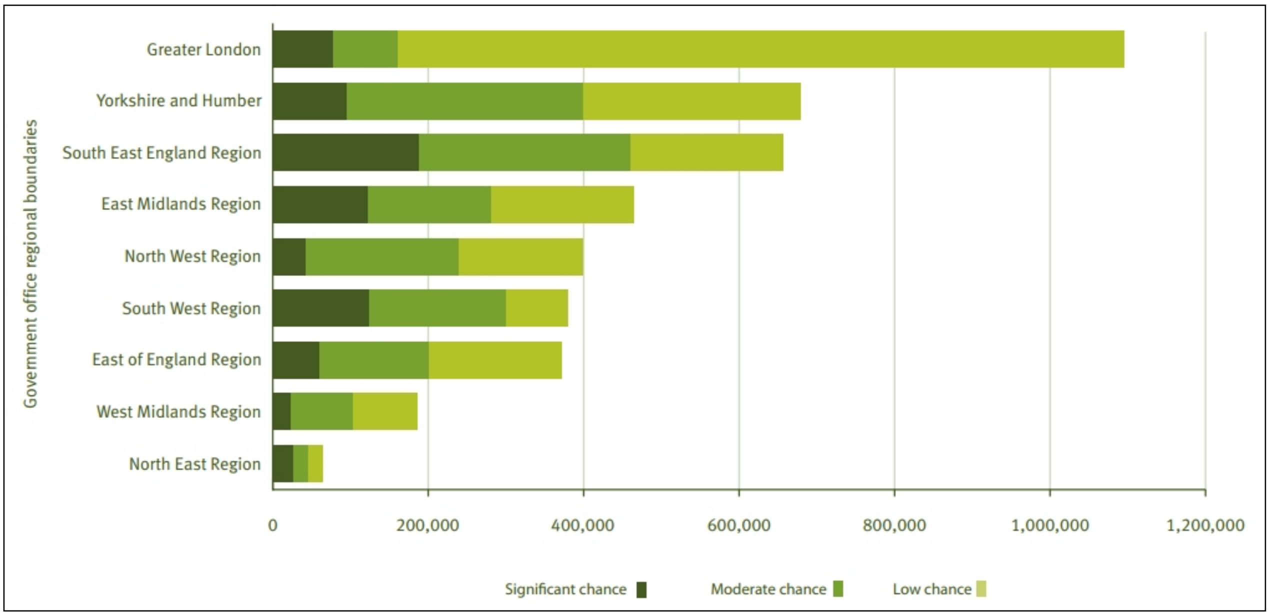



***Figure 2.4** – Number of people living in the floodplain in England (ranked by Government office regional boundaries) who have a low, moderate or significant chance of flooding (Source: Environment Agency, 2009).*

### 2.4 Case study (1): the 2007, 2012 and 2013-2014 UK floods

The UK has experienced a number of flood events in recent years, including summer 2007, summer 2012 and winter 2013-2014 floods. Although these are well-known events, many smaller and localised flood events occur more frequently and often without warning.

In 2007 the UK experienced the wettest summer on record, with heavy rainfall falling in an exceptionally short period of time (Pitt, 2008; Shaw *et al*., 2011). A review of the floods was undertaken by Sir Michael Pitt who confirms that emergency services rescued approximately 7000 people, 13 people died and a total of 55,000 properties were flooded (Pitt, 2008). There was also mass disruption to transport networks, critical infrastructure and some communities were completely isolated and surrounded by flood water, as Figure 2.5 illustrates. South Yorkshire, Hull, Gloucestershire, Worcestershire and the Thames Valley were by far the worst affected areas. The Pitt Review made several recommendations, primarily to ensure the UK is better prepared for floods in the future which the governmental organisations have acted on significantly since they were made.

There were multiple flood events in the UK throughout 2012. For example, on the 6-7$^{th}$ July Devon, Dorset and Somerset experienced persistent and heavy rain, leading to a number of 'Severe Flood Warnings' being issued by the Environment Agency which received widespread media coverage. Headlines such as '*Floods as torrential rain hits UK*' (BBC, 2012) were common to the public at the time. June 28$^{th}$ 2012 saw unusually warm and humid air move northwards across the UK. This resulted in intense heavy thundery storms which caused widespread river and surface water flooding across North East England, including the famous 'Toon Monsoon' in Newcastle upon Tyne which experienced 45mm of rain in less than a 2 hour period (Kutija *et al*., 2014). Smaller communities were also affected, including Whitley Bay which saw 56.4mm rain fall in just in 2.5 hours (Northumberland County Council, 2013). The Met Office confirmed that 2012 was the second wettest year since records began, with the total UK 2012 rainfall being just over 1330mm (Met Office, 2013).


***Figure 2.5 –*** *Widespread damage and disruption caused as a result of the summer 2007 floods (Source: Pitt, 2008)*


The Daily Telegraph

Flood chief: Should we protect town or country?

***Figure 2.6 –*** *The Daily Telegraph front page (3rd October 2014) on the December 2013 to February 2014 floods (Source: Hope, 2014)*

More recently extreme flooding occurred in the south east and south west of England over the prolonged period of December 2013 to February 2014. This event generated huge debates between local residents and land owners with the Environment Agency and other relevant governmental bodies. People were left flooded for months, including during the 2013 Christmas period, with dredging, austerity, the Somerset Levels and upland catchment management all being at the forefront of the discussions (see newspaper headline in Figure 2.6).

## 2.5 Case study (2): Agricultural intensification and rural runoff in the UK

Agricultural activities have changed considerably in the UK (and Europe) since the 1940s and have, in general, intensified in order to meet the demands of a rising global population and in line with technology. Withers *et al.* (2014) have reviewed key agricultural milestones which have had an impact on the way farmers have utilised catchments. A selection of these include:

- 1946 – the National Agricultural Advisory Service was set up to assist with increasing agricultural production;
- 1962 – The Common Agricultural Policy was introduced across the European Union (EU) to support productivity and subsidise farmers;
- 1984 – Over-production of milk was limited by the 'dairy quotas';
- 1986 – The sensitivity of the environment to farming was recognised through the implementation of the first agri-environment scheme;
- 1990s – Farmers were subsidised to ensure 'set-aside' and other compulsory measures were introduced to protect the environment;
- 2000-2014 – Various Common Agricultural Policy reforms.

Agricultural practices had become so successful that by the 1980s and 1990s, there were food surpluses and the impact on the environment was starting to show. Farming practices have become more efficient through the use of machinery and fertiliser which has negatively affected the land-water interface in many ways, as exemplified in Table 2.2 and Figure 2.7. Referring back the Eden catchment in North West England, out of a total area of 2300km$^2$, 97% of the catchment is use for agricultural activities, equating to more than 2000 individual farms (Eden Rivers Trust, 2013). A large amount of research has been undertaken within the Eden in order to better understand the relationships between different farming practices, the impacts from rural runoff downstream and how this changes through utilisation of rural land management techniques (e.g. Owen *et al.*, 2012; Terry *et al*, 2014).

| Cause | Impact |
|---|---|
| a) Use of fertilisers and pesticides | Fertilisers and pesticides encourage crop growth but can also diffuse into the river network, especially during winter months or following heavy rain. This typically increases the level of phosphates and nitrates in the river network, enriching the water body with nutrients and encouraging algae to grow. If algae flourishes, it can clog up the river system, lower light and oxygen levels and suffocate aquatic species (a phenomenon known as 'eutrophication'). Some species are extremely sensitive to high levels of pollutants themselves. |
| b) Increased stocking density, overgrazing and in-stream cattle activity | Increasing the number of cattle may 'overgraze' the land. This can damage the soil structure and reduce vegetation cover, which in turn reduces infiltration rates and encourages soil, sediment and pollution particles to wash away. Water also reaches the network much faster than in a natural case. Overgrazing can also lead to river bank collapse ('poaching') and alter the river morphology, damage habitats, as well as cause in-channel disturbances. |
| c) Use of machinery and cultivated soils | Heavy farm machinery, such as tractors, compact the land, altering the underlying soil structure. In particular, this reduces pore space and the soil's capacity to retain water. Plough lines and tyre tracks can connect fields with water courses. |
| d) Diffusion of animal manure | Whether it leaks from a designated manure heap or whilst cattle are grazing in close proximity to a stream or river, animal waste (ammonia) is toxic to fish and invertebrates. |
| e) Field drainage | In order to maximise agricultural outputs, farmers have drained fields through dykes, ditches and pipes. This has further connected the land with water, encouraging rapid runoff. |

***Table 2.2*** *- Negative impacts on the water-land interface associated with modern day farming practices*
*(sourced from O'Connell et al., 2007; Terry et al., 2014; Withers et al., 2014)*

| a) Nutrient enrichment: algal growth | b) Overgrazing: river bank erosion |
| --- | --- |

*Figure 2.7 – Examples of how modern day farming practices are catalysing the land-water interaction*
*(photographs by Eleanor Starkey)*

Farmers are both land owners and users of catchments, they live and work in and around the river environment and are also a rich and valuable source of local knowledge. Farmers are therefore key stakeholders in the catchment management process.

# 3 Managing the water environment

## 3.1 Roles and responsibilities

The roles and responsibilities associated with managing the water environment across the UK have changed dramatically over the years, with professionals now recognising that a multidisciplinary approach is required. The European Environment Agency (EEA - http://www.eea.europa.eu/) is a part of the EU which works closely with the national environment agencies from cooperating countries. The Department for Environment Food and Rural Affairs (Defra - www.defra.gov.uk) is a division in the UK Government which is responsible for the protection of the natural environment and sustainable development. In England, Defra has appointed the Environment Agency (www.environment-agency.gov.uk) to lead on regulating rivers, contaminated land, water quality and the conservation of fish and ecology. SEPA, Natural Resources Wales and the Northern Ireland Environment Agency are the equivalent for the rest of the UK. Despite being the overarching statutory bodies, they all still work in close collaboration with other relevant authorities and organisations on a local level.

On a catchment scale, roles and responsibilities depend on whether flood risk or wider catchment issues are of question. Due to past events and potential impacts on people, property and infrastructure, flood risk management is a key concern for the UK Government which is why there are a number of authorities and organisations collectively responsible, as shown in Figure 3.1 (again with England as an example but the same structure applies for the rest of the UK). The Environment Agency and Natural England are also primarily responsible for the management of the wider environment, including water quality monitoring and management, with support from other organisations.

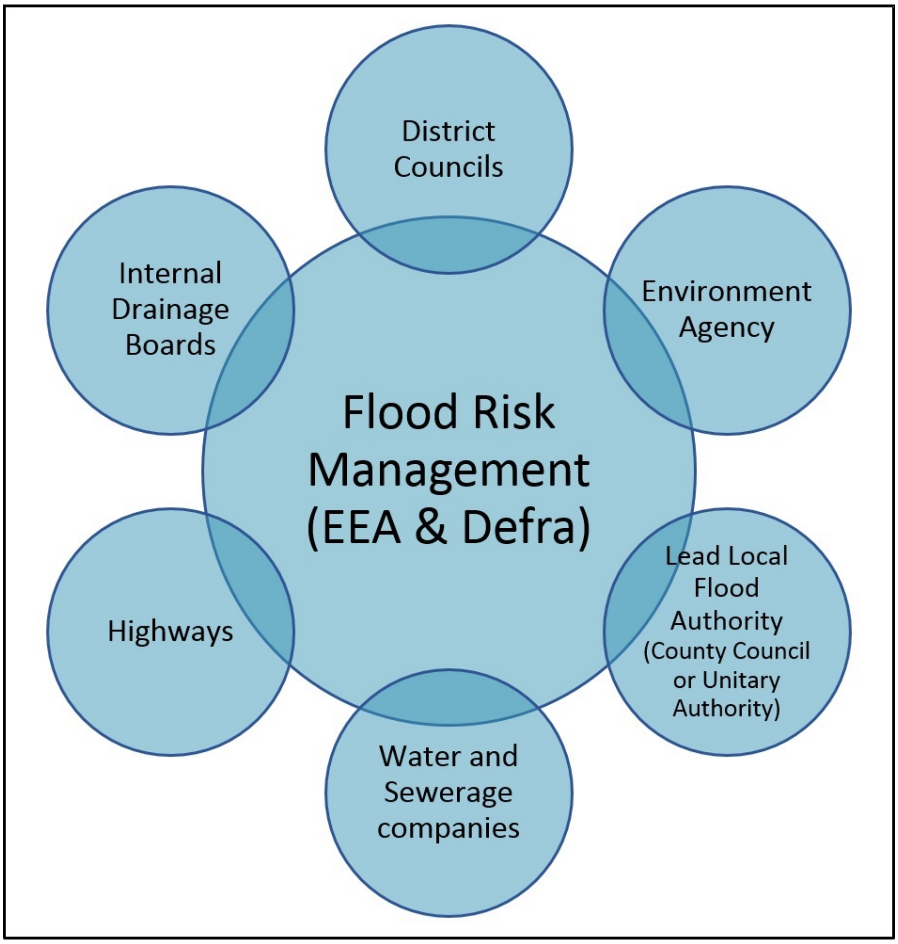



***Figure 3.1** – Organisations and authorities traditionally responsible for Flood Risk Management in England*
*(Source: Defra, 2014)*

Although they are not statutorily responsible, a wide range of local groups and organisations are now becoming increasingly involved in the flood risk and catchment management process, forming flood and catchment partnerships. For example, Rivers Trusts (case study in Section 3.5), National Parks, Wildlife Trusts and local community groups are all now key stakeholders, thus Figure 3.1 could potentially be extended.

**3.2 Overview of legislation, policies and frameworks (UK/EU)**

As outlined in previous sections of this ROCK, there are many natural and human-induced factors affecting the characteristics and response, as well as use of, catchments. Catchments must therefore be managed sustainably to ensure the water environment can be used and enjoyed by everyone now and generations to come.

The EU and UK Government often shape policies around environmental disasters which have been experienced, thus efforts are often reactive, particularly following widespread flood events. A well-known example is the 2007 Pitt Review (Pitt, 2008) which consulted with relevant stakeholders, including emergency responders and the public, to review experiences and the lessons to be learned from the UK 2007 summer floods. The report concluded a number of key statements and recommendations, highlighting how the UK should increase the public's awareness of flooding and be better prepared for future events, for example:

***"The review calls for urgent and fundamental changes in the way the country is adapting to the likelihood of more frequent and intense periods of heavy rainfall"*** Pitt, 2008 (Foreword).

***"The Government should give priority to both adaptation and mitigation in its programmes to help society cope with climate change"*** Pitt, 2008 (Recommendation 1).

***"The Environment Agency and the Met Office should work together, through a joint centre, to improve their technical capability to forecast, model and warn against all sources of flooding"*** Pitt, 2008 (Recommendation 6).

***"The Government should establish a programme to support and encourage individuals and communities to be better prepared and more self-reliant during emergencies"*** Pitt, 2008 (Recommendation 70).

Making Space for Water (Defra, 2005) carried out a similar earlier review in 2004 which concluded that the Government should develop a more comprehensive, holistic and integrated approach to flood risk management. Although they are not legislative, both reports have profoundly driven, shaped and reinforced how catchments have been managed over the past 10 years and still underpin choices made today.

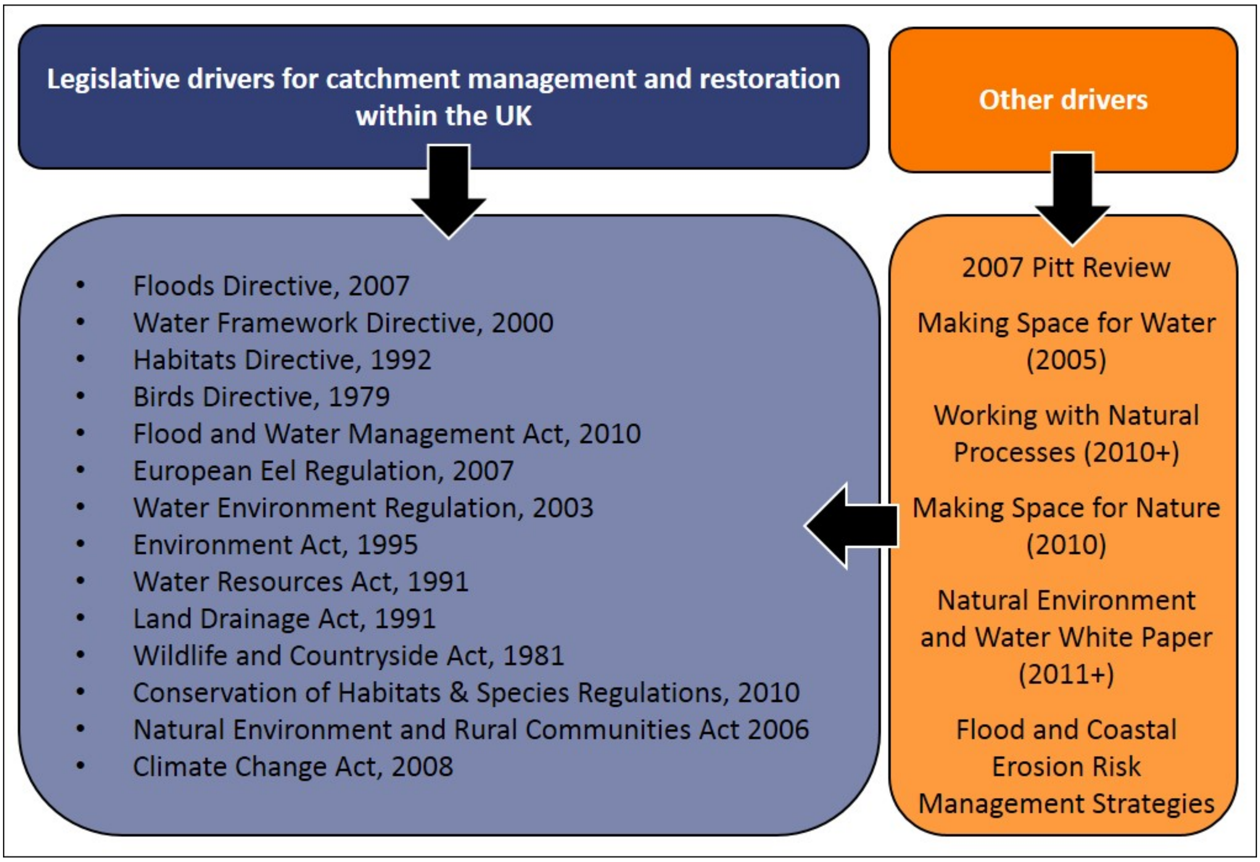



***Figure 3.2 –*** *The main drivers for catchment management (adapted from Barlow et al., 2014). Directives apply on an EU level and the remaining drivers/acts apply to England and Wales. Scotland and Northern Ireland have similar drivers in place e.g. Flood Risk Management (Scotland) Act 2009*

Several catchment-related legislative policies and frameworks are in place today across the UK (and the EU) which principally drive catchment management activities and set plausible targets. They span across the whole catchment management spectrum, supporting the management and conservation of floods, water quality, habitats, species and water as a resource to humans (with the main and current drivers listed in Figure 3.2). The EU Floods Directive and Water Framework Directive (WFD) drive most of the monitoring and catchment management activities within the UK whilst also complementing each other. They are also closely linked to more specific legislations, including the Nitrates Directive (1991), Groundwater Directive (2007) and the Bathing Water Directive (2006). The majority of the catchment issues detailed within Section 2.5 only hinder reaching targets set out by each of these laws. The two key Directives are described below:

**EU Floods Directive (2007/60/EC):** Published in 2007, this Directive requires members to assess all watercourses and coastlines, identify and map all areas at risk of flooding (from all sources) and quantify the risks to people and property. The development of flood risk management plans have been requested for each river basin to focus on flood prevention, preparation and preparedness (European Commission, 2014a). UK specific Acts reinforce this piece of legislation, particularly the Flood and Water Management Act 2009 in England and Wales, Flood Risk Management (Scotland) Act 2009 and the Water Environment Regulation (Northern Ireland) 2009. Flood-related legislation now emphasises the need to communicate flood risk with the public and ensure they also have access to flood risk information. Draft flood risk management plans have been created for individual river basins across the UK, setting out how flood risk will be managed until 2021. They are currently within a public consultation phase, with the final reports expected to be published by December 2015.

**EU Water Framework Directive (2000/60/EC):** This Directive came into force in 2000, as it was increasingly recognised that Europe's waters are under pressure from human activities and climate change. The WFD aims to prevent deterioration and ensure all European waters are at least in 'good condition', a classification which takes chemical, ecological and hydromorphological considerations into account. Similarly to the Floods Directive, the WFD aims to acquire public support and involvement and it also recognises that watercourses flow between different political boundaries (European Commission, 2014b). River Basin Management Plans have been created for individual river basins across the UK which document their current status and set targets in order to improve water quality.

It is clear that there has been and still are many different policies and frameworks in place which has left the catchment management process fragmented. Nevertheless, to some extent this has been recognised, and organisations are creating multi-partnership projects in order to tackle multiple issues, whilst providing multiple benefits. An example of this is the Environment Agency's 'Working with Natural Processes' Framework (Barlow *et al.*, 2014).

### 3.3 Traditional monitoring and data availability

In order to characterise river networks and corridors, identify sources and pathways, detect changes and relationships, achieve legislative targets, and provide catchment managers with confidence when trying to implement mitigation measures, various monitoring techniques can be performed. Traditionally, monitoring is carried out by professionals who have been trained to install and maintain instruments, download, process and analyse the data as well as utilise it for further and specific applications. This provides information on the quantity and the quality of the water environment and even if the parameters are being measured indirectly, it provides catchment managers with an indication of the behaviour and health of the water environment. However, as Herschy (2009) points out, good practice in catchment management is dependent on reliable and good quality data collected out in the field.

As expected, monitoring of catchment parameters has improved in line with technology, allowing lengthy datasets to be created for any measurable hydrological parameter. Historically, monitoring equipment could only be observed and recorded manually. Today instruments are capable of logging and storing data within the device itself, and if monitoring budgets allow, real-time data can be obtained remotely by means of a 'telemetry system' (Shaw *et al*., 2011). Telemetry systems transfer and receive data wirelessly which has radically improved the Met Office and the Environment Agency's ability to forecast extreme weather and floods, providing emergency responders and the public with the 'heads up'. It has also improved the UK's spatial coverage of monitoring equipment as devices can now be left to work in remote locations automatically that are difficult to access. Automated monitoring equipment also has the added benefit of being able to take a measurement as often as the user specifies, including temporal resolutions even finer than once every minute. Table 3.1 provides a few examples of equipment commonly used to monitor catchments. Furthermore, remotely sensed data from radar and satellite observations are now possible, providing a better appreciation of spatial variability in catchments.

There are records to suggest that rain gauges were first used in Korea in the 1400s AD (Shaw *et al*., 2011). Although many professionals and amateurs will have made their own observations over time, Bayliss and Reed (2001) and Kjeldsen *et al.* (2014) comment that generally systematic hydrological measurements and subsequent time series data is only available from around the 1850s in the UK, with the average record length being only 20-40 years. Water quality, morphology and habitat related monitoring networks are less established. There are national rainfall, weather and river level monitoring stations installed across the UK today, owned and operated by the Met Office, Environment Agency, SEPA, Natural Resources Wales and the Northern Ireland Environment Agency (Shaw *et al*., 2011). For instance, the Met Office (2014) now has over 200 automatic weather stations across the UK which are estimated to be approximately 40km apart (see map in Figure 3.3). The National River Flow Archive (NRFA - http://www.ceh.ac.uk/data/nrfa/) also holds data obtained from more than 1500 UK hydrometric gauging stations. However, looking at the density of the national monitoring networks, they still fail to characterise each unique catchment on a local level. There are some dense, nested and multi-scale monitoring hydrometric networks installed but these are usually associated with research projects similar to Defra's 'Demonstration Test Catchments' (DTCs) (Owen *et al*., 2012) and may not be maintained once funds terminate.

Despite the advantages of modern fieldwork techniques, the equipment is expensive to buy and maintain and monitoring stations only represent a single point on the Earth's surface which does not represent natural variability. Users must also be trained and have the relevant computer skills and software to operate them. Monitoring equipment is subject to vandalism and theft, particularly if solar panels are on display. Also, given that individual catchments are extremely variable, monitoring is required on a local level if the data (thus evidence) is expected to inform management decisions.

| Traditional monitoring equipment | |
|---|---|
| <br>**Rain gauge:** a tipping bucket rain gauge is being programmed to measure rainfall every 2 minutes. | <br>**Water level recorder:** measures temperature and pressure which converts into water level. |
| <br>**Logger box:** telemetry system which uses a 'machine to machine' (M2M) data SIM card to transmit and receive data via the internet. | <br>**Solar panel:** often used to power hydrometric networks, in this example an impress pressure transducer (water level recorder). |
| <br>**Water quality monitoring hut:** built to house automatic water quality monitoring kit on site. | <br>**Weather station:** an automatic weather station monitoring many parameters e.g. wind speed |

***Table 3.1*** *– Examples of traditional monitoring equipment used to characterise and quantify the water environment*
*(photos by Eleanor Starkey).*

A cost-benefit analysis is often used to determine whether it is necessary to install and run a monitoring site (Herschy, 2009; Shaw *et al.*, 2011), therefore small rural catchments often fall short.

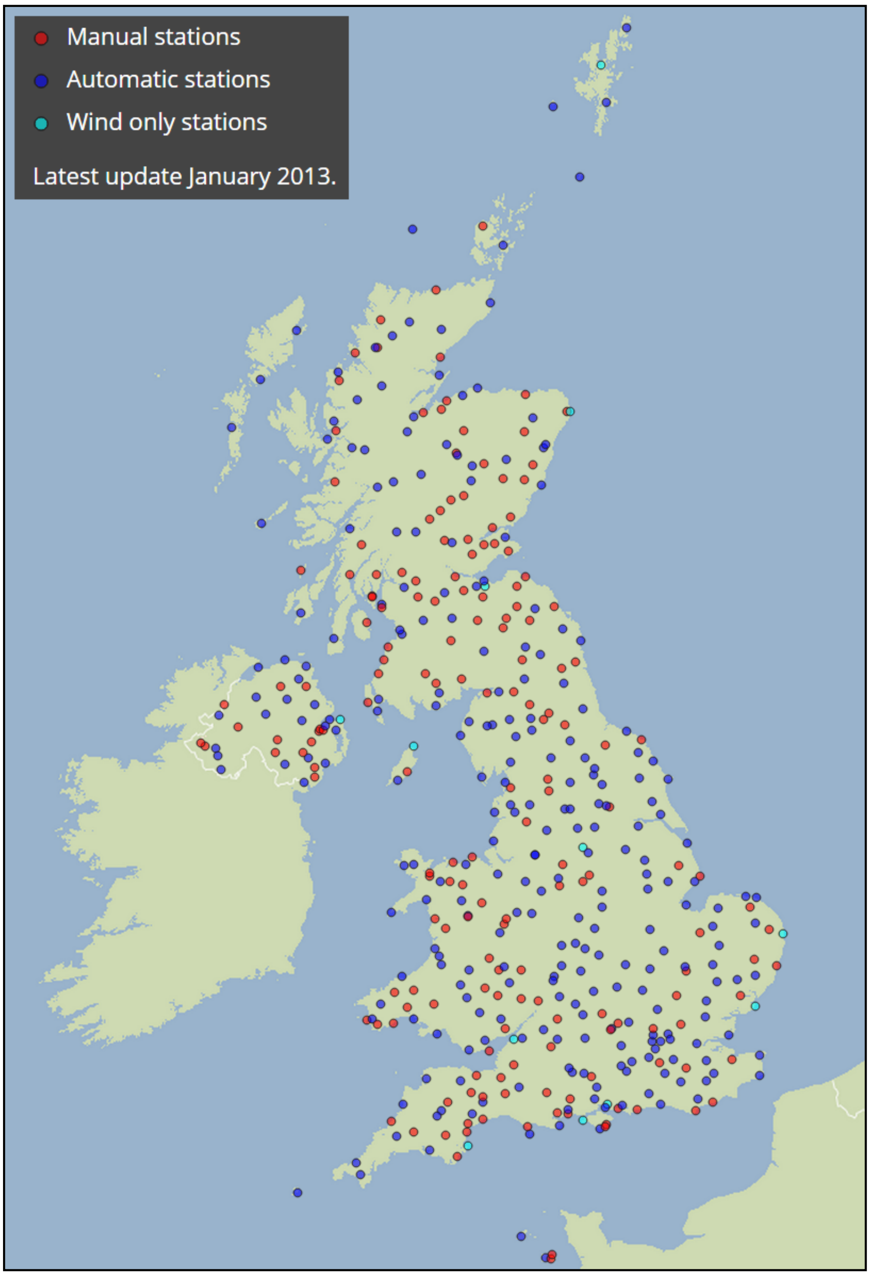



***Figure 3.3 –*** *Map showing the Met Office's automatic network of weather stations (blue dots). Note that red dots represent manual stations which are operated by volunteers (Source: Met Office, 2014)*

Although legislative frameworks now require that the public should be better informed about catchment related issues, and open Government data licences have been introduced, hydrometric datasets are still not readily available to the public or for commercial purposes. This also applies to researchers to some extent as it is often a lengthy process to find out what data is available and to obtain copies, which themselves are restricted by copyright laws. Professionals are monitoring and using the data in isolation; many communities are simply unaware that there may be a hydrometric monitoring network in close proximity to their homes.

**3.4 Disseminating and communicating catchments to the public**

Following Pitt's (2008) set of recommendations to the UK Government that the public should be made more aware of flooding and also self-reliant during an event, significant efforts have been made to ensure a number of information sharing tools and services are now available. Classic examples include:

- **"*Know your flood risk*" campaign:** The Environment Agency are currently raising awareness and encouraging the public to find out whether they live or work within a flood risk area (see example in Figure 3.4). This includes further efforts to inform communities who are identified as being at risk during flash flood events.

- **"What's in your back yard":** an Environment Agency mapping portal which allows the public to search for environmental information in their own area. For example, river and sea levels are available which are graphed online in real-time and are also linked to social media (see Figure 3.5). Equivalent organisations have similar facilities available in Scotland, Wales and Northern Ireland.

- **Flood forecasting and warning:** The Environment Agency, SEPA, Natural Resources Wales and Environment Agency (Northern Ireland) now push flood warnings out to the public once river levels reach a certain trigger level or when there is a significant risk to life. These services are usually limited to the major watercourses where the telemetered equipment is installed.

- **Met Office National Severe Weather Warning Service:** Warnings and alerts are issued to the public when severe or hazardous wind, rain, snow, fog or ice conditions are expected up to five days ahead.

- **Flood alleviation schemes:** Public drop-in sessions are organised to share plans with the local community. This gives the public a chance to understand flood risk within their local area and how it will be mitigated.


***Figure 3.4*** *– Examples of public engagement material used by the Environment Agency to raise flood risk awareness*

*(Source: Environment Agency, 2014)*

Communities are certainly playing a much greater role in the flood risk management process today, even if it is just engaging and learning about flooding through social media. However, being led by statutory organisations themselves, the approaches listed within this section still entail a 'top-down' approach. Despite the importance of catchment connectivity, local communities are still not encouraged to consider wider catchment issues and solutions beyond their back yard. Rivers Trusts on the other hand are encouraging and enabling the public to explore their local water environment for the first time, as Section 3.5 details.

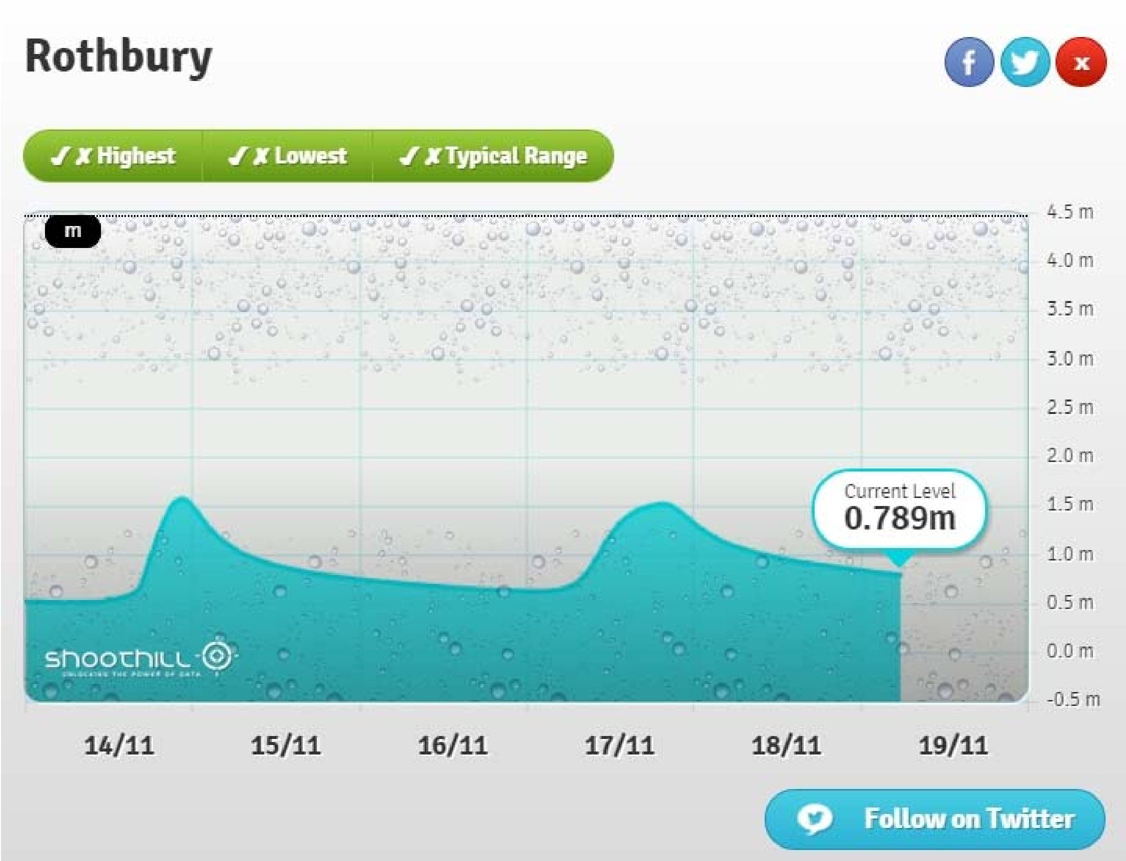



***Figure 3.5 –*** *Example of live river level information available online to the public*

*(Source: Shoothill, 2014)*

**3.5 Case study: Global Thinking, Local Action – The Rivers Trust**

Established in 2001 and renamed in 2011, The Rivers Trust is a registered environmental charity representing a network of Rivers Trusts that work on a local level within individual catchments. They promote sustainable and holistic approaches to catchment management, with great emphasis on engaging, educating and actively working with members of the public and supporting community-based restoration projects (The Rivers Trust, 2014b).

There are catchment-based River Trusts across England and Wales, River and Fisheries Trusts of Scotland and the Ballinderry River Enhancement Association in Northern Ireland. Tyne River Trust for instance is based in North East England. With projects focussed around habitat, wildlife and water quality improvement works (as Figure 3.6 exemplifies) from source to outlet within the Tyne Catchment, Tyne Rivers Trust is dedicated to involve local communities every step of the way. Input from local land owners, farmers and other interested individuals in the form of local knowledge is *extremely valuable* and at the same time, by being involved they are also increasing their own knowledge of the water environment on a catchment scale.

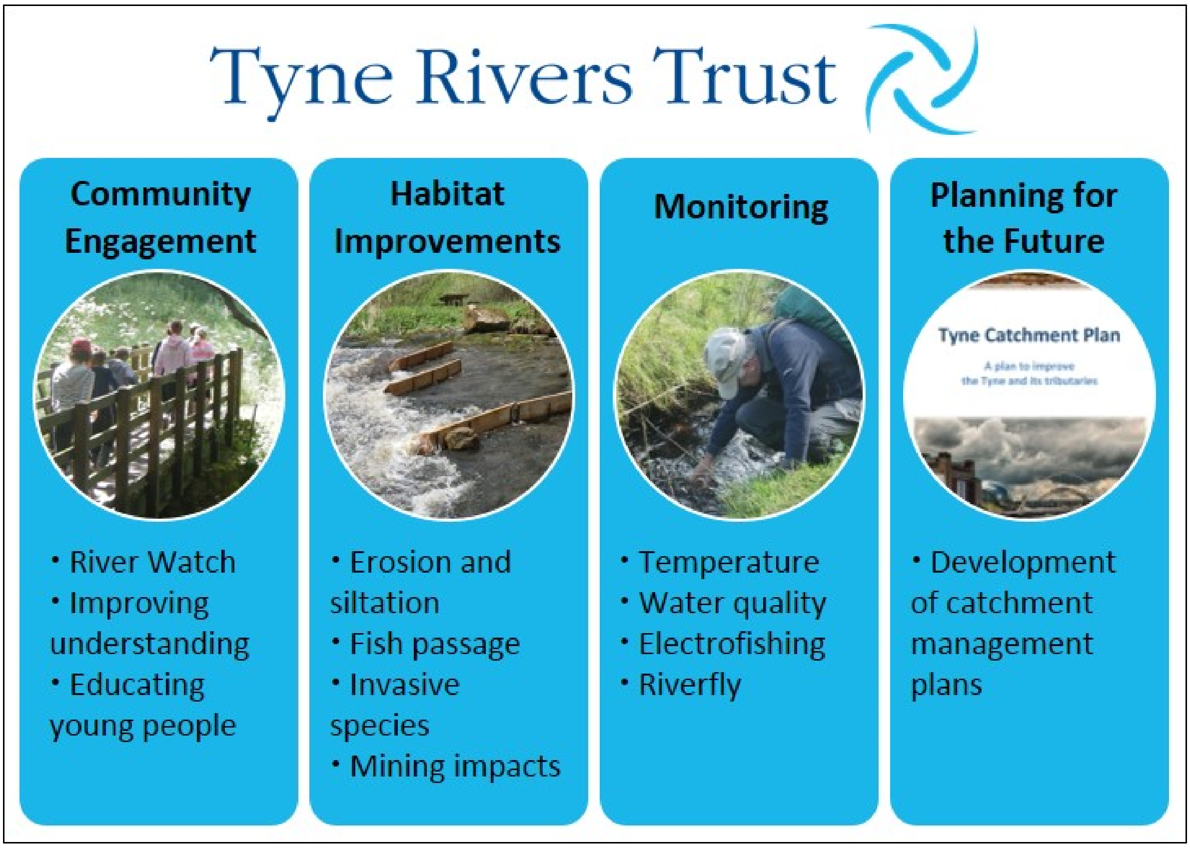



***Figure 3.6*** *– Tyne Rivers Trust's key areas of work, including community engagement (see Tyne Rivers Trust, 2014) which are common across all local Rivers Trusts.*

# 4 A new direction: integrated catchment management

## 4.1 Coupled human and natural systems

It is well established that there are multiple and complex catchment issues, both the land and water are connected and that catchments are influenced by both human activities and natural processes. Together with publically led debates following recent flood events, the EU and UK catchment-based policies are encouraging stakeholder participation, including the general public. By considering all of these drivers, catchment management is becoming progressively integrated. Today catchment management, particularly flood risk, is therefore becoming more 'people-centred' and social scientists are starting to work in collaboration with catchment scientists and engineers (O'Connell and O'Donnell, 2014). This holistic approach permits the catchment management process to rest more uniformly across the social, economic and environmental aspects of sustainability. O'Connell and O'Donnell (2014) point out that stakeholders are required because they live within, and are affect by catchment (flood) issues and discuss the concept of 'coupled human and natural systems'. To further refine this concept, Sivapalan *et al.* (2012) and Di Baldassarre *et al*. (2012) introduce the term 'socio-hydrology' in the context of floods, stating that almost one billion people live on a floodplain and so humans and nature have notably co-evolved with each other over time. They conclude that humans are now part of the water cycle and should not be isolated from the management process.

### 4.2 Bottom-up philosophy: the Catchment Based Approach (CaBA)

Although the EU WFD was launched back in 2000, the first cycle of River Basin Management Plans produced in the UK were deemed inadequate. It was concluded that there were limited efforts to include all relevant stakeholders, there was limited flexibility on a local level and that catchment management was far too broad scale. Funded by Defra and the Environment Agency, the 'Catchment Based Approach' (CaBA) was subsequently launched in 2011, a new approach which fundamentally (Defra, 2013):

- Recognises the need for an integrated approach to catchment management and for multiple benefits to be achieved;
- Encourages people to think locally, yet catchment wide, in order to meet the requirements of national and international standards;
- Identifies what really matters on a local level;
- Promotes the development of innovative and holistic catchment management measures and the sharing of best practice;
- Calls for greater partnership and stakeholder engagement – an integration of people who have a shared interest in the water environment;
- Ensures communities are more informed about their local water environment, are engaged to preserve and improve the status of their catchment, take ownership of the issues around them (sense of empowerment) and support the delivery of local measures.

The latter point is by far the most essential aspect of CaBA which Defra (2013) hopes will support transparent and shared decision making as well as achieve multiple benefits in order to improve the quality of the water environment. Public participation also supports the delivery of the many drivers listed in Figure 3.2.

Twenty-five CaBA pilot projects were launched on the ground in May 2011 which were then evaluated in early 2013. So much interest was shown by organisations wanting to host the pilots that Defra awarded a small sum of money (£5k) to a further 41 smaller pilot catchments to initiate the catchment-based approach. It was agreed that these additional pilot catchments would report progress in January 2013, although they did not form part of the formal evaluation. Pilot catchments were set up to test the viability of CaBA whilst developing best practice (Defra, 2013). A team led by Cascade Consulting evaluated the pilot phase on behalf of Defra which established that there are no blueprints for the CaBA process; each catchment has its own set of circumstances and priorities which local stakeholders need to identify (Cascade Consulting, 2013; Corbelli, 2013). However, the evaluation has highlighted best practice, informed the development of CaBA and provided an abundant set of case studies. Cascade Consulting's evaluation confirmed that it was widely agreed CaBA pilot projects were successful and worthwhile, presenting a strong case for wider adoption. It has highlighted a number of useful methodologies and tools which can assist stakeholders to, for example, identify what is important within a catchment, how to effectively engage with the public and what type of catchment data is required. Some pilots also emphasised how important it is to identify existing groups of people in a catchment who are already up and running in order to stimulate effective collaboration (Cascade Consulting, 2013).

CaBA was fully rolled out in June 2013. Being a ‘catchment-based’ approach, this meant that England’s 10 river basins suddenly became approximately 80 individual hydrological catchments in which the CaBA would be applied. For instance, the Humber River Basin was divided into 15 catchments (as illustrated in Figure 4.1) which would drastically support a commitment to localism.

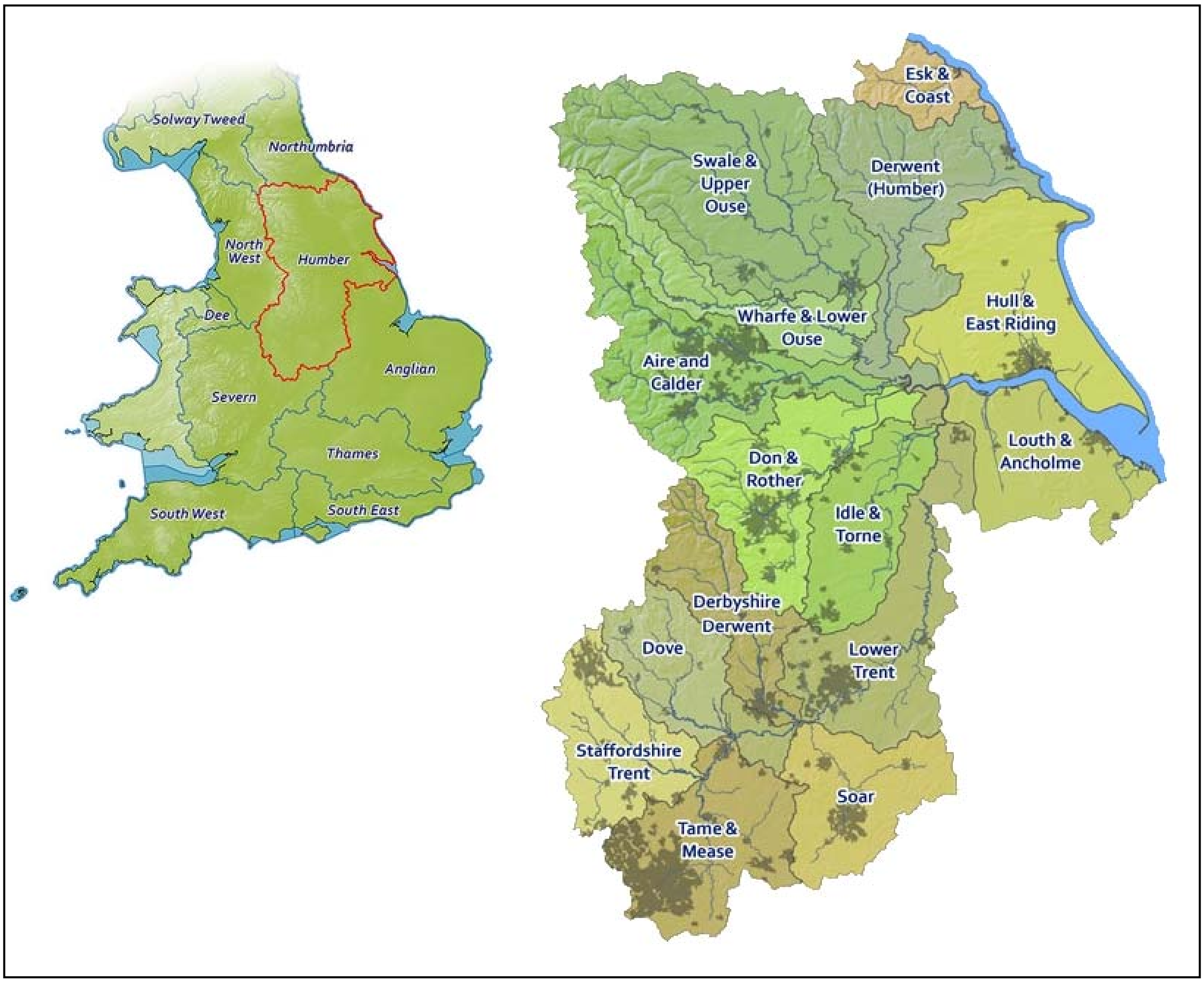



***Figure 4.1 –*** *Humber River Basin (in the left UK map) which has been split into 15 catchments as part of CaBA (right map)*
*(Source: CaBA, 2014)*

An online CaBA forum was set up (catchmentbasedapproach.net) to allow those involved in the CaBA, and wider catchment management process, to post topics, communicate with other organisations and individuals, upload material and view information. The site primarily aims to support those involved in the CaBA and share best practice. In conjunction with CaBA, the Catchment Change Management Hub (http://ccmhub.net) was developed and launched to provide catchment stakeholders and members of the public with a central place to find, share and comment on catchment information. It has been designed carefully (taking stakeholder feedback into consideration) in order to cater for different audiences, with some users commenting (Black, 2013):

***"I'm a visual person and I really like all the photos and the interactive stuff"***
***"The language isn't patronising"***
***"It's a great idea to have a repository to enable everyone to take action"***

As stakeholder collaboration grows and members of the public become increasingly involved in the catchment management sector, co-production and collective use of tools and material will be essential, as will the involvement of social scientists.

Despite increased requirements for public participation, it can be a challenge to engage with local communities successfully and sustainably. It is imperative that involvement is open to anyone across the community, that their time and efforts are valued and that they too benefit from, rather than become exploited during, the participatory process. Engagement, training, tools, creativity and continuous feedback are required to ensure the public do not become disinterested with time. Varying (and sometimes contrasting) levels of understanding, expectations, attitudes and perspectives of the public within each catchment must also be managed carefully. Public engagement and participation therefore opens up new set of skills which catchment scientists and engineers increasingly require to support the delivery of CaBA and other catchment-based drivers.

**4.3 Evidence-based Catchment Management**

Catchment management activities must be underpinned by robust and reliable evidence-based science. This will provide catchment managers and relevant stakeholders with confidence that they are implementing cost-effect measures and are prioritising those returning multiple benefits. The need for quantitative evidence stems from evidence-based policies and frameworks such as CaBA and the WFD. More recently, the Chartered Institution of Water and Environmental Management (CIWEM) held a conference at the University of London in September 2014, with focus on 'evidence requirements' in the field of Natural Flood Management (NFM – see Section 4.4. for further details on this). It was notable that there are a number of catchment restoration projects being carried out across the UK but in order to implement new and innovative approaches and subsequently share best practice, rigorous evidence is required to determine how effective they are. Most conference speakers concluded that measurable evidence is exceptionally valuable, that long term datasets are required at a catchment scale and that monitoring must continue into the future. The Environment Agency has also recently launched their latest 'research and development framework' (Barlow *et al*., 2014) which is again heavily leaned towards ensuring evidence-based science is available to support decision making. To add to this, reliable evidence is also necessary to provide local residents and land owners with confidence that catchment management techniques proposed are viable and worthwhile.

Although there are national networks monitoring the water environment and a number of short-term networks installed for detailed research purposes, such as the DTCs (Owen *et al*., 2012), many of the smaller and more rural catchments have little historic and contemporary datasets available. This is problematic if evidence is required to support management measures on a local level. This is when engagement with the local community and transfer of *local knowledge* becomes extremely valuable, providing 'evidence' in new formats which scientists are less familiar with as opposed to traditional quantitative information.

## 4.4 Natural Flood Management (NFM)

River, coastal and tidal flooding (and erosion) has traditionally been managed and the risks reduced through the use of 'hard' engineering techniques. This has involved building man-made structures which are designed to separate and retain flood water from properties and infrastructure. Techniques include building barriers, dams, walls and revetments and in many populated areas, bank straightening and stabilisation. This has led to various large engineering projects; for instance the Thames Barrier (Figure 4.2) is one of the largest moving flood barriers in the world, which has significantly reduced the likelihood of tidal flooding to Central London. Spanning 520 meters across the River Thames, the barrier cost £500 million to build, consists of 10 heavy steel gates (Environment Agency, 2012a) and requires an extensive amount of ongoing monitoring, testing and repair work to prevent failure in the future.

Although hard engineering solutions typically offer high standards of protection, it is being increasingly acknowledged that they:

- Offer very little or no benefits to other environmental Directives, Acts and Frameworks, thus they do not usually provide multiple benefits or integrated and sustainable solutions to the wider river corridor;
- Are expensive to build, maintain, monitor and repair, while risks associated with failure will always remain;
- Are known to 'pass on' the problem downstream or downdrift, interfere with natural processes and negatively impact biodiversity;
- Are not regarded as a cost-effective solution for areas with a low number of properties at risk of flooding (villages and small towns);
- Provide very little opportunities for stakeholders, especially the public, to become involved in the management process as efforts and confidence are focussed on the engineers.

***Figure 4.2 –*** *Thames Barrier was built in 1982 in the Woolwich area to protect London from tidal surges*
*(Source: Environment Agency, 2012a)*

Natural Flood Management (NFM) has emerged over recent years as an innovative way of managing multiple catchment issues. There are various definitions used to describe NFM; SEPA (2012) defines NFM as:

*"A suite of measures used to manage flood risk which includes a range of techniques that aim to work with natural hydrological and morphological processes to manage the sources and pathways of floodwaters."*

NFM alters, restores and/or uses the landscape features (Wentworth, 2011) by working with natural processes (rather than against), which therefore categorise it as a 'soft' or 'green' engineering approach to flood risk management. The main philosophy of NFM is to hold back (attenuate) and store flood water until the peak of the event has subsided, reducing the river networks velocity, which in turn decreases its erosive power and ability to transport debris. Reviews, Directives, Acts and Frameworks (Figure 3.2) have all contributed to the growth in development and use of NFM because they all commonly request i) greater working with natural processes ii) adoption of innovative solutions on a catchment and local scale iii) management of future flood risk (climate change).

Flood risk is not necessarily the overarching issue at every site. As the Environment Agency rightly points out (Barlow *et al*., 2014), 'working with natural processes' (WwNP) can entail management methods which secure and improve biodiversity, water quality and sediment systems too, as well as NFM.

Table 4.1 provides some examples of innovative NFM (and wider WwNP) features which have been implemented within the UK. It is also important to note that techniques and names of features often vary between catchment as they are very much a site-specific intervention which is tailored to the combination of properties, processes and activities present at the location of interest. The Belford Burn NFM pilot in Northumberland is also described in Section 4.5, providing an excellent example of how soft engineering can provide multiple benefits in a smaller and more rural catchment.

Although NFM and wider WwNP techniques have been adopted across the UK to date, there are still big challenges associated with implementing this approach sustainably (SEPA, 2012). This is primarily because of:

- The absence of reliable data (evidence) which can be used to quantify and predict how effective these approaches are at a catchment scale;
- Getting land owners and other stakeholders on board and to appreciate the benefits of NFM;
- Who should makes space for, pay and maintain features in the future.

| | |
|---|---|
| <br>‘Slowing the flow’ – Pickering, North Yorkshire<br>(Forestry Commission, 2014) | The town of Pickering is vulnerable to flash flood events. ‘Soft’ techniques have been introduced to assist with storing and slowing the flow higher up in the catchment. Techniques include woody debris, flood storage bunds and creation of floodplain woodlands..<br>Community involvement has been the key to the project’s success. |
| <br>Bowmont Catchment - Scottish Borders<br>(Wilkinson *et al*., 2014) | NFM measures have been installed in the Bowmont catchment to capture the sediment, protect the riverbank from erosion and store water on the floodplains during flood events. An example includes ‘log jams’ which work with natural processes to trap sediment, reduce erosion and improve habitats. Local land owners were key stakeholders. |
| <br>Littlehaven Beach – South Tyneside<br>(South Tyneside Council, 2014) | To protect against coastal erosion and flooding, South Tyneside Council encouraged ‘managed retreat’ along the South Shields coastline. An attractive promenade was built for locals and tourists whilst the beach was widened by 50m. Previous coastal defences were deteriorating so locals welcomed the works. |

***Table 4.1 –*** *Examples of Natural Flood Management features (Working with natural processes) which are now regarded as innovative and holistic catchment management measures.*

**4.5 Case study (1): Belford Burn NFM scheme, Northumberland**

The Belford Burn catchment in Northumberland is a small 5.7km$^2$ predominantly rural catchment which has historically and more recently been flooded (Wilkinson *et al*., 2010). Flooding affected properties, businesses and infrastructure in at least 1997, 2002, 2005 and 2007. Due to the low number of properties officially at risk, it is not cost effective to implement traditional ‘hard’ flood defences such as flood walls and the village did not qualify for a national Environment Agency flood defence scheme.

As part of a research pilot study led by Newcastle University and the Environment Agency, the Belford Burn catchment has become a UK NFM demonstration site, with a whole raft of low-cost features now installed. Described as runoff attenuation features (RAFs), a number of strategically placed soft engineered features were constructed within the landscape to intercept, store, slow down and filter flood water at source to reduce flood peaks and improve water quality (Wilkinson *et al*., 2008; Wilkinson *et* al., 2010; Barber and Quinn, 2012). RAFs included bunds, drain barriers, runoff storage features (ponds), woody debris dams, buffer strip management, planting vegetation and willow barriers (see Figure 4.3 for exemplars). NFM features have been designed to release flood water slowly and are therefore temporarily activated features which only react following heavy rainfall.

Prior to the pilot project, there was no traditional monitoring equipment in the catchment, therefore a network of instruments were placed upstream, within and downstream of RAF features to try to quantify their performance. Data was also required to characterise the local hydrology and locate problematic sub-catchments. Through engagement workshops, residents and local land owners also viewed evidence to see how their local water environment was reacting to the features, with Wilkinson *et al*. (2008) emphasising how important it is to have stakeholder involvement and feedback. Evidence suggests that the RAFs have been effective at storing and slowing water down, significantly reducing the travel time of the flood peak, supporting biodiversity and improving water quality.

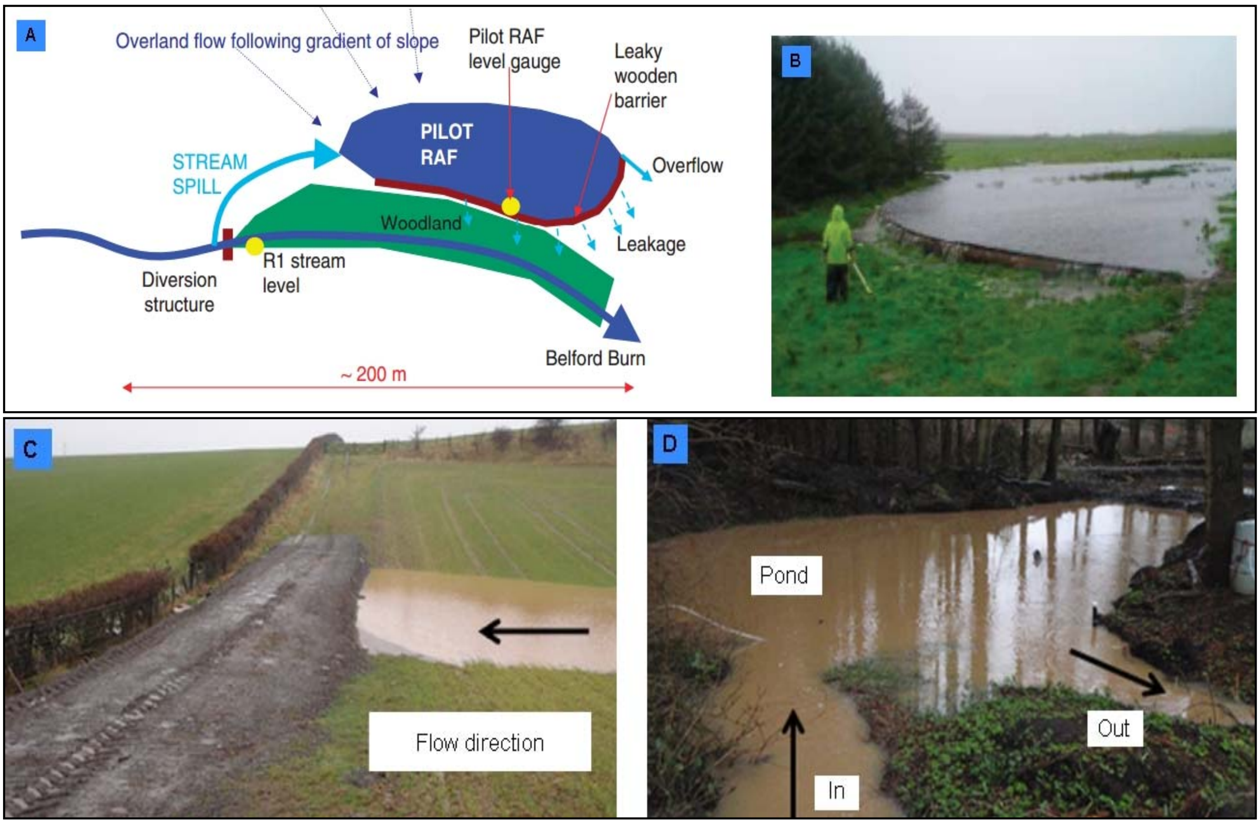



*Figure 4.3 – Natural flood management features installed in the Belford Burn catchment: (a) general RAF schematic (b) example of a RAF (c) example of a field bund (d) example of a storage pond (Source: Wilkinson et al., 2008; Wilkinson et al., 2010; Barber and Quinn, 2012). Project website: https://research.ncl.ac.uk/proactive/belford/*

**4.6 Case study (2): Taking responsibility on a local level – Community Flood Plans**

In an attempt increase flood risk awareness and to ensure people are more prepared and self-reliant during a flood event (as recommended by Pitt (2008)), many communities now have a community flood plan in place. These plans have been created in different ways, some of which have been produced entirely by the community themselves, others have had guidance and support from the Environment Agency, SEPA, flood forums or flooding partnerships. As the name suggests, flood plans aim to assist communities with planning for a potential flood event, but more specifically they ensure that communities (Environment Agency, 2012b):

- Understand different sources of flooding, national flood warning systems and which organisations respond during an event;
- Know which areas in their community are at risk;
- Have planned and are equipped for a flood event;
- Are able to respond effectively and minimise any impacts;
- Have designated flood wardens (volunteers) in place who can assist with helping others and can be contacted during a flood;
- Have a list of useful contact numbers – both members of the community and emergency responders;
- Consider practicing for a flood event.

The village of Acomb (Northumberland) provides an excellent case study where the local community has recently implemented a community flood plan. The village has been affected by river and surface water flooding over recent years, including during the summer of 2012. Driven by an existing community group, ‘Action 4 Acomb’, this small community now has a flood plan coordinator, a lead flood warden and at least 12 flood wardens in place. These volunteers are responsible for a designated area of the village, monitoring weather and flood forecasts, communicating flood risk to the wider community (see poster in Figure 4.4), reporting flooding to relevant organisations, checking for blockages and making flood related observations. Through questionnaires, Action 4 Acomb have also liaised closely with the wider community to receive feedback on the flood plan. This flood plan means that people are now understanding flood risk on a personal level.

Community flood plans are another example how local communities are becoming more involved in the catchment management process. It also encourages the community to build relationships and communicate between different stakeholders.

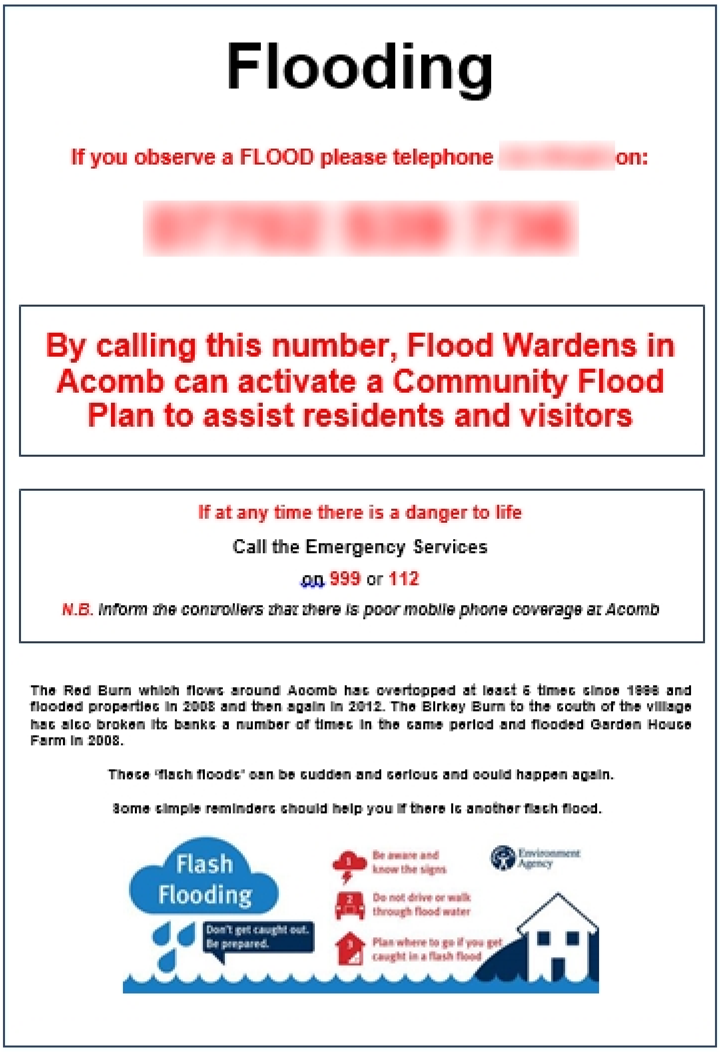



***Figure 4.4.*** *– A poster used by flood wardens in Acomb (Northumberland) to raise the wider community’s awareness*
*(Source: courtesy of Action 4 Acomb)*

## 5 Monitoring by communities: a citizen science approach

### 5.1 Defining citizen science

Citizen science is the modern day term used to describe the process when members of the public perform research design, data collection, sharing of knowledge and/or analysis activities alongside professional scientists (Buytaert *et al.*, 2014). Wentworth (2014) states that citizen scientists support trained scientists to answer real-world environmental issues because scientists can never do this alone due to the sheer scales and complexities involved. This co-production of knowledge is currently opening up a whole new array of innovative opportunities for scientific research projects and is extremely relevant across most environmental disciplines (Socientize Consortium, 2013).

The process of recruiting and encouraging volunteers to support environmental monitoring schemes is not a new phenomenon. For instance, Charles Darwin was not trained as a scientist himself and he also relied on data collected by volunteers to emerge his theory of evolution by natural selection in the 19$^{th}$ Century (Science Communication Unit, University of the West of England, 2013). A social scientist, Alan Irwin, introduced the term citizen science in 1995 (Irwin, 1995), yet it was only entered into the Oxford English Dictionary in June 2014. Some projects do not necessarily categorise themselves as 'citizen science'; instead terms such as 'community-based', 'participatory' or 'crowd-sourced' are often used (Buytaert *et al.*, 2014). Various definitions have emerged simply because there are different types of citizen science projects active with varying levels of involvement. Haklay (2012) has produced a framework which categorises citizen science based on the level of engagement and involvement (Figure 5.1). Citizen science projects can also occur on a range of scales, from individual local efforts to national and even global scales (Socientize Consortium, 2013). Furthermore, activities may be designed and driven by different groups of people and occur for varying lengths of time (Socientize Consortium, 2014). Although public involvement and the co-production of environmental knowledge is not a new occurrence, evolving technology, tools and communication facilities has meant that it has grown massively over the last few years. Smart phones, social media, apps, crowd sourcing and wireless data connections allow citizen scientists (through mass participation) to submit data anywhere, at any time and about any topic.

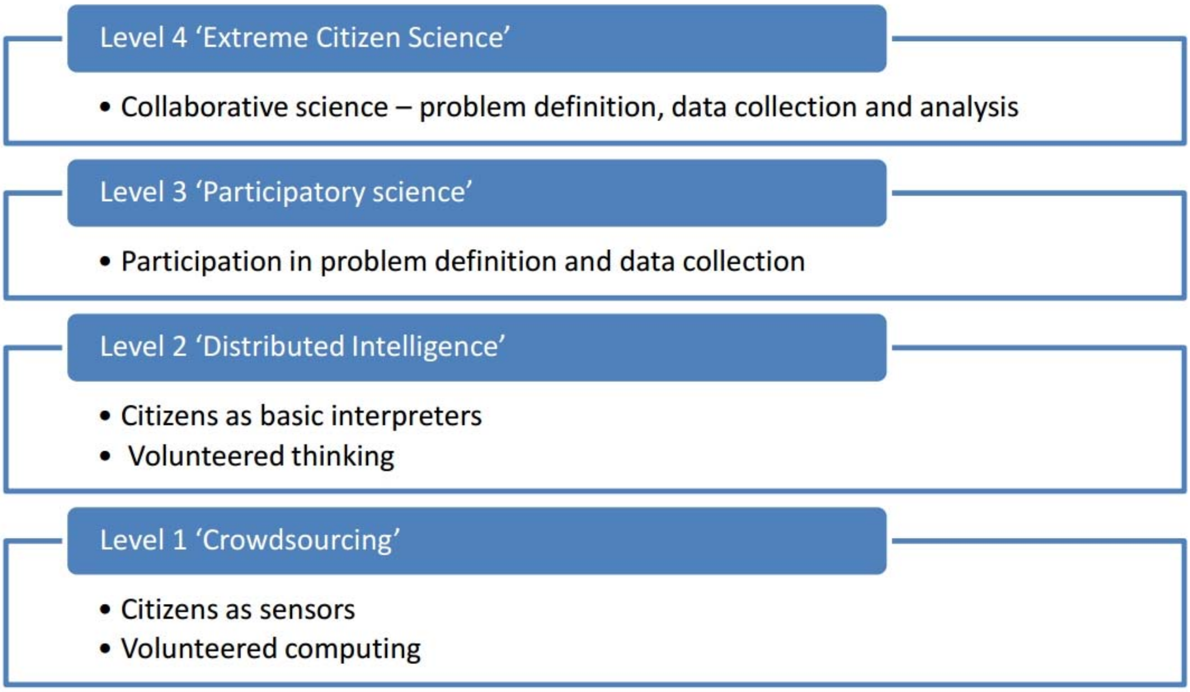



***Figure 5.1. –*** *A framework which Haklay (2012) uses to define citizen science based on engagement and involvement levels.*

To date, modern citizen science has largely supported natural or environmental disciplines due to the importance of the environment to people, because people are interested in conserving their environment more than ever before and because it helps to deliver change on a local level (Winfield, 2014). Citizen science has also been used for more high profile applications, for example, a media article written by Stout (2014) compliments citizen scientist efforts when they assisted with tracking the missing Malaysian aircraft in March 2014. They analysed satellite images and submitted information using social media applications.

Despite its growing popularity, citizen science has also raised a number of challenges and barriers, particularly relating to the scientific value of information obtained by citizen scientists and how far it can really support traditional scientists to solve real-world applications. It also means that scientists need to start thinking on a multidisciplinary level, collaborate with, for example, social scientists and develop new scientific cultures.

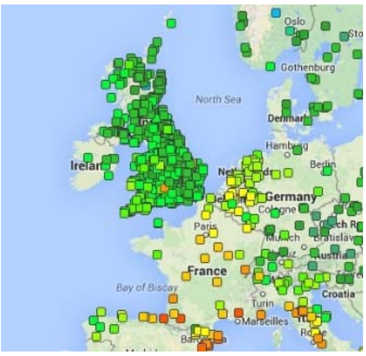
**5.2 The rise in citizen science for environmental monitoring schemes**

Volunteers have assisted bird watching and other wildlife monitoring programmes since the 1900s. For example, the Christmas Bird Count is one of the longest running surveys which attracts thousands of volunteers each year in North America (Science Communication Unit, University of the West of England, 2013). Following a digital revolution, citizen science has spread across various environmental disciplines, particularly those which are interested in detecting patterns, species and change over time and across a wide area. Citizen scientists can also use the internet and smartphones to submit their observations almost immediately. Real-time observations sourced from citizen scientists have therefore also supported environmental hazards and disasters, notably:

- Aulov and Halem (2012) describe how humans were used as a real-time solution to the collection of useful data during the Deep Water Horizon oil spill disaster within the Gulf of Mexico in 2010. Images posted by members of the public on Flickr, an online image and video sharing site, were used to determine the extent of the oil spill and forecast movement. Humans are essentially the ‘sensor’ collecting information;

- Stone *et al*. (2014) evaluates the success of a community-based monitoring scheme which involves local citizens collecting scientific data around a volcano in Ecuador. This network of volunteers and their observations significantly reduces the risks associated with local volcanic eruptions, acts as a communication channel, enhances preparedness prior to an eruption and thus provides their own early warning system;

- The US Geological Survey has developed a Twitter Earthquake Detection (‘TED’) system which gathers real-time tweets (containing specific words and with locational information attached to them) from members of the public to help improve earthquake response (Aulov and Halem, 2012).

| Citizen science project | Description |
|---|---|
| **OPAL surveys**  | The Open Air Laboratories network encourages UK citizen scientists to take part in ongoing tree, bug, climate, biodiversity, water, air and soil surveys. Project outcomes are focused around the educational values of participation. (www.opalexplorenature.org/surveys) |
| **Fluker Post Project**  | This simple citizen science scheme in Australia encourages any member of the public to take and submit a photograph of a fixed point (at a Fluker Post) as they walk past to assist Land Managers with on-going environmental issues and to detect changes over time. (www.flukerpost.com/) |
| **Met Office WOW**   | Supported by the UK's Department for Education, the Met Office launched a 'Weather Observation Website' in 2011 which encourages ordinary people to submit weather measurements, descriptions and photographs to a shared website. The facility is now used worldwide, with more than 38 million observations being submitted within the first year (http://wow.metoffice.gov.uk/). |
| **Creek Watch**   | Creek Watch is a crowdsourcing project in California which allows members of the public to submit simple data about their local watercourses using an iPhone app in order to tackle pollution issues. Data collected is fairly basic but it provides professionals with an indication of the water's health. (http://creekwatch.researchlabs.ibm.com/) |

| | |
|---|---|
| **CoCoRaHS** | The 'Community Collaborative Rain, Hail and Snow' monitoring network encourages volunteers to make precipitation observations in their back garden or local area using low cost measuring equipment across the US. The data is mapped online and is used for many applications and by many audiences, including schools, individuals and the National Weather Service. (www.cocorahs.org) |
| **Morpeth*Flood* and Toon*Flood***  | Newcastle University implemented a crowdsourcing approach to gather information from local residents following two severe flash flood events which occurred in North East England (Morpeth and Newcastle in 2008 and 2012). Data collected was used to reconstruct how the flood occurred, which later supported a flood defence scheme. (http://ceg-morpethflood.ncl.ac.uk/) |

***Table 5.1** – Examples of citizen science projects where information has/is being collected by the public about the weather and water environment.*

The public are increasingly becoming involved in monitoring the weather experienced and their local water environment. Drawing upon local, national and international case studies, examples can be found in Table 5.1.

The Haltwhistle Burn pilot (research) project provides a novel UK-based case study (Section 5.5) where citizen science has been introduced to support the catchment management process. Citizen science also has widespread potential in developing countries, where data are scarce and governance systems are often relatively poor (see the Ethiopian example in Section 5.6). In Tanzania, Gomani *et al*. (2010) detail how a low-cost approach provided local people with a sense of ownership in their catchment. Participatory approaches have been shown to provide distinct benefits in identification of local problems, selection of community-based indicators for monitoring purposes and development of management scenarios relevant to community concerns (Ridder and Pahl-Wostl, 2005). However, a lack of stakeholder capacity building and uninformed communities can result in inefficient resource utilisation (Tambudzai *et al*., 2013; Watanabe *et al*., 2014).

**5.3 Benefits, challenges and credibility of monitoring by communities**

When considering citizen science across wider environmental disciplines, it can offer a comprehensive range of benefits to scientists, research projects and communities themselves. The Socientize Consortium (2014) has recently released a White Paper on Citizen Science for Europe, highlighting the general benefits (see Figure 5.2).


***Figure 5.2 –*** *What citizen scientists are doing to traditional research projects (Source: Socientize Consortium, 2014)*

A number of authors have recently reviewed environmental citizen science and it is apparent that the benefits are becoming more widely recognised. Key benefits and capabilities associated with environmental monitoring by citizen scientists (with some specific examples related to catchment monitoring) are detailed below:

**Mass data collection:** although participation levels may vary between individuals, together citizen scientists have the potential to collect mass data over a wide area in a cost effective manner (Science Communication Unit, University of the West of England, 2013; Pocock *et al*., 2014). Local knowledge is also extremely valuable for aquiring historical contexts and rare events, which can assist catchment managers with locating sources, pathways and receptors across an entire catchment.

**Good quality and real-time data:** in some cases it has been found that volunteers collect data that is of a similar or higher standard to that collected by professional scientists (e.g. Danielsen *et al*., 2013; Holt *et al*., 2013). Volunteers are full of valuable local knowledge and they are often extremely cautious of skewing scientific data. If required, there are tools available to provide instantaneous information and automatically check data. Evidence collected before, during and immediately after flash flood events in the area where volunteers live would otherwise be missed by scientists and engineers.

**Tools already exist:** the general public already have access to the internet, smartphones, social media, apps and other relevant communication, sensor and data submission tools. There are also a number of open source (freely available) tools, software and maps available for use (Tweddle *et al*., 2012; Wentworth, 2014).

**Environmental education:** monitoring activities raise awareness and understanding of environmental issues. Volunteers also gain new skills themselves whilst participating (Science Communication Unit, University of the West of England, 2013). Catchment monitoring by communities will aid them to appreciate the concept of catchment connectivity and how different land uses affect the quantity and quality of river flows in watercourses.

**Collaboration with scientists:** Volunteers have the opportunity to work with scientists and feel part of the team (Tweddle *et al*., 2012).

**Wider community involvement:** monitoring activities open up new opportunities to the wider community and any age group, building a network of people who share the same goals.

**Community ownership and empowerment:** Hacker (2013), Burgos *et al.* (2013) and Winfield (2014) suggest that by getting communities involved in participatory and active research, it builds relationships, breaks down barriers, encourages data-driven decisions and communities begin to take ownership of issues around them. In turn it can catalyse change on the ground at a local level and help translate research into practice.

Although citizen science based monitoring offers a range opportunities to support scientists, it also brings a number of challenges and barriers. These are summarised briefly in Table 5.2.

Credibility currently acts as the main barrier to the real-world and routine use of citizen science data, although it does depend on its end use. Research is still required before data collected by citizen scientists will be fully accepted and used by professional scientists. Nevertheless, some scientists are starting to appreciate that monitoring carried by communities can only add to, and support, traditional techniques by providing additional resources and new types of data (Winfield, 2014). The importance and value of citizen science is also starting to be recognised, as exemplified by the following quotes:

***"Data collected by volunteers already plays a critical role in environmental monitoring. With appropriate quality assurance measures, citizen science can generate high quality environmental data"*** Parliamentary Office of Science and Technology (Wentworth, 2014).

***"In the debate that is ongoing all across Europe, the bottom-line question is: Do we want to improve Europe or give it up? My answer is clear: let's engage!"*** President of the European Commission (Socientize Consortium, 2013).

| Challenge | Description |
|---|---|
| **Funding** | Despite being 'low cost', there are expenses associated with developing new tools, training material, websites etc. Specialists may be required to keep tools up-to-date. |
| **Engagement** | It can be a challenge to engage with a wide audience and to keep volunteers interested over time. Citizen science may be seen as a chore to some if it is repetitive. |
| **Evolving tools and technology** | Technology, which many people are often unfamiliar with, evolves rapidly. Volunteers may find it difficult to adapt. |
| **Data quality and reliability** | Citizen scientists are amateurs, collecting data using simple and low-cost techniques. Accuracy and reliability of observations is generally perceived as being low compared with that collected by trained scientists and can often be in qualitative or descriptive formats. Some organisations may also become overwhelmed by data. |
| **Facilitation** | Monitoring programmes will require a professional or community-based leader (and time) to design and drive the project. It is also essential that monitoring efforts are appreciated by providing regular feedback to community involved. |
| **Ethics** | Data protection acts must be considered carefully when storing, sharing and using data from multiple sources. This includes anonymisation of monitoring locations if the project involves individual properties. |

***Table 5.2*** *– Key challenges associated with citizen science and environmental monitoring schemes*
*(Source: Tweddle et al., 2012; Burgos et al., 2013; Buytaert et al., 2014; Socientize Consortium, 2013; 2014; Wentworth, 2014)*

**5.4 Embedding monitoring by communities into the catchment management process**
Overall, a citizen science approach provides professional scientists with an effective, inexpensive and timely solution which is required to meet the pressures and demands for evidence-informed environmental decision making on a local level. Many of the benefits associated with citizen science slot comfortably within the existing catchment-related policy Directives, Acts, Frameworks and wider drivers listed in Figure 3.2. More specifically, involving the public through citizen science encourages catchment-wide observations to be made, helps residents and land owners to appreciate catchment connectivity, supports local decisions, raises awareness of issues, strengthens work currently carried out by governmental organisations and River Trusts and generally welcomes the public to be part of the catchment management process.

Hydrologists have developed and refined standard monitoring methodologies and technologies over decades (as Section 3.3 details) which automatically raises concerns over the quality, thus scientific credibility of citizen science data in this sector (Buytaert *et al*., 2014). Next steps involve testing citizen science monitoring techniques alongside more traditional methods in order to understand the capabilities of citizen science. Rainfall, river levels, flood events, water quality, sediment, habitat and biodiversity related monitoring schemes, whether they are existing schemes or new, all have the potential to support catchment management and restoration activities. The Haltwhistle Burn project (Section 5.5) has already implemented a citizen science based monitoring scheme and is starting to evaluate its potential to support the management of the water environment.

### 5.5 Case study [1]: Haltwhistle Burn Catchment, Northumberland

The 42km$^2$ predominantly rural Haltwhistle Burn catchment is situated in the centre of Britain within the County of Northumberland (see Figure 5.3 for location). The town of Haltwhistle (population of just under 5000 – Office for Statistics, 2011 census) is also located close to the catchment outlet where the land becomes steep and narrow. The Haltwhistle Burn catchment has a history of flooding, with records dating back to at least 1892, affecting the town in numerous locations during the 2007, 2012, 2013 and more recently, April and May 2014 events. As a result, the Haltwhistle Burn catchment is listed on the Environment Agency’s Rapid Response Catchment (RRC) register due to its flashy nature. The catchment also suffers from other pressures, including agricultural diffuse pollution, high rates of sediment erosion and transportation and it is currently failing to reach the WFD’s ‘good ecological status’ target. The Haltwhistle Burn is also a prime example of a catchment which does not benefit from any national automatic monitoring networks.

Using effective engagement techniques, a citizen science based monitoring approach has been implemented in and around this catchment by the authors of this ROCK (Newcastle University, 2014). This research project is also supporting Tyne River Trust’s wider ‘Haltwhistle Burn Total Catchment Approach’ project funded by Defra’s Catchment Restoration Funds Project (CRF). Enthusiastic ‘River Watch’ volunteers are sharing their catchment-related knowledge and regularly monitoring several catchment parameters in order to understand their local water environment and how it responds. Using training cards and several data collection, submission and visualisation tools, low-cost monitoring techniques are now being used widely and successfully. Lengthy flood, rainfall, river level and water quality datasets are now available for this catchment and are shared online with the wider community. In order to understand the level of uncertainties, thus scientific capabilities and reliability of this approach, traditional monitoring equipment (including automatic tipping bucket rain gauges and water level recorders) have also been installed. Although the monitoring scheme has only been interested in the hydrological data collected, names, addresses, contact details, monitoring locations (often the volunteer’s home address) and photographs of volunteers are regularly collected. Careful ethical procedures have therefore been implemented to ensure this type of data has been stored, processed and disseminated correctly.

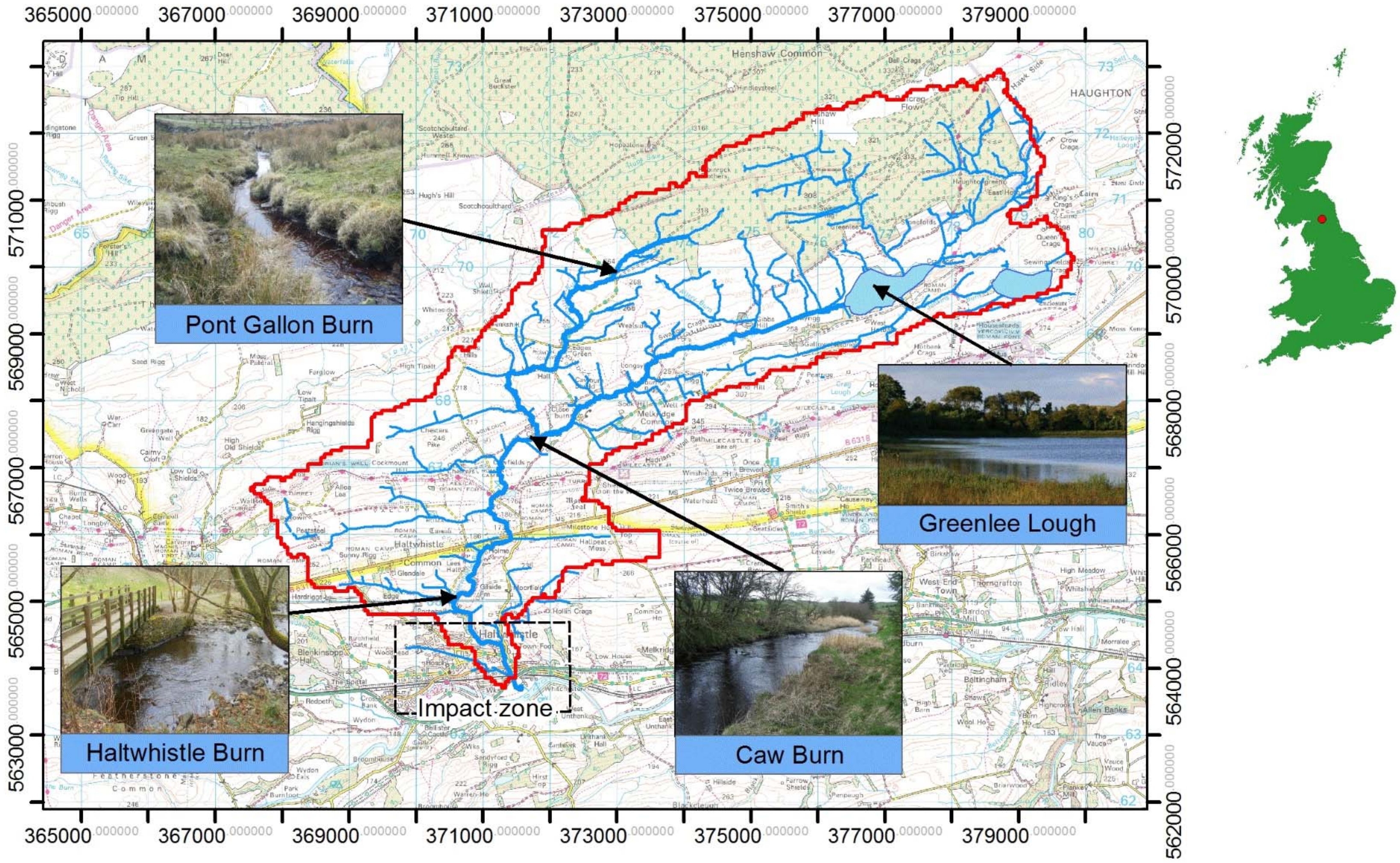



***Figure 5.3** – Maps to show the location of the Haltwhistle Burn catchment (right map) and its complex and elongated river network (left map). The 'impact zone' highlights the town of Haltwhistle.*
*(Source: Newcastle University, 2014. Map backdrops downloaded using: EDINA Digimap Ordnance Survey Service)*

| | |
|---|---|
|  Sharing and mapping local knowledge during a river watch workshop |  Manual river level gauge boards are compared to automatic equipment |
|  Simple water quality test kits used by volunteers during a walking festival |  Extra photographs and videos taken by the community following heavy rain and floods |
|  Encouraging the wider community to use community apps and fixed photo posts |  Data collected using manual rain gauges shows high variability over the catchment. |

***Table 5.3*** *– Examples of material from the Haltwhistle Burn citizen science project, in Northumberland, led by Newcastle University (see project website: http://research.ncl.ac.uk/haltwhistleburn/)*

Initial results confirm that volunteers are capable of collecting regular data over a wide area, they understand the importance of, and collect more data before, during and after flood events, their observations significantly supplement the availability of traditionally sourced data and volunteers are starting to understand the wider picture. Data collected by volunteers has already highlighted hotspot areas for NFM and subsequently supported the creation of a runoff management plan. It has also assisted with setting location specific trigger levels and alarms for a telemetered system. Rainfall monitoring has also highlighted how spatially variable rainfall is across this small catchment, which will significantly support future application and activities carried out by scientists and engineers. This citizen science project highlights how successful engagement and participation is closely related to the environmental issue being monitored - many members of the Haltwhistle Burn community have been directly affected by flooding over recent years. Table 5.3 illustrates the Haltwhistle Burn project through exemplar material.

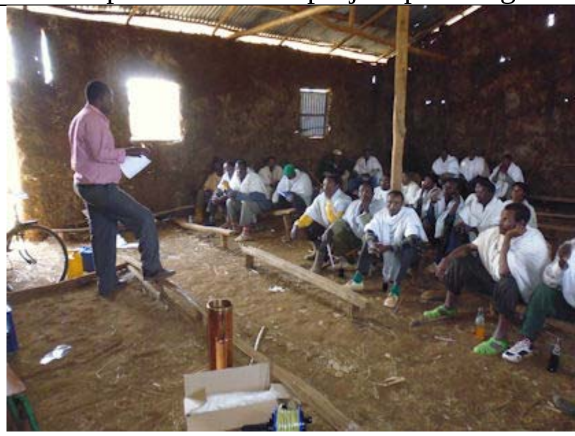
**5.6 Case study [2]: Hydro-meteorological monitoring in Ethiopia**

The Dongila woreda (a local administrative district) is situated in the Amhara region in the Ethiopian highlands. The total population of Dangila woreda is about 279,500 people in an area of about 800 km$^2$, with their main source of livelihood being crop–livestock mixed subsistence farming. There are many shallow (10-12m) hand-dug wells, used with manual water lifting for domestic supply and household ‘backyard’ irrigation only. This project (*AMGRAF: Adaptive management of shallow groundwater for small-scale irrigation and poverty alleviation in sub-Saharan Africa*) focussed on community-led adaptive resource management, to support development of dry season groundwater-fed irrigation for improved livelihoods and food security (Parkin *et al*., In Prep.). Although indigenous knowledge generally exists in sub-Saharan Africa on the seasonal performance of wells during typical and drought years, this knowledge is often localised, qualitative and unrecorded.

Typical hand-dug well and bucket used for household irrigation


Participatory mapping used for knowledge co-production and project planning

Community installation of manual river level gauge boards



Training workshop in use of hydro-meteorological equipment.

***Table 5.4** – Participatory monitoring by Ethiopian communities in the AMGRAF project, led by Newcastle University (see project website: http://research.ncl.ac.uk/amgraf/)*

The project was undertaken in collaboration with a community in the Dangeshta kebele (a smaller administrative area, roughly equivalent to a parish council) within the Dangila woreda (see Table 5.4). Gender-separated focus groups helped to clarify understanding of water resource availability, and to identify difficulties in water use particularly in drought periods, aspirations for development of irrigated agriculture for products that could be sold at markets, and the opportunities and constraints to these developments. Appropriate sites were identified jointly between hydrologists and the local communities for daily monitoring of rainfall, groundwater levels, river levels and flows (within the Kilti river catchment, one of the headwater tributaries of the Blue Nile). Local observers were trained and data have been collected through dry and wet seasons.

The data collected by the Dangeshta community observers has provided valuable quantitative evidence on the relationships between climate and how groundwater and rivers respond. This is now being used in computer modelling to support understanding of the vulnerability of shallow groundwater resources to drought. Further work will continue with the communities for planning development of irrigated agriculture and long-term sustainable management of their local water resources.

# 6 Using observations made by communities

## 6.1 Applications and end users of observations made by communities

Given that citizen scientists have the potential to collect an abundance of information about the water environment, there are many applications and end users who can benefit from this. The concept of using citizen scientists to make observations about the water environment allows for ‘mass data collection’ over space and through time, often in locations which professional scientists would never be able to cover alone. Furthermore, citizen science projects thrive on innovation – there is no definitive list of tools, techniques and activities available for use. Each citizen science project is therefore unique, and as technology continues to evolve, the nature, diversity and quantity of observations made will also progress in line with this.

Citizen scientists are already making observations about the weather and water environment, as detailed in Section 5.2 and are also being used to support further applications. Although these observations may not be explicitly intended for use within the catchment management process, many existing citizen science projects are harvesting relevant information. Figure 6.1 summarises the main observable parameters, data users and potential applications of citizen science data, in the context of UK catchment management. End users and applications typically fall under two distinct categories (i) social (ii) scientific, each of which rely on extracting meaningful information from the observations made by citizen scientists. In the Haltwhistle Burn citizen science project (Newcastle University, 2014), rich rainfall, river level and flood datasets have been collected by volunteers, and this is one of very few schemes to routinely use this type of data to support the catchment management and restoration process in the UK. To add to this, a short lived ‘cloud burst’ event occurred on the 30th April 2014. Heavy rain (41mm – as measured by a member of the community) fell in Haltwhistle within about a 40 minute period. A timeline of this extreme flood event was captured by citizen scientists using social media (Twitter), providing an early warning for residents and evidence for catchment managers and researchers. A number of ‘professionals’ have also shown an interest in the project to date, for instance:

*“We would find peak river levels and flood information collected by the community very useful”* Partnerships and Strategic Overview Officer, Environmental Agency (July 2014).

*“We couldn’t produce them [flood plans] without the local knowledge and enthusiasm.”* Northumberland County Council (July 2014)

*“A better appreciation of the flow regime and catchment behaviour would certainly help to inform future management options”* Flood and Coastal Erosion Risk Management, Northumberland County Council (March 2014).

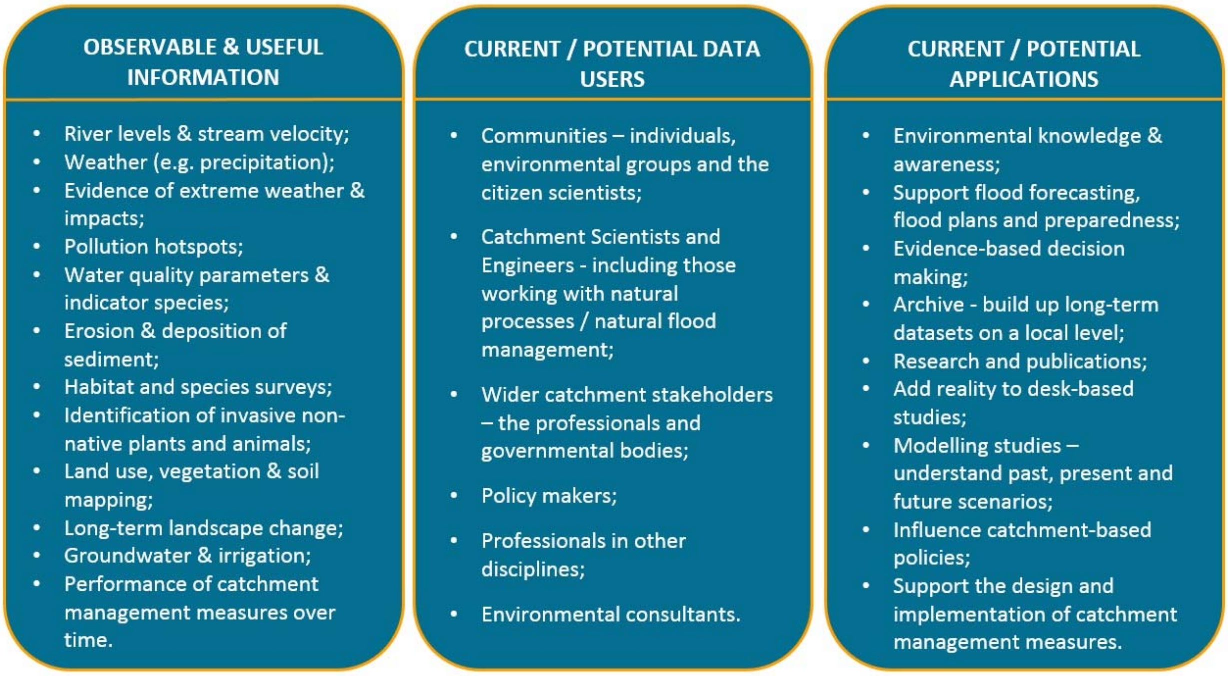



***Figure 6.1** – Current and potential users and applications of catchment-related citizen science data (lists based on typical catchment parameters, issues and management measures presented within Sections 2 to 5).*

In addition to making observations about the water environment, local knowledge is also a vital source of information as it provides historical context. Ewing *et al*. (2000) describe a catchment management study in Australia involving hydrological and water quality scenarios, showing how they have harvested local knowledge to support the catchment planning process as it provided them with a 'reality check'. Oliver *et al*. (2012) also utilised local knowledge as 'expert data' in the Taw Catchment (Devon) to support water quality related decisions. This is similar to the work completed by Norton *et al*. (2012) who gathered local knowledge to understand and manage algal blooms in the Loweswater catchment (Lake District).

As Roy *et al*. (2012) and Buytaert *et al.* (2014) point out, before any data can be used to support professional applications, it must be stored, anonymised, checked (quality assurance procedures in place), filtered, processed and then analysed. This can be a lengthy procedure, particularly as observations made by citizen scientists are often in a variety of formats. Whilst it is sufficient to carry out these tasks manually when small projects are involved, automated techniques may be required for larger catchments. It does however provide volunteers, who have computer and data handling skills, with the opportunity to become more closely involved as a citizen scientist.

### 6.2 Modelling for catchment management

It is not possible to monitor every parameter and process everywhere in order to understand the behaviour and response of an individual catchment. To add to this, extreme weather events are often short lived and rare, particularly flash flood events, so there is little time to gather evidence. Catchment issues like climate change are also related to future scenarios which cannot be monitored. Professional scientists and engineers therefore commonly represent catchments, processes and behaviour through time and space using mathematical equations and algorithms

(Shaw *et al*., 2011). A computer can use these equations embedded within modelling software to 'simulate' or predict catchment behaviour including river levels, water quality parameters, flood extents, and morphological and ecological activity. Catchment models are used to simulate past, present and future scenarios (Novak *et al*., 2010), including the prediction of potential impacts associated with catchment management measures. Catchment modelling is, however, a challenging activity given that the models require real, high quality, reliable and lengthy datasets in order to replicate reality (Beven, 2012). It is also important to remember that computer models are a simplification of the real world, which are heavily dependent on the quality of the data used to build the model and any assumptions which have been made. Some catchment models represent highly simplified catchments where information is 'lumped' together, whereas others are 'spatially distributed' and provide detailed information across the catchment. The modelling process has significantly improved in recent years in line with the availability of computational power.

A simple schematic illustrates the concept of modelling in Figure 6.2 and the generic steps involved. Although catchment models seek to overcome the limitations of being unable to monitor everything and everywhere, they still require real data – as input data but also to calibrate and validate models. This is where citizen science data can potentially support the modelling process (Buytaert *et al*., 2014), as can local knowledge because it is real information collected out on the ground on a local level. There are concerns over the varying quality and formats of data which is why citizen science data is not yet routinely used to support the catchment management process. Once citizen science data is pooled together, it is often regarded as being sporadic in nature as opposed to that collected by more traditional and automated methods. River level observations are an obvious example as they depend on when and how many passers-by there are. Rainfall is one of the most common model parameters; citizen scientists generally only observe rainfall totals once per day which will not depict the intensity and nature of heavy and flashy rainfall events. Buytaert *et al*. (2014) have carried out an extensive reviewe of citizen science in the context of hydrology and has suggested that interpolation and merging of datasets (with other citizen science and/or traditional datasets) is one solution. Spatially distributed catchment models are required in order to make use of the abundance of different monitoring sites and thus will depict spatial patterns across a catchment. Photographs and videos (which are most commonly collected by citizen scientists) visually show catchment behaviour and impacts which professionals can interpret. They are also a form of evidence which all stakeholders are familiar with.

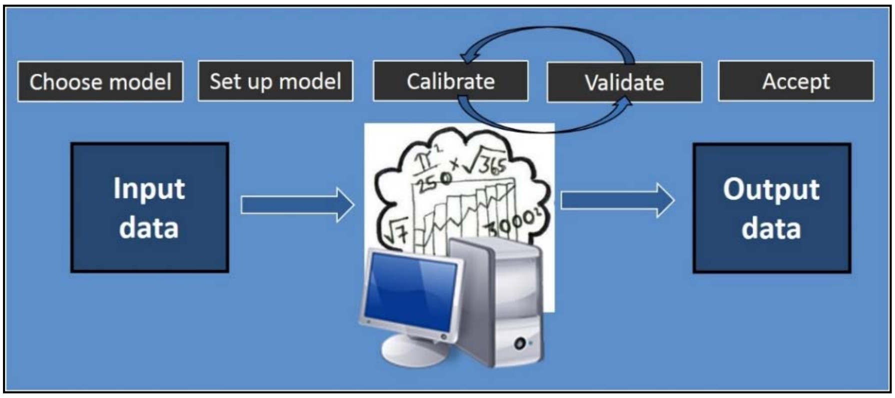



***Figure 6.2 –*** *Schematic of catchment modelling and the main steps involved (after Beven, 2012)*

Kutija *et al*. (2014) have used data collected by the Newcastle upon Tyne community during and after the 28th June 2012 'ToonFlood' event to improve the performance of their model. Observations including time, location, a description of the flood impacts and photographs were collected from the public ('crowd-scoured') and used to validate and calibrate their flood model 'CityCAT'. Kutija *et al*. (2014) concluded that this type of citizen science data has proven to be extremely useful, increasing their confidence in CityCAT's ability to model complex flows during urban flash floods.

Citizen scientists can also support the modelling process in other ways. For example, Climate*prediction*.net (2014) is the world's largest climate modelling experiment which makes use of volunteers' computing power. The project team run climate models on volunteers' personal computers to reduce computation demands and increase the amount of data processed. Results are sent back to the project team where they then contribute to the wide climate change picture. There are also many examples of 'participatory modelling' activities in the literature where catchment management stakeholders, including locals, work with professional modellers to take part in the different modelling stages (e.g. Garrod *et al*., 2013). Tyne Rivers Trust (2014) use their 'RiverSim' with local community groups, a river simulator containing sand which behaves in a similar way to river beds and banks (see Figure 6.3). Participants can physically carve into the river by hand, thus can model different management scenarios. Despite variations in citizen science based modelling techniques, all activities provide volunteers with increased awareness and understanding of catchments and the management process.


***Figure 6.3 –*** *Tyne Rivers Trust 'RiverSim', an innovative and interactive way of involving communities in the modelling process (photos by Tyne Rivers Trust).*

### 6.3 Visualising: importance of feedback and presenting catchment information in a meaningful way

If local communities are to become (i) more involved in the catchment management process and (ii) act as citizen scientists and observe the water environment, it is important that the feedback loop is complete and they benefit from new knowledge that is being generated about their local water environment. Roy *et al*. (2012) carried out an extensive review on 35 well-known environmental citizen science projects. A large number of these projects confirmed, through hands-on experience, that constant communication and effective feedback to volunteers is vital in order to retain motivation and participation. This also ensures that the importance of their contribution is acknowledged.

All catchment information shared with the public should be presented in a meaningful and effective way. This applies to data collected by citizen scientists, but it also stands when professionals are trying to disseminate and communicate information to the public, especially flood risk (as detailed in Section 3.4). This needs to be understood by all stakeholders, including a lay person with little or no experience of engaging and reviewing traditional scientific data sources and terminology. It is common for catchment modellers to work in isolation and to, for example, present flood maps which are poorly understood by the public. In the context of flood risk management, a resident of Morpeth in Northumberland remarked "*how can we the residents come to the table with coherent arguments when we are pitted against the new god of mathematical modelling?*" (Wright, 2013). Haklay (2008), a geospatial expert, also commented on how maps often separate rather than include people in understanding their environment, including the Environment Agency's flood risk maps. Effective techniques and considerations associated with presenting meaningful information to communities include:

- 3D models;
- Photograph albums and videos (especially You Tube and Flickr);
- Short animations;
- Interactive graphs;
- Story graphs;
- Word Clouds;
- Posters and newsletters;
- Infographics;
- Art and artist impressions;
- Paper- versus web-based techniques;
- Annotations and labels;
- Highlight places of interest;

Interactive graphs, animations and small infographics have been used by the Haltwhistle Burn project (Newcastle University, 2014) to present more meaningful information back to the citizen scientists and wider community. Graphs include anecdotes and images supplied by members of the community to assist with telling a 'story' over time and to interpret lengthy datasets. Positive feedback has been received by the community, including ***"Now I'm intrigued"*** and ***"I must say, I do like these little graphics you are tweeting. Really good"*****.** Most active citizen science projects have web-based maps containing observations which volunteers have submitted. This is useful as the whole community (and other communities) can benefit from the knowledge generated, even if they have not made any observations themselves. Evans *et al.* (2014) successfully communicated flood risk through three-dimensional (3D) visualisations in order to raise awareness on a local level (see example in Figure 6.4). They stress how difficult it is to communicate flood risk to communities effectively. 3D visualisations of flooding from the River Exe in Exeter were therefore created displaying places of interest (buildings and infrastructure), the river overtopping muddy water, the spread and inundation of the flood, aerial imagery, a fly through over the whole city and extracts from different time stamps during the flood to assist with telling a story. It was found that the visualisations used had removed the need to interpret any data or maps. The visualisations were shown to the community during workshops and were regarded as being an effective and realistic engagement tool.

An additional consideration to think about is how catchment information will be physically shared/disseminated back to the community. Websites, social media and face-to-face workshops (Roy *et* al., 2012) are likely to reach a wider public audience and be much more effective than academic papers. By closing the feedback loop in this way, it allows the public to understand the meaning behind their data, it shows that their efforts are valued and they are contributing to evidence-informed knowledge and thus decisions for catchment management.


***Figure 6.4 –*** *Communicating flood risk effectively to the Exeter community using 3D visualisation tools (Evans et al., 2014). See You Tube animation:* [*https://www.youtube.com/watch?v=0QL0hYIURyk*](https://www.youtube.com/watch?v=0QL0hYIURyk)

## 7 The future of monitoring by communities for catchment management

Monitoring, modelling and management of the water environment has evolved considerably over the twentieth and twenty-first centuries. Professional scientists and engineers working in this sector have developed robust protocols and refined procedures to achieve this. Yet as catchment managers are faced with multiple pressures, there is still very limited data available, thus knowledge, to fully understand how individual catchments behave on a local level. Innovative mitigation measures, including WwNP and NFM, are now established but evidence is still required to support their use, confirm their overall impact and raise confidence amongst relevant stakeholders. Citizen science and monitoring by communities offers a timely solution, supporting the requirements of various catchment related policies and frameworks. This ROCK highlights how community involvement is now the norm in the context of the UK water environment (even if the degree of involvement varies or is still limited to awareness raising activities). Although monitoring by non-experts is not a new phenomenon, the availability of technology now provides catchment stakeholders with a set of exciting tools for collection, submission, analysis and sharing of data in a number of innovative ways. There are limitations and issues which still need addressing, particularly around data quality, but citizen science is likely to play an important and ongoing role in the catchment management and restoration process. Baytaert *et al.* (2014) and Wentworth *et al.* (2014) allude that new technologies and techniques will continue to emerge and improve over time which advocates that credibility, and therefore number of users and applications of citizen science, is only going to increase. Unlike many other citizen science projects, those related to the water environment and catchment management involve people on a local level and are concerned about issues which directly affect and are relevant to the volunteers themselves.

There is still work to be completed before citizen science will be fully accepted. More research studies are required to quantify errors associated with monitoring by communities – comparisons with scientifically robust data are required. This will help convince the scientific community that the data is suitable for use across a number of applications. There is also a need for continued science-society-policy interactions (Socientize Consortium, 2014) and to find innovative ways of embedding citizen science into existing initiatives, including educational curriculums. If citizen science is to be adopted nationally for dedicated purposes and routinely used within the catchment management process, funding and incentives may be required to sustain monitoring by communities in the future. However, flood risk, climate change and poor water quality may be enough to keep enthusiastic communities engaged and involved. Local people are also full of local and historical knowledge which is invaluable. This information, along with new observations, need to be captured, shared and routinely used to support the catchment management process. For this to occur, robust and systematic procedures are required to ensure this type of information reaches all the relevant organisations, including the Environment Agency.

Citizen science and monitoring by communities offers a vital component to the CaBA and the delivery of the Floods Directive and WFD. Involvement of the public in this way also offers a legacy for continued engagement, understanding and involvement of local communities in the catchment management process. Catchment management partnerships are therefore expanding to include a wide spectrum of relevant stakeholders (Figure 7.1); an integrated approach which is now emerging throughout the UK. An integrated approach also allows for multiple catchment issues to be appreciated together which is essential given that catchments are connected from source to mouth.

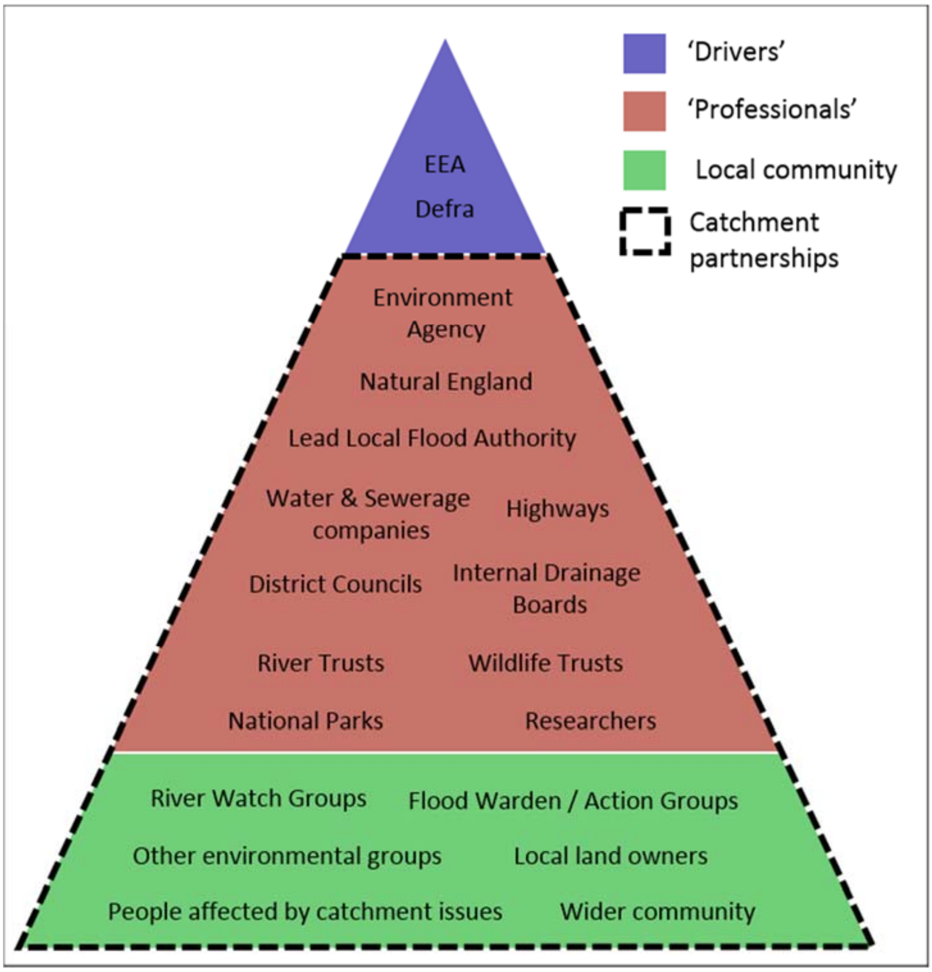



***Figure 7.1 –*** *Stakeholders involved in the modern day catchment management and restoration process. The wide base of the pyramid represents how local community groups now support multi-partnership projects*

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