



## Priority water research questions as determined by UK practitioners and policy makers<sup>☆</sup>

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### ABSTRACT

Several recent studies have emphasised the need for a more integrated process in which researchers, policy makers and practitioners interact to identify research priorities. This paper discusses such a process with respect to the UK water sector, detailing how questions were developed through inter-disciplinary collaboration using online questionnaires and a stakeholder workshop. The paper details the 94 key questions arising, and provides commentary on their scale and scope. Prioritisation voting divided the nine research themes into three categories: (1) extreme events (primarily flooding), valuing freshwater services, and water supply, treatment and distribution [each >150/1109 votes]; (2) freshwater pollution and integrated catchment management [100–150 votes] and; (3) freshwater biodiversity, water industry governance, understanding and managing demand and communicating water research [50–100 votes]. The biggest demand was for research to improve understanding of intervention impacts in the water environment, while a need for improved understanding of basic processes was also clearly expressed, particularly with respect to impacts of pollution and aquatic ecosystems. Questions that addressed aspects of appraisal, particularly incorporation of ecological service values into decision making, were also strongly represented. The findings revealed that sustainability has entered the lexicon of the UK water sector, but much remains to be done to embed the concept operationally, with key sustainability issues such as resilience and interaction with related key sectors, such as energy and agriculture, relatively poorly addressed. However, the exercise also revealed that a necessary condition for sustainable development, effective communication between scientists, practitioners and policy makers, already appears to be relatively well established in the UK water sector.

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## 1. Introduction

The disconnection between policy makers, practitioners and researchers is common to many sectors and academic disciplines (e.g. [Bogenschneider and Corbett, 2010](#)) but the last decade has seen increasing emphasis being placed on 'evidence-based policy', which aims to replace ideological policies with rational decision making ([Sutcliffe and Court, 2005](#)). In the UK, an inquiry into evidence-based policy making concluded that government should acknowledge more openly the many drivers of policy making, as well as any gaps in the relevant research base. It was suggested that it should also invest more heavily in research to underpin policy making, and embed 'horizon scanning' into the process to combat the short-term nature of the political cycle ([House of Commons Science and Technology Committee, 2006](#)). Evidence from ecology focused researcher-policy maker dialogue (e.g. [Sutherland et al., 2006](#)) has suggested that some parts of the water sector are considered to be good examples for the process of identifying gaps in the evidence base used by practitioners and policy makers. Nevertheless, in many parts of the world water managers are facing a series of unprecedented problems meaning that there is a critical need for more researcher–practitioner debate to stimulate attempts to find appropriate solutions.

In the UK, a range of concerns exist related to the management of water resources ([Defra, 2008](#); [Environment Agency, 2009](#)). For example, energy use in the water utilities is considered a major problem due to the rising cost of energy for treatment and distribution, as well as pressures for a low carbon economy ([Ainger et al., 2009](#)). There are uncertainties over future flooding ([Pitt, 2008](#); [Henderson, 2010](#)) and climate change (e.g. [Fowler and Ekström, 2009](#)), and three million new homes are expected to be built in England and Wales by 2020 ([DCLG, 2007](#)) potentially exacerbating problems of water pollution and flooding, and increasing demand for water (e.g. [Williamson et al., 2002](#)). Rising demand inevitably leads to a conflict where there is pressure to over-abstract waters needed to maintain ecological health ([Acreman et al., 2008](#)). This problem could compound failures to meet ecosystem quality targets set by the EU Water Framework Directive, particularly where pollutants such as those from agricultural and urban diffuse sources are proving difficult to control ([Environment Agency, 2007](#); [Crabtree et al., 2009](#); [SEPA, 2009](#)). Other issues include a continuing legacy of historic pollution (e.g. [Edwards et al., 1997](#); [Macklin, 1997](#)) and the emergence of problematic new pollutants such as pharmaceuticals ([Hilton et al., 2003](#)) and nano-particles ([Moore, 2006](#)).

A further key issue facing the management of UK water resources relates to how the water sector is structured and governed. Within the water and sewage industry, there is a different company ownership structure in each of the devolved nations of the UK ([APPWG, 2008](#)) and when the wide range of other bodies with water management responsibilities are considered (e.g. environmental protection agencies, internal drainage boards, planning authorities, etc.) it is evident that the UK water sector is institutionally complex. Such complexity risks hampering sustainable water management ([Pitt, 2008](#)). Financing of the water industry also has significant implications for innovation intended to promote water sector sustainability. For example, in England and Wales, regulators' concerns over customers' ability to pay for water services means that water utilities must renew an ageing infrastructure against a backdrop of tight budgetary constraints ([All Party Parliamentary Water Group \[APPWG\], 2008](#)), rising customer debt ([Emaginating, 2009](#)), and five year planning cycles which are arguably too short to promote long range planning for sustainability. Alongside this, investment in research and development in the UK water sector has declined by 60% since 2000 ([APPWG, 2008](#)).

From their wide-ranging inquiry, the [APPWG \(2008\)](#) noted that, faced with numerous challenges around affordability, efficiency, flooding, resource management, and the regulatory system, the UK water industry must begin to lay the foundation for a sustainable

future. Such challenges need to be addressed through strategic actions and decision making that are driven by evidence-based policy. Conversely, research needs to be clearly directed at issues that influence policies. In this context, this paper discusses an exercise which identified 94 key research questions for which UK water policy makers and practitioners require information based on from the scientific community. It discusses the process through which these questions were developed ahead of, during and after a scientific workshop organised by [water@leeds](#), an inter-disciplinary collaboration of academics working on water issues at the University of Leeds, UK. Our approach was inspired by earlier scientist-policy maker workshops which had aimed to identify priority research questions to inform biodiversity and conservation policy ([Sutherland et al., 2006](#); [Morton et al., 2009](#); [Wenger et al., 2009](#)).

## 2. Methods

Research questions were obtained from the UK water community in two ways. Firstly, over 50 governmental institutes, non-governmental organisations, professional bodies and independent policy institutes were invited to submit questions because they are involved in creating UK water policy, are highly influential in shaping policy development, or are key practitioners. Representatives were asked to consult with colleagues to generate questions with the greatest priority for their organisation. Secondly, an invitation to submit questions for consideration was distributed through public mailing lists including European Water News, the British Hydrological Society and Water Forum, as well as a private mailing list held by Aqua Enviro Ltd. Respondents were requested to submit questions (together with affiliation details) via an online survey hosted at [www.surveymonkey.com](#) which was live from 07/10/09 to 09/11/09. The participating organisations that did not express a wish to remain anonymous are listed in [Appendix A](#). The initial consultation received >350 responses and 747 questions were submitted. The subject of some questions was essentially identical, as found in previous studies of this kind (e.g. [Sutherland et al., 2006](#)). This provided a means of identifying topics that were potentially considered to be of widespread importance and, prior to the workshop, allowed questions to be grouped into four broad categories so as to facilitate group working: (i) flooding and surface drainage, (ii) water quality and ecosystems, (iii) supply and waste water, and (iv) socio-economics and demand. Representatives of the organisations who were asked to submit questions were also invited to attend a workshop held at the University of Leeds on 11/11/2009 to discuss, short list and prioritise the full list of 747 questions. This invitation was also extended to participants of the online survey who fulfilled the criteria of being involved in policy development, implementation or practice. Along with workshop facilitators from the University of Leeds, 35 representatives of water policy-orientated organisations accepted invitations and participated in the workshop.

During the workshop, participants selected one of the four categories so that they were able to participate in detailed discussions of the questions relevant to their area of interest. For each of the categories, the list of questions was reduced by: (a) combining similarly worded questions, (b) identifying questions with a similar underlying focus and rewording into a synthesis, (c) rejection of any questions that participants knew to have been researched already, and (d) deletion of 'questions' that were merely comments or observations. Questions were retained by mutual agreement among theme participants. The workshop led to an initial shortlist of 72 questions. Thereafter, documents were circulated with these questions both to workshop participants and some interested parties who were unable to attend the workshop. Through consensus working, the list was then expanded to the final 94 questions by splitting any that covered two topics, or to include some questions that respondents felt had not been discussed sufficiently at the workshop.

A prioritisation exercise was subsequently undertaken whereby the 94 questions were hosted on the [www.surveymonkey.com](http://www.surveymonkey.com) website and invitations to participate were circulated using the same approaches for the initial online survey. Participants were asked to vote for the ten questions that they considered as highest priority. A similar prioritisation exercise was undertaken during the workshop based on the initial draft shortlist. As part of the prioritisation exercise, online participants were asked to provide an indication of the 'sector' to which their organisation belongs in order to determine the extent of agreement on priority research questions across different types of practitioners.

Herein, the 94 questions are grouped into nine 'themes' based on similarity of content, although there is inevitably some overlap reflecting the systemic nature of water research. The nine themes presented below reflect the thematic areas that emerged from the workshop and they, and the questions therein, are not presented in any 'priority' order. In an attempt to reflect the fundamental nature of the 94 question, they were further summarized into question 'types': Process understanding, Reducing uncertainty, System management, Appraisal, Decision making, Communication, and Governance.

### 3. Results

#### 3.1. Extreme events

The UK government has developed new strategies for future flood risk (DEFRA, 2005) in response to recent high profile flood events in the UK. In Scotland there has also been the introduction of a new flood risk management bill (Natural Scotland, 2010) and recent policy changes have been influenced by the need to comply with the European Directive on the Assessment and Management of Flood Risk (Floods Directive; 2007/60/EC). In addition, droughts of 1995–97 and 2004–06 (Marsh, 2007) have meant a need for continued investment to underpin drought planning (CIWEM, 2007). There is a clear recognition of the need to consider the possible effects of predicted climate change on extreme events, implement policies to better manage urban drainage issues and to develop robust strategies for adaptation to hydrological change. All of the questions outlined below and relevant to flooding considered the multiple sources of coastal, fluvial, pluvial and groundwater flooding, except where explicitly stated.

1. How can we work with natural ecosystems such as wetlands, salt marshes, upland forests, and moorland to reduce flood risk?
2. How much water will be coming through UK river networks under different climate change scenarios?
3. What are the best ways to retain more water upstream for supply purposes in times of drought, or to prevent flooding events downstream during extreme precipitation events?
4. What are the risks to water supply infrastructure under future scenarios of extreme rainfall events?
5. How can we reduce uncertainty in the prediction of floods and droughts?
6. How can we efficiently and effectively plan adaptation measures to cope with extreme events given the uncertainty associated with model predictions?
7. How can we improve flood resilience and adaptation at the individual, community and population level to improve emergency planning and protect key infrastructure?
8. How can proper economic analyses be integrated into flood management budgets?
9. What opportunities exist for improving dissemination and communication of flood information, particularly that on risk and flood warnings?
10. Who is responsible for reducing risk from flooding, including economic loss from infrastructure damage?

11. How far should we go with managed realignment of coasts and flood banks?

#### 3.2. Freshwater pollution

UK river water quality, measured using various chemical and biological parameters, has generally improved over the past two decades (DEFRA, 2009; SEPA, 2009). However, the recent EU Water Framework Directive classifications have required the incorporation of hydro-geomorphological, chemical and ecological evidence into water quality management practices. Evaluations of all English and Welsh water bodies (including rivers, lakes, groundwater) incorporating these criteria suggest only 29% are classed as "good" or better on the standard scale which grades water quality from "very poor" to "very good" (Furse et al., 2006). In Scotland the picture is better with 64% of all surface water bodies, and 76% of ground waters classified as "good" status or better (SEPA, 2009). However, diffuse pollutants and stressors (e.g. excess nitrogen and phosphorus, sediments, pesticides, highway runoff) continue to be a problem (Environment Agency, 2007; Natural Scotland, 2010). A range of emerging pollutants including pharmaceuticals, personal care products, nano-materials, and radio-nuclides are also of concern (Environment Agency, 2000; Hilton et al., 2003). The questions below apply to all of these pollutants except where specified.

12. Should we continue to spend money on reducing pollutant input to water bodies to meet new standards if there is no evidence of change to the biota after previous interventions?
13. Given the lack of unimpacted 'reference' systems in the UK, how can we develop a systematic approach that uses local 'before-after controls' to compare environmental response to remediation strategies?
14. How are upland lake and stream ecosystems responding to changes in water quality (e.g. rising dissolved organic carbon and nitrogen concentrations)?
15. How do water–substrate interactions in stream hyporheic zones or lake sediments influence pollutant concentrations?
16. What are the effects of pollutant fluxes, pollutant patterns through time and peak concentrations on aquatic species, populations, community processes and functioning?
17. How do the timing and magnitude of pollutant inputs affect freshwater ecosystems, and what implications do they have for pollution regulation to remain within environmental limits?
18. What are the cumulative effects (synergistic, additive) of multiple-stressors? For example, how will changes in thermal dynamics due to environmental change influence the mobility and effect of pollutant loads?
19. Where should monitoring technologies be deployed to better detect environmental problems?
20. Where, and under what conditions, could the remobilization of historic pollutants threaten the status of freshwaters?
21. How can we improve models to better understand and predict the impacts of effluent on river water quality?
22. What impacts will targeted sediment management in catchment headwaters have further down the system? (e.g. removing sediment supply to estuaries, changing niche space).

#### 3.3. Freshwater biodiversity

Freshwaters have a disproportionately high diversity (estimated at least 6% of all global species, > 100,000 species globally: Dudgeon et al., 2006) relative to the area of habitat available (0.8% Earth's surface) but this diversity is threatened by a range of pressures. Whilst major decisions are being made in Europe to improve and protect freshwaters, our current level of understanding of freshwater community responses to these improvements makes predictions about the

outcomes highly uncertain (Ferguson and Brierley, 2008). In addition, environmental change is expected to alter the timing, magnitude and predictability of river flow regimes, water levels in both surface and ground waters, and water quality (e.g. water temperature, nutrient loads; Woodward et al., 2010). These changes, combined with anthropogenic stressors, further complicate estimation of ecological responses (e.g. Ormerod et al., 2010). Such complexities have significant implications for the way freshwater biodiversity should be managed and conserved (Mainstone and Clarke, 2008). The research questions proposed below apply equally to all major groups of freshwater organisms.

23. How will changing flow regimes affect freshwater and estuarine ecosystem structure and function?
24. What can be done to stop the spread of invasive alien aquatic species?
25. How can information on species traits and responses to environmental stressors be aggregated and disseminated to inform studies of biodiversity and ecosystem resilience?
26. How can functional redundancy in aquatic ecosystems be evaluated best, and can information on redundancy (or lack of) inform freshwater ecosystem management?
27. What is the role of freshwater biodiversity in freshwater ecosystem functioning?
28. How much 'new' knowledge could be derived from comparative analysis of all available long-term freshwater ecology datasets?
29. How are ecosystem functioning, functional diversity and water quality related?

#### 3.4. Valuing freshwater services

The recognition that the socio-economic system is not distinct from but dependent upon the environment is increasingly recognized by economists (e.g. Costanza et al., 1998; MEA, 2005) and businesses (Armsworth et al., 2010), who now seek to place an economic value on 'ecosystem services' so that their real value can be recognized in development decisions. The ecosystem service concept now forms a central component of UK environmental management policy (e.g. Defra, 2007; Scottish Government, 2010) which builds on the Millennium Ecosystem Assessment (MEA, 2005; Haines-Young and Potschin, 2007). The new cross government Natural Environment PSA28 target aims 'to secure a diverse, healthy and resilient natural environment, which provides the basis for everyone's well-being, health and prosperity now and in the future; and where the values of the services provided by the natural environment are reflected in decision-making'. Questions on the theme of valuing freshwater services were:

30. What is the total economic value of a clean water supply to the UK?
31. What is the full ecosystem service value (including regulating, provisioning, cultural and supporting services) of freshwaters?
32. When considering trade-offs between catchment ecosystem services (e.g. flood water storage versus food production; flood protection versus ecosystem function), where does the balance lie between human and environmental needs and how do you quantify it?
33. What impact do existing reservoirs have on the range of ecosystem services that would otherwise be provided?
34. If the public's understanding of the Water Framework Directive's concept of Good Ecological Status can be raised, will their appreciation of the value of freshwater increase?
35. How can ecosystem service values be incorporated into development appraisal tools, and what new ecosystem service valuation tools do we need?

36. How can the full value of water be integrated into stakeholder decisions?
37. To what extent could UK ecosystem service valuation methods be used to levy pollution fines in line with the true damage to the receiving system and the human population reliant on the services delivered by that water body?
38. How far should we go with improving the environmental quality of water?
39. What is the true economic loss of leakage, what is an acceptable loss, and what is the most effective way to achieve such a level of efficiency?
40. What tariff structures will best support sustainable management of water resources, recognizing ecosystem services and human need?
41. How can alternative charging systems, such as lifetime and marginal utility tariffs, be efficiently and effectively implemented?

#### 3.5. Water supply, treatment and distribution networks

Despite significant investment, much of the UK's water distribution and treatment infrastructure is old, reflecting its 19th century origins (Bakker, 2001). In some ways this may restrict innovation as new solutions are bolted on to existing infrastructure. Questions that were raised with respect to water infrastructure instead took a view that we should be looking ahead to the 22nd century and what the ideal supply, treatment and distribution processes should look like; for example is it more effective to optimize inherited systems or to develop new ones? It was noted that further research was needed on whether water and wastewater treatment should be carried out at more numerous smaller, distributed sites or at a few large centralized facilities (Burkhard et al., 2000; Makropoulos and Butler, 2010). Water infrastructure questions included:

42. To what extent can the trade effluent system (i.e. the agreements between business and water companies or the regulator allowing trade effluent discharge to sewers) be improved to ensure robust catchment-scale risk assessments of sewer inputs?
43. How do we reduce industrial effluent fluxes to sewage plants?
44. If water conservation measures reduce the flows to sewage treatment works, what conveyance measures will be needed for sludge produced in the sewage plant?
45. How can the quality of effluent to sewage treatment works be improved; (e.g. how do we influence the public on issues such as detergent use)?
46. What would we do with sewage and water supply networks if we started afresh (and considered all factors such as changing climate, population and policy); is current technology up to the job?
47. What would a modern water/wastewater treatment plant look like if we could start afresh?
48. How do we develop and implement low energy water and wastewater treatment processes?
49. How do we optimize existing sewer networks (and what adaptations are needed to respond to changes in the type and volume of effluent)?
50. Is local treatment more sustainable than a fully sewered system?
51. How will climate change influence hydrological regime changes in lakes, rivers and ground waters impact on water supply?
52. Can we optimize water supply within catchments?
53. What is the best solution to water supply over periods longer than the next 30 years, and what are the potential barriers to success?

54. What is the right future delivery mechanism for water in the UK?
55. What water conservation and wastewater retrofit options are needed for existing buildings?
56. How does public perception of water management affect their response to calls for water conservation?
57. How can we improve people's perceptions of re-use options such as grey water recycling?
58. What are the effects of wasted energy, materials and resources on biodiversity?
59. Do 'soft engineering solutions' such as constructed wetlands offer a cost-effective means of dealing with water treatment problems (e.g. water colour, nitrate) and if so, where in the system could these solutions be sited?
60. What are the marginal benefits of additional water treatments on public health?
61. What are the environmental impacts of different uses of sludge as a product (e.g. energy source, fertilizer)?
62. How can we re-use sludge from sewage treatment so that it provides the best value to society?
63. Should we be using treated water to recharge groundwater as well as rivers?

### 3.6. Water industry governance

All ten major water and sewerage companies in England are privately owned, although other, smaller, private companies that only supply water also exist. Scottish Water is a publicly owned company directly answerable to the Scottish Parliament and Northern Ireland Water was formerly an Executive Agency in the Northern Irish Department for Regional Development but became a Government-owned company in 2007. Dwr Cymru (Welsh Water), the sixth largest water and sewerage company in England and Wales, has, since 2001, been owned, financed and managed by Glas Cymru, a company limited by guarantee with no shareholders (dividends are paid to customers), and with day-to-day activities executed by contract partners through competitive tendering (APPWG, 2008). There is no competition for customers between utilities because each supplies to a pre-defined area. However, there is competition in the sense that utilities seek to operate efficiently to maximise profits while their consumer prices are regulated (Cowan, 1997) and very limited competition exists for commercial customers. The workshop discussed what the future focus for the water industry might be and raised a number of specific questions, below, that related to whether the current system of private operation for English water utilities maximizes customer service, innovation and environmental good, or whether it is simply reactionary to regulation.

64. Could water exchange agreements between utilities work?
65. Would competition among water utilities deliver the right benefits for consumers and the environment?
66. How efficient does comparative efficiency between utilities make the water industry?
67. What would be the best way to modify the current five year Asset Management Plan cycle in England to incorporate dynamic changes and to achieve long-term sustainability of the water industry?
68. How could we use institutional processes to manage holistically the water cycle in the UK?
69. How do we ensure that innovation, particularly related to sustainable solutions, is maximized in the water industry?

### 3.7. Understanding and managing demand

Whilst further development of supply may be necessary in some parts of the UK, demand side measures remain the first option to

consider when addressing water stress. However, understanding of future demand remains uncertain, and forecasting techniques poorly address the wide range of factors that drive demand for domestic and commercial customers, and over a range of spatial and temporal scales. Furthermore, such techniques are generally poorly equipped to address the range of demand side measures (pricing, technology, regulation, and education) that may mitigate against future demand increases (Butler and Memon, 2006). Concern for low income households (and a lack of universal metering) limits efforts to introduce price based demand control. Indeed, levels of water debt in the UK are high and rising (domestic customers cannot have their water supply cut-off for non-payment of bills). Whilst water utilities do recover some monies via debt auctions, this is unsatisfactory for both water utilities and customers. The following questions around demand and demand side management were identified:

70. How effective are current water demand forecasting techniques, and what developments are needed to better improve accuracy and address changing drivers of, and controls on, water demand?
71. How do we change consumer behaviour regarding water (e.g. reducing the duration and volume of showers, minimizing chemical use in the home)?
72. What are the best ways to analyze the relative risks of different water demand management measures?
73. What is the best practice in residential and industrial water conservation?
74. How can we use technical solutions, novel tariff structures and communication for consumer engagement to make water metering more effective?
75. What are the implications of changing household technology for the water industry (e.g. impact of low flush toilets on solids transport; disposal of organic waste by sink maceration; water conservation technology rebound effects)?
76. What are the most appropriate mechanisms for dealing with water consumer debt?
77. Can income support be better targeted so that water and fuel poverty can be reduced?
78. How can 'can't pay' water debtors be differentiated from 'won't pay' debtors, and what pricing structures and measures are best able to deliver water justice and cost recovery?

### 3.8. Communicating water research

Better communication of water research was identified as an important area by workshop participants, particularly in the context of a perceived lack of future awareness-raising with the public. This is considered by many to be a constraint on developing more sustainable water management strategies. For example, it was noted that the government had used potential future energy shortages and climate change projections to push forward the construction of new nuclear power stations (e.g. Kennedy, 2007) but that there was no parallel agenda pushing to secure water supplies in the future. There were also important issues around public perceptions about water re-use and recycling. For example, it is generally seen as unacceptable by the UK population to supply treated wastewater as drinking water. Many large supermarkets also refuse to stock food that has been fertilised using treated sewage sludge despite existing guidance on the safe application of sludge to specific crops (ADAS, 2001).

79. How can researchers improve communication of water research to policy makers, practitioners, the public and lay audiences?
80. How can policy makers, regulators and practitioners improve the flow of knowledge to scientists to ensure adequate pre- and post-monitoring of new policies?

81. How do we create the most realistic public perception of security?
82. How do we improve knowledge transfer from research to the stakeholders with a view to implementation and practical benefits?

### 3.9. Integrated catchment management

Integrated Catchment Management (ICM) is a process that recognizes the river catchment as a basic organising unit for understanding and managing ecosystem processes. Decisions concerning the use of land, water and other resources are considered within a wider framework of environmental, social and economic issues (e.g. Falkenmark, 2004; Wheater and Peach, 2004). The issue of balancing human demands for water with the needs of terrestrial and aquatic communities is central to river basin management plans (e.g. Griffiths, 2002), which detail ways in which European member states are aiming to meet requirements of the EU Water Framework Directive. However, a series of research questions arose from the workshop indicating a need for further research from the scientific community to underpin implementation of ICM policies.

83. How do we change or align upstream land management to reflect long-term water quality, quantity and resource requirements and reduce the need for downstream technological fixes?
84. How do we trade-off the requirements of the Water Framework Directive with other global concerns (particularly growing demand for food and energy from biofuels)?
85. Where water utilities and regulators perceive catchment solutions to be important, what will be the effects on tenancy agreements, farmer's undertakings and the degree of compensation?
86. What is the right balance between the cost of treatment and in stream ecosystem benefits?
87. Will the drive for spatial connectivity in aquatic ecosystem restoration lead to real improvements in aquatic biodiversity?
88. What are the effects of local-scale engineering schemes (e.g. hydroelectric schemes) on river ecosystems, how can we

- regulate them, and to what extent do these developments conflict with the policy of barrier removal to aid fish migration?
89. Where are the key opportunities for restoring UK floodplain space along river corridors in a manner similar to central European examples (e.g. Paillex et al., 2009)?
90. To what extent can we apply ideas of hydrological connectivity to prioritise restoration of water bodies?
91. How will hydrological and ecological connectivity between the array of freshwater bodies (streams, floodplains, ponds, lakes, groundwater) be affected by future changes in the hydrological cycle?
92. What are the benefits of targeted river morphological restoration schemes for the wider catchment, and how can these benefits be assessed?
93. How can we adapt agricultural systems to reduce water use in times of shortage?
94. How do we manage the water cycle to further improve public health and environmental protection?

### 3.10. Question prioritisation

The first online survey and subsequent workshop led to the identification of the above research questions. These were then subject to a second online survey, in which 1109 votes were cast, to select the priority questions (Table 1; Fig. 1). The 15 top ranked questions collectively received 39% of votes. Addressing extreme events was the top rated theme overall (Fig. 2). The analysis highlighted a particular demand to better understand the effect of management interventions on the water environment, as well as a strong desire to improve understanding of fundamental processes.

## 4. Discussion

### 4.1. Emerging priorities

The UK water sector currently faces a diverse series of major challenges, many of an unprecedented nature (see Introduction).

**Table 1**

Priority questions from online voting for questions shortlisted by workshop participants. Question numbers from the list of 94 are in parentheses.

Rank	Question (number in text)	Workshop priority?
1	How can we work with natural ecosystems such as wetlands, salt marshes, upland forests, and moorland to reduce flood risk? (1)	Yes
2	How much water will be coming through UK river networks under different climate change scenarios? (2)	Yes
=3	When considering trade-offs between catchment ecosystem services (e.g. flood water storage versus food production), where does the balance lie between human and environmental needs? (32)	Yes
=3	How can the full value of water be integrated into stakeholder decisions? (36)	
=5	What are the best ways to retain more water upstream for supply purposes in times of drought, or to prevent flooding events downstream during extreme precipitation events? (3)	
=5	How can we efficiently and effectively plan adaptation measures to cope with extreme events given the uncertainty associated with model predictions? (6)	
7	How do we ensure that innovation, particularly related to sustainable solutions, is maximized in the water industry? (69)	
=8	What would be the best way to modify the current five year Asset Management Plan cycle to incorporate dynamic changes and to achieve long-term sustainability of the water industry? (67)	
=8	How do we improve knowledge transfer from research to stakeholders, with a view to implementation and practical benefits? (82)	
10	How can we improve flood resilience and adaptation at the individual, community and population level to improve emergency planning and protect key infrastructure? (7)	Yes
=11	How will changing flow regimes affect freshwater and estuarine ecosystem structure and function? (23)	
=11	How are ecosystem functioning, functional diversity and water quality related? (29)	
=11	What is the full ecosystem service value (water supply, water purification, flood storage, fishery support, leisure and tourism, etc.) of freshwaters? (31)	
=11	How do we change consumer behaviour regarding water? (e.g. reducing the duration and volume of showers, minimize chemical use in the home) (71)	
=15	How can we reduce uncertainty in prediction of floods and droughts? (5)	Yes
=15	How far should we go with improving the environmental quality of water? (38)	
=15	How do we change or align rural land management to reflect long-term water quality, quantity and resource requirements? (83)	Yes
=15	What are the risks to water supply infrastructure under future scenarios of extreme rainfall events? (4)	

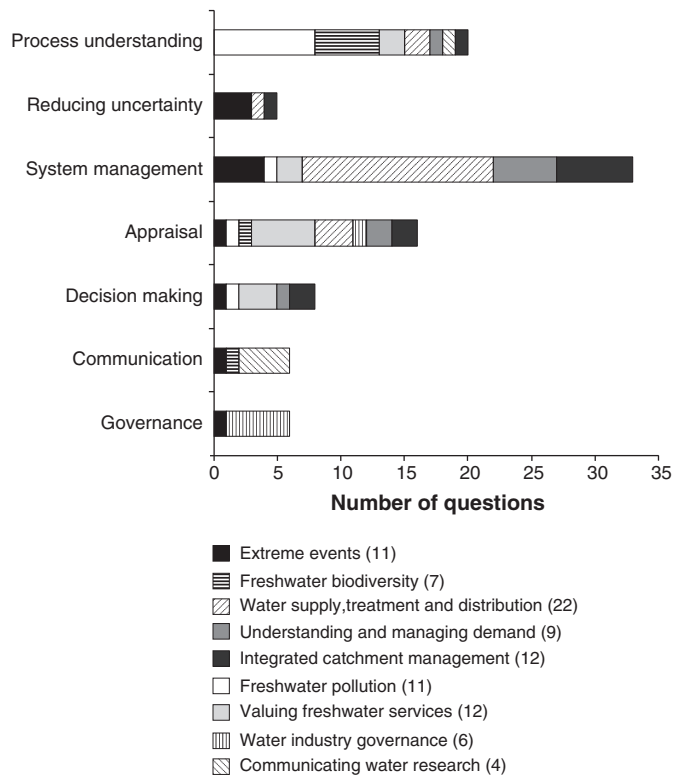


Fig. 1. Shortlisted questions by question type [number in parentheses refers to number of questions of each theme in the shortlist].

Thus, it was very welcome to see substantial engagement from a broad spectrum of UK water stakeholders in a collaborative exercise designed to develop a consensus view on the research priorities most relevant to UK water policy makers and practitioners. The exercise reported here has led to the identification of 94 key research questions across nine diverse themes, with additional survey and analysis designed to identify the priority themes by stakeholder group, the priority questions, as well as the nature of questions being posed.

We note some resonance between the findings of Sutherland's (2006) exercise on UK ecological research needs, and our own on water. This is perhaps unsurprising as there are clearly some fundamental drivers (e.g. demographic changes, climate change) giving rise to common concerns (e.g. impacts of urbanisation or farming). Some concerns and perceived solutions were common to both surveys (e.g. valuation of ecosystem services, carbon fluxes, diffuse pollution, invasive species, habitat restoration) indicating that there are mutual advantages to be had in inter-disciplinary approaches. As further experienced by Sutherland et al. (2006), many of the questions submitted prior to the workshop were similar in their theme and topic, illustrating a broad consensus among practitioners about the most pressing research questions. However, as also seen in other studies (e.g. Sutherland et al., 2006; Wenger et al., 2009), there were a number of 'questions' for which detailed studies already exist, suggesting that there are problems in terms of transferring accrued knowledge from researchers to some end users.

The popularity of general questions addressing broad policy issues, over narrow ones that scientists are best equipped to answer, was evident in some of the inputs to our exercise similar to Sutherland et al. (2006) and Morton et al. (2009). Moreover, in the post workshop dialogue, some respondents sought to aggregate questions into something overly broad and complicated (e.g. with

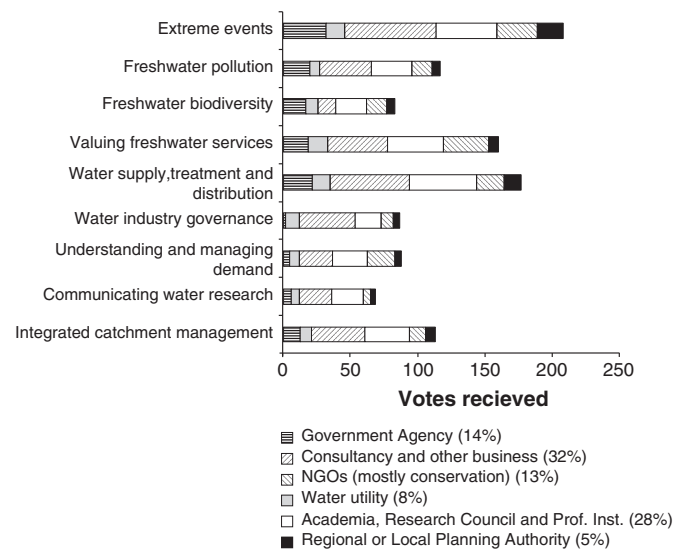


Fig. 2. Priority themes as identified following the online prioritisation survey. Each bar represents the total number of votes for all questions within a theme; themes do not have equal number of question (see text). Values in parentheses denote the stakeholder sector share of 1109 votes cast.

respect to water industry governance: "what is the best model for sustainable water and waste water service provision to ensure fair, transparent and accessible water for all, in a manner that reflects true whole life cost accounting (including ecosystem service) to current and future generations and the natural environment". There is a clear need to extract underpinning specific questions to allow researchers to proceed, but there is also a need to be clear how these underpinning questions can collectively address wider policy ambitions.

From a state of the art review of urban stream ecology, Wenger et al. (2009) concluded that scientific advances are often poorly communicated to planners, managers, and decision makers, and are often not practically implemented. This resonates with conclusions from several other studies (Sutherland et al., 2006; Morton et al., 2009; Armsworth et al., 2010) which identified a need for a more integrated analytic-deliberative process in which issues of concern can be discussed in an iterative fashion between scientists and policy makers, practitioners and businesses. This process should be supported by accumulation of evidence and meta-analysis (Pullin and Stewart, 2006). However, the good practice examples pointed out by Sutherland et al. (2006) as lessons for UK ecologists were drawn from the UK water sector (e.g. the Foresight panels' report on the Future of Flooding – Evans et al., 2004; Defra's Making Space for Water report – Defra, 2005). This, taken with wider European experience (Quevauviller et al., 2005) on science-policy integration with respect to WFD implementation, would suggest that the UK water community is developing a sound collaborative basis from which to tackle issues of water sustainability. Communication was identified as a priority theme throughout our exercise but it was the lowest ranked following the prioritisation exercise. This could indicate that good progress is being made in some areas of water research, but obstacles preventing communication of user needs and knowledge remain to be overcome in others.

The most common type of shortlisted question related to water 'system management'. Questions in this theme typically sought to understand what the effects of management interventions might be, with most of these questions of direct relevance to the water supply and sewerage industry. This indicates a clear demand for water

researchers to engage more with applied topics, many of which are multi-dimensional in scope requiring multidisciplinary approaches to tackle. The next most frequent type of question posed was that which seeks to develop basic scientific understanding, either of a physical or socio-economic process. There were several questions calling for reduced uncertainty over how a process works, mirroring long standing desires to improve the information used to underpin decision making (e.g. Reckhow, 1994). Several of the top priority questions were concerned with uncertainties in scientific research, particularly addressing the need for improved prediction of the effects of effluent on river water quality (21), future water demand (70), and particularly flooding (2, 5). It is clear from these findings that stakeholders continue to recognize the importance of basic research alongside the more problem-specific applied research that end users clearly require.

The second most common type of question asked related to appraisal, with this form of question posed across all the themes except communicating water research (although an appraisal of the efficacy of knowledge transfer routes in the water sector would clearly be useful). This desire for more integrated appraisal (IA) in the water sector reflects a wider movement towards IA observed in other domains in the UK (e.g. a formal requirement for sustainability appraisal of statutory land use plans), and elsewhere (e.g. Deakin et al., 2007). About a sixth of all shortlisted questions (including three in the priority list) explicitly address aspects of appraisal, either through a requirement to incorporate criteria normally absent from appraisal processes (e.g. ecosystem service values), or requirements to address trade-offs between potentially competing objectives not previously considered together before. This trend is consistent with the broader government agendas of evidence-based policy and of sustainable development (e.g. Sanderson, 2002).

Several of the questions that were grouped under the theme of appraisal related specifically to ecological valuation (31–37), and collectively these were the third most voted for questions in the post workshop online prioritisation exercise. This is perhaps a reflection of the extent to which the 'ecosystems approach' and the concept of 'ecosystems services' has permeated the UK water and environment sector. The importance of healthy, functioning ecosystems has come more to the fore in the last decade, as has the need to value ecosystems, following the Millennium Ecosystem Assessment (MEA, 2005) and the ongoing UK National Ecosystem Assessment (Holt and Hattam, 2009). The introduction of the EU WFD also raised awareness of the value of aquatic ecosystems but the questions that arose from the workshop suggest that much remains to be done to fully embed the 'ecosystem concept' in the water sector (see also Sutherland et al., 2006; Moss, 2008).

The theme areas voted for most in the post workshop survey were extreme events, and water supply, and the prioritisation of extreme events (see Table 1) largely reflected a concern with flooding. This is perhaps unsurprising, given the occurrence of major flood events in the UK immediately prior to the workshop (Henderson, 2010). However, it is notable that discussion of planning for, and addressing, extreme events more generally (e.g. drought) was largely absent from the debate. The strong representation of questions addressing water supply, treatment and distribution, which together with questions on demand account for a third of all questions posed, is notable. Whilst 40% of post workshop voters were from a water utility or consultancy (most of whom have water utilities as clients), these sectors were not disproportionately represented at the workshop which selected the shortlist from the questions submitted in advance. We speculate that the reason these issues receive such attention, is because the spatial and temporal dynamics of water supply and treatment are fundamental aspects of the water distribution network with major implications for all the other themes.

#### 4.2. Sustainability in the UK water sector

Whilst the UK water sector has much to do to embed sustainability in day-to-day practice, the exercise revealed that the concept of sustainable development is at least becoming more evident in the lexicon of water policy makers and practitioners. Sustainable development could not be identified as a distinct group of questions, 'corralled into their own silo'. Rather, associated concepts were threaded throughout the questions posed and several ideas consistent with sustainability goals were evident. First, long-term thinking and planning (consistent with the inter-generational equity principle; Asheim, 2010), as opposed to short-term intervention, was a recurrent theme perhaps permeating outwards from UK foresight initiatives in flooding related topics (Evans et al., 2004). This is evident in, for example, questions that address the effects of climate change on extreme event magnitude, developing the best long-term solution to water supply, and how to align agricultural policy with water resource goals. There was support also for thinking of optimal system design (e.g. 'What should a modern water/wastewater treatment plant look like if we started afresh', and 'What is the best long-term solution to water supply over periods longer than the next 30 years'). A willingness on the part of policy makers and practitioners to seek innovation from the water research community to deal with water issues in the long-term was also evident. Thinking about the next century rather than just the next five or ten years is clearly important for the future of society and the sustainability of activities that impact on water and the wider environment (e.g. Sutherland and Woodruff, 2009).

Our exercise revealed that water policy makers and practitioners were keen to address a wide range of issues across economic, social, and environmental domains. Questions addressing issues of social justice (e.g. with respect to water debt), and ecosystem services were strongly represented, illustrating that water policy makers and practitioners recognize the dependence of society upon the environment, and the importance of addressing and maintaining carrying capacity (Haines-Young and Potschin, 2007). Of itself, this broad scope of questions arguably does not point to an emerging alignment with sustainability concerns. However, many of the questions addressed the interface between the economic, social and environmental domains: for example: (31) 'What is the full ecosystem service value (including regulating, provisioning, cultural and supporting services) of freshwaters?', (40) 'What tariff structures will best support sustainable management of water resources, recognizing ecosystem services and human need?', and; (86) 'What is the right balance between the costs of water treatment and in stream ecosystem benefit?'. Such interdisciplinary questions perhaps indicate there is increasing desire to value and manage water issues in a holistic manner (Hannah et al., 2004; Petts et al., 2006), rather than by traditional economic or engineering-based forms of water management.

A characteristic of much of the discussion and many of the emergent research questions, however, was a preoccupation with resolving problems and addressing future threats through an increase in the efficiency of systems, whether they be physical, or socio-economic. The danger inherent in continually increasing systemic efficiency is increasingly recognized in the sustainability literature, which borrowing from the ecological sciences, notes that high efficiency is accompanied by a lack of system resilience, and an inability to respond to shock (physical, economic, etc.), without major adverse consequences (Gunderson and Holling, 2002; Berkes et al., 2003). This aspect of systems thinking for sustainability is beginning to emerge in an applied sense with respect to fields such as computer engineering (Jen, 2005) and urban planning (Newman et al., 2009), but with the exception of flood adaptation (and some obvious ecological instances), was not evident from outputs of our water policy exercise.

Finally, an area that received surprisingly little attention was the interface of water issues with other key sectors such as food and energy security, despite representation from both of these sectors in

the initial consultation. It is clear that water cannot be managed sustainably without consideration of other sectors that impact upon, and are in turn impacted by, water. This was recently stressed by the UK chief scientist who highlighted that global demand for water is set to increase by 30% to 2030, whilst over the same period, demands for food and energy are both expected to increase by 50% (Beddington, 2009). Key issues here might include, for example, the implication of food or biofuel production on water demand, the managed release of agriculturally productive land for flood control, and the energy/carbon cost of providing water services to a UK population expect to grow from current levels of ~60 million today to ~70 million in 2029.

#### 4.3. Limitations

It is recognized that our approach to forming and prioritising research questions is not without limitations. It may be that the survey did not gather input from some interested stakeholders either because they were inadvertently not contacted in the first place, or because the stakeholders chose not to be involved. Furthermore, individual stakeholders cannot have expertise on all relevant issues, so this could lead to a lack of recognition or emphasis being given to cross-cutting issues. It is also possible that some stakeholders took a more personal view about priority questions whereas others adopted the position of an organisation they were representing. It is not clear which position individuals adopted and whether that would in any way affect the outcome of the process. Throughout the workshop and subsequent discussions, the rewording of questions may have resulted in a loss of the original meaning of a particular stakeholder's question. However, this rewording process enabled the group to reach a consensus to ensure that all appropriate questions were relevant across a wide range of stakeholders. This was considered a powerful approach as it enabled people to openly discuss and iteratively develop ideas. Despite these limitations, we believe that the overall technique was effective, enabled wide-ranging input and was as inclusive as possible.

#### 5. Conclusions

The exercise reported here resulted in the development of a shortlist of key water questions posed by, and of relevance to, UK water professionals. The intention of the exercise is that our identification of a specific and detailed list of questions, and general issues more collectively, will contribute to a more focused and beneficial linking of water policy makers and practitioners with the water research community, both within the UK, and potentially, internationally. Analysis of these questions, and the priority ascribed to them in the post workshop online survey, has identified a number of issues which cut across these subject areas, namely:

- (1) A strong demand for improved understanding of the effects of management interventions across a range of water issues;
- (2) A need for more basic scientific understanding of a range of biological, physical and socio-economic processes;
- (3) Major concerns about extreme events, and how to manage in light of this uncertainty;
- (4) The need for more holistic appraisal of water management policy and practice to facilitate better informed decision making with respect to sustainability goals;
- (5) The need to further develop and improve collaboration working and knowledge transfer practices that currently exist between policy makers, practitioners and researchers;
- (6) A need to translate the emerging understanding of sustainability concepts into policy and practice;
- (7) A need to ensure that adequate attention is given to systemic issues, including those related to resilience, and to the interface with other strategically critical sectors, particularly energy and food.

Despite the clearly expressed need for policy and practice relevant research, we note the pertinent observations of the recent parliamentary review of the UK water sector (APPWG, 2008) that: (i) UK water research funding is currently very low at only 0.3% of water supply industry turnover (and does not support knowledge transfer to exploit innovation to the same level as currently enjoyed by the UK energy sector), and; (ii) the UK water supply/sewerage industry is largely driven by short-term planning, making it risk averse and less able to support innovative water research. The UK water community will need to find ways of overcoming these problems if the priority questions that have emerged via the collaborative workshop are to be taken forward by the research, stakeholder and policy community.

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#### Appendix A. List of organisations that contributed to the initial consultation which generated 747 questions

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5deep GmbH  
 Advanced Bioprocess Development Ltd  
 AECOM  
 Agri-Food and Biosciences Institute  
 Association of Drainage Authorities  
 Atkins Limited  
 BASF  
 BAWAG  
 BGS  
 BioFuture Ltd.  
 Black and Veatch  
 Bristol Water plc  
 BSI  
 BWB Consulting Ltd  
 Cancer Prevention & Education Society  
 CEC  
 Centre for Water Systems  
 Chartered Institute of Environmental Health  
 Clydesdale Bank plc  
 Community Composting Network  
 Dwr Cymru Welsh Water  
 East of England Development Agency  
 Eco-nomic Ltd  
 Eco-Solids International Ltd  
 EnginSoft UK  
 Entec UK Ltd  
 Environment Agency  
 Environmental Sustainability KTN  
 EURAQUA UK  
 Farrer Consulting  
 Flood hazard research centre, Middlesex university  
 Flotech Solutions Ltd  
 Flowco Mariflo Limited  
 Food and Environment Research Agency  
 GHA Livigunn  
 Grontmij  
 Halcrow Group  
 Imtech Process Ltd  
 Inspectahire Instrument Co. Ltd  
 Isle of Man Water Authority  
 Kelda Water Services  
 Morgan Est  
 Mott MacDonald

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## Appendix A. (continued)

MWH UK Ltd  
 Nice-Pak Int. Ltd  
 North Caspian Operating Company  
 North Wyke Research  
 Ofwat  
 Perth and Kinross council  
 Portsmouth Water Ltd  
 Public Services International Research Unit  
 Pullman Instruments Ltd  
 Royal Haskoning  
 Scott Wilson Ltd  
 SEAMS Ltd  
 SeSys Ltd  
 Severn Trent Water  
 Sorbisense A/S  
 South West Water Ltd  
 SWW  
 TaKaDu  
 The Difference Exchange  
 Tim Evans Environment  
 Trilogy Group  
 Trow Consulting Ltd  
 United Utilities  
 UNESCO Centre for Water Law, Policy & Science  
 URJC  
 URS Corporation  
 Van Walt Ltd  
 Veolia Water Shared Services  
 Waterwise  
 Wessex Water  
 WYG Engineering Ltd  
 Yorkshire Water Services Ltd

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