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Developing adaptive capacity within groundwater abstraction management systems

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Abstract

Groundwater is a key resource for global agricultural production but is vulnerable to a changing climate. Given significant uncertainty about future impacts, bottom-up approaches for developing adaptive capacity are a more appropriate paradigm than seeking optimal adaptation strategies that assume a high ability to predict future risks or outcomes. This paper analyses the groundwater management practices adopted at multiple scales in East Anglia, UK, to identify wider lessons for developing adaptive capacity within groundwater management. Key elements are (1) horizontal and vertical integration within resource management; (2) making better use of water resources, at all scales, which vary in space and time; (3) embedding adaptation at multiple scales (from farm to national) within an adaptive management framework which allows strategies and management decisions to be updated in the light of changing understanding or conditions; (4) facilitating the ongoing formation through collective action of local Water Abstractor Groups; (5) promoting efficient use of scarce water resources by these groups, so as to increase their power to negotiate over possible short-term license restrictions ; (6) controlling abstractions within a sustainable resource management framework, whether at national (regulatory) or at local (Abstractor Group) scales, that takes account of environmental water needs; and (7) reducing non-climate pressures which have the potential to further reduce the availability of usable groundwater.

Keywords Adaptation, robust, climate change, resilience, vulnerability, social learning

1. Introduction

Groundwater is a key resource for agriculture, which uses approximately $9x10^5$ Mm^3 of groundwater in producing a global output valued at $210-$230 billion each year (Shah et al., 2000). However, resulting over-abstraction is leading to falling groundwater levels in many aquifers throughout the world. The sustainable management of these underground resources requires that their use be attuned to their rate of replenishment through recharge, but which is becoming increasingly vulnerable to disruption due to climate change (IPCC 2007a). Although the large size and long residence times of many groundwater systems provide them with a buffer against short-term fluctuations, many systems are extremely vulnerable to the direct and indirect effects of climate change on their recharge (Holman 2006). Despite the great importance of groundwater for agriculture and this obvious vulnerability, there is widespread lack of quantification of the impacts that climate change is likely to have on the resource (Dettinger and Earman, 2007; IPPC 2007b), as the Second, Third and Fourth Assessment Reports of the IPCC have recognized.

Given the inevitability of some degree of climate change, a number of authors have proposed groundwater adaptation measures, both actual adjustments in practice and changes in decision-making environments (Mohapatra and Mitchell, 2009; Kelkar et al., 2008; Crabbe and Robin, 2006; Tanaka et al., 2006). However, these approaches which rely on a strong ability to predict future risks or to foresee the eventual outcomes of decisions are an inappropriate paradigm for conditions of significant spatiotemporal uncertainty. Some years ago, Rosenhead et al. (1972) suggested the concept of robust decision-making, which incorporates flexibility in the way that decisions are taken in the face of multiple possible futures. Instead of a prescriptive long-term plan for a certain future, the process involves drawing up a series of "small plans"; and a decision-maker chooses only the first plan while keeping the remaining plans open to revision as future conditions becomes clearer. The concept is therefore similar to adaptive planning. However, there are as yet no studies that explore how adaptive capacity can be developed to allow this kind of decision-making to be integrated into groundwater management regimes.

This paper focuses on groundwater for irrigation in East Anglia, UK, and examines how management practices that have recently been adopted at farm to national scales in a situation of increasing uncertainty have increased adaptive capacity. Also drawing on studies from other regions where farmers are facing a similar challenge, it identifies wider lessons for the development of groundwater management systems which are able to adjust to climate change (including climate variability and extremes) so as to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007b).

2. Overview of the Region

East Anglia, located in eastern England (Figure 1), has a more ‘continental’ climate than the rest of the UK. Average annual rainfall and reference evapotranspiration are around –600 mm and 530 mm, respectively. Rainfall is evenly distributed throughout the year, with the main growing season extending from around March until October and the recharge period from December to March, inclusive. Most land lies below 60 m above sea level. As a consequence of its low-lying topography, relatively dry climate, and fertile soils, this is the most intensively cultivated region in the UK. The extensive underlying aquifers, mainly the unconfined Cretaceous chalk (Hiscock et al., 1996) and Pleistocene Crag (Holman et al., 1998) aquifers have allowed many farmers to benefit from groundwater irrigation.

. Irrigation in the UK occurs on about 150 000 ha of land and, in a 'dry' year, uses approximately 160 Mm^3 of water (Woods 2000). This represents less than 1.5% of total annual abstraction, but during peak periods irrigation can account for more than 70% of abstraction in the intensively irrigated areas of East Anglia. Despite the small volumetric demand, supplemental irrigation is of great economic importance to farmers and the food industry, as it greatly improves not just yields, but the quality, consistency and reliability required by supermarkets and consumers.

The present system for abstraction control in England and Wales was introduced by the Water Resources Act of 1963, which replaced the earlier system of riparian rights. Licences are issued by the Environment Agency on a 'first come, first served' basis, with protection from derogation by new licences. Licences specify where and when water can be abstracted, the quantities that can be drawn out, and the use to which that water can be put, and they contain cessation clauses to protect other users and the environment. It is important to note that there is no provision in the law for communal rights, such as might be held in other countries, for example, by existing -- and often ancient--communities of irrigators.

3. Likely impacts of climate change

. Climate change in East Anglia is projected to produce milder wetter winters and warmer drier summers, with an increased frequency and severity of extreme events such as floods and droughts (Murphy et al. 2009). The projected changes will impact directly on groundwater systems (Holman 2006) in a number of ways:

1. Increased potential evapo-transpiration will lead to soils drying out sooner in the spring, bringing an earlier end to the winter recharge period;
2. Drier summers and increased summer and autumn evapo-transpiration will lead to a delay in the soils wetting up to field capacity, and hence to a further shortening of the recharge season;
3. Increased potential evapo-transpiration in the winter will lead to increased vegetation water use;
4. Wetter winters may increase winter recharge;
5. Increased rainfall intensity may lead to increased runoff and reduced recharge;
6. Increased atmospheric CO_2 concentrations will increase the rate of photosynthesis, reduce transpiration and dark respiration (MAFF, 2000; Drake et al., 1997) and lead to increased usage efficiency of radiation and water.
7. Salt water intrusion is unlikely to be a significant limit to groundwater abstraction in the region in the future.

Whether future groundwater recharge increases or decreases in eastern England will depend on whether the increased winter precipitation (central estimates of change of +12-16% by the 2050s across the emissions scenarios) compensates for the shortening of the recharge season of up to 6 weeks (Holman and Loveland, 2001). However, studies by Holman et al. (2005, 2009), Holman (2006) and Herrera-Pantoja and Hiscock (2008) suggest that future regional groundwater recharge will decrease by around 5-20% by the 2050s. The likely increasing demand for irrigation caused by climate change (Weatherhead and Knox, 2000) will be in competition for water with other users (e.g., domestic consumers and the environment), whose demand for water will also reflect climate change as well as other socio-economic changes (Henriques et al., 2008; Environment Agency, 2001). A recent survey of irrigators by the National Farmers Union (NFU, 2007) found that 58% of respondents were affected by the most recent 2006 drought, of whom 61% see climate change as a threat to their future water use and 53% are concerned about planning for future droughts.

4. Adaptation in groundwater irrigation management at national to farm scales

The abstraction licensing authority (the Environment Agency), like the irrigators, faces many challenges in managing for, and coping with, the potential impacts of climate change. This uncertainty is recognised in the national Water Resources Strategy (Environment Agency, 2009). However, whilst there is an expectation that direct abstraction of groundwater for irrigation will become increasingly less secure as a consequence of the impacts identified in Section 3, the combination of uncertainty arising from the implementation of new European and national policies, and the short-term economic pressures faced by agriculture, means that few irrigators are taking action to cope with the anticipated future climate change. Nevertheless, a number of actions have been implemented in recent years at national to farm scales to cope with current climatic variability. These actions and their contribution to increasing adaptive capacity to the expected climate change are reviewed in the following sections.

4.1 Changes to the abstraction licensing system

The Government publication “Taking Water Responsibly” (DETR and Welsh Office, 1999) introduced changes in the abstraction licensing system. Foremost among these was the proposal for the development of Catchment Abstraction Management Strategies (CAMS), which aim “to provide a framework for resource availability assessment” and produce a “licensing strategy which aids the sustainable management of water resources on a catchment scale”. Key elements of the CAMS are:

- The resource assessment, resource availability status and sustainability appraisal components are within a 6-yearly water resource planning cycle. By providing an indication of the availability of water resources within river catchments taking into account the environmental needs of rivers and wetlands (Dunbar et al., 2004), CAMS highlight where additional abstraction may take place – designated as “water available”. They also identify where current levels of licensed abstraction exceed the resources available- “over-licenced” or “over-abstracted”. Where this is the case, CAMS facilitate discussion of the mechanisms to regain a sustainable level of abstraction.
- Abstraction decisions take place at a local level - catchments are divided into water resource management units (WRMUs), which define the largest subdivision of the aquifer or catchment that can be managed in the same way;
- The CAMS process makes more information on water allocation publicly available and allows a balance to be struck, in consultation with the local community and interested parties, between the needs of abstractors and those of the aquatic environment (Dunbar et al., 2004).
- Integration of surface and groundwater resources - a water balance is calculated for each WRMU based on river flows, groundwater recharge, abstractions, discharges, and a resource allocation for the environment and any

other water uses or features that require protection. Managing surface and groundwater resources within a single framework should allow more efficient conjunctive use;

- CAMS should facilitate more licence trades in the future to encourage a better utilisation of scarce resources (Environment Agency / Ofwat, 2009).
- All new licences are issued on a time-limited basis, but with a presumption of renewal provided that the licensee continues to meet three renewal tests- continued environmental sustainability (as determined by the CAMS process), continued justification of need (as demonstrated by the farmer) and efficient use of water (by the farmer).

4.2 Changes in the management of land overlying aquifers

High and/or rising nitrate levels in some groundwater management units in East Anglia is restricting the use of that groundwater for drinking water, putting increased pressure on better quality groundwater in nearby units and reducing future adaptive capacity. Traditionally, water policy and agricultural policy have been independent in Europe, but the European Nitrates Directive (91/676/EC), the Water Framework Directive (2000/60/EC) and the daughter Groundwater Directive (2006/118/EC) will affect the way that the land overlying aquifers is managed in order to enhance water quality:

- The Nitrates Directive requires that all land draining into waters--both ground and surface-- affected by nitrate pollution are designated as Nitrate Vulnerable Zones (NVZs). In these areas an Action Programme of measures must be implemented to reduce nitrate losses within a 4 year review period: e.g., limiting application of inorganic and organic fertilisers, and closing certain months to the use of slurry, sludge and manure on high-risk soils.

- The Water Framework Directive (WFD) establishes a strategic common framework for managing surface water and groundwater. Key environmental aims of the WFD for groundwater are: (1) to protect, enhance and restore polluted groundwater to ‘good status’ based on targets for both quantity and quality, (2) to prevent or limit input of pollutants into the groundwater, and (3) to reverse any significant upward trends in the concentration of particular pollutants. Most of the groundwater units in East Anglia have been identified as being ‘at risk’ of failing to meet the chemical content objectives, particularly from diffuse source pollutants. The environmental objectives and the programme of delivery actions to meet them are embedded within a 6-year cycle of River Basin Management Plans.

4.3 Development of Water Abstractor Groups

Over 1000 farms in eastern England, both large and small, depend on supplemental irrigation in order to supply high quality produce for the market. However, agriculture is last in line when it comes to allocating water in times of severe drought; domestic and industrial users and ‘the environment’ are given higher priority. To counterbalance this, irrigators arguably need to have a more coordinated and coherent voice at the local level in order to ensure that they get an adequate or ‘fair’ share of the available water resources at such times (Knox et al., 2007). In any discussion of what a ‘fair’ share might be, farmers must be able to demonstrate the importance of water to agriculture and to the nation’s food supply and security.

Developing farmers' institutional capacity to organize themselves to defend their water rights is therefore central to ensuring the long-term future of irrigated farming (Leathes et al., 2009).

For many farmers in the east of England, working together to form Water Abstractor Groups (WAGs) is an effective way of creating a robust lobby to better defend and secure their water rights, especially in the face of a growing risk of scarcity. Although a relatively new concept in UK agriculture (Rudge and Gowing, 2002), many successful abstractor groups—more often referred to as irrigation communities--are found throughout the world, often having been in existence for long periods of time (e.g. Peru, Mexico, Spain, India, Nepal, the Philippines – Trawick, 2003, 2008). Two examples of groundwater-focussed WAGs in East Anglia are the East Suffolk Water Abstractors Group (ESWAG) and the Broadland Agricultural Water Abstractors Group (BAWAG).

ESWAG was formed in 1997, at a time when local irrigators felt threatened by a possible cessation order from the Environment Agency, which would curtail abstractions during a drought (Water Resources Act, 1991, Section 57). This resulted in a confrontation, in part because the two sides disagreed on the data that should be used in making decisions on the cutbacks. The irrigators felt powerless in the face of a regulator that they believed did not appreciate the importance of irrigation in the region. Today, ESWAG provides a united and credible voice to put forward reasoned arguments to the regulator within an open and cooperative relationship, which increases their ability to meet future challenges (Knox et al., 2007).

BAWAG has 170 members (representing around 80% of the area's abstractors), and was formed in 1998 in response to a slightly different set of concerns. Farmers were troubled by proposed changes to the abstraction licensing procedure, by the increased difficulty that some were having in renewing existing licences, and by a sense that farmers needed to work together in order to represent effectively their mutual interest. Today BAWAG aims to maintain good dialogue with the Environment Agency, to participate in public consultations, and to promote best irrigation practices amongst their members, for which BAWAG was recognised at the Environment Agency Water Efficiency Awards 2007. Because members are now seen to be irrigating responsibly, a much better working relationship with the Environment Agency has emerged, making sudden and unexpected restrictions on their abstractions in times of future drought much less likely (Leathes et al., 2008).

Where Water Abstractor Groups have formed, farmers have come together to defend their rights to irrigate, to build a direct channel of communication between themselves and the regulator, to foster a firm commitment among members to use water efficiently, and to provide a strong voice to influence future water policy. WAGs can facilitate an ongoing constructive dialogue with the Regulator on how best to use limited water resources in their catchments and how to deal with supply issues during times of drought. Members of both groups are keenly aware that that their negotiating power in this regard is much greater than that of irrigators who have not organized.

4.4 Investment in more efficient irrigation technologies

Farmers must now pass tests within the abstraction renewal process demonstrating: 1) continued ‘reasonable need’ , and 2) efficient use of the abstracted water . In this effort, farmers benefit greatly from being able to show that they are using improved irrigation technologies and improved scheduling methods, both of which are being supported by a range of regionally and nationally funded initiatives, including workshops and published guides (e.g. Knox and Kay, 2007). Efficiency improvements are also occurring due to the significant typical total average costs for applying irrigation water of £0.40–£0.45/m^3 for direct abstraction, and £0.63/m^3 for water stored in a farm reservoir (Knox et al., 2000), both of which include the full recovery of the costs and Environment Agency charges.

Weatherhead (2007) shows that there has been continual growth (up from 52% of the total irrigated area in 2001 to 60% in 2005) in the proportion of the region where irrigation is scientifically scheduled. The main approaches used are water balance calculations and in-field soil moisture measurement. However, farmers still rely on their own judgement and on traditional indicators--e.g., feeling the soil, inspecting the crop, etc-- on 34 % of the total irrigated area. It is not clear whether scientific scheduling is leading to less water being used (as better management should allow a given area to be irrigated with a smaller volume, but could also allow an expansion of the irrigated area), but it does allow farmers to demonstrate 'efficient use' to the Environment Agency. NFU (2007) found that 82% of respondents said they were more aware of water efficiency than they were five years ago (62% in 2001), and that 88% of farmers carry out at least one water saving tactic and 64% use two or more tactics.

Weatherhead (2007) showed that hose-reel irrigation systems remain by far the predominant technology used by area (86%), but that the proportion irrigated by hose-reels fitted with booms rather than guns has increased slightly. Little change was observed in the proportion of land watered using static or hand-moved sprinklers, spray lines, centre pivots or linear moves, and trickle or drip irrigation methods. This differs from NFU (2007) which showed a significant reduction in the area irrigated using rain-guns, with a much greater area being irrigated using the alternative, more water-efficient methods.

It is likely that the increased awareness and application of water saving tactics results from a sequence of events – the sudden past imposition of drought restrictions; the increasing difficulty in getting new summer licences; the increased cost of energy- which has been reinforced by messages from the Environment Agency, the UK Irrigation Association, the National Farmers Union etc., about future climate change.

4.5 Installation of on-farm reservoirs

Several factors are adversely affecting the availability of water supplies for irrigation in the region, including more environmental protection requirements embedded in the CAMS and the WFD and increasing competition for water from other sectors. New licences for summer abstraction are now widely unobtainable. In addition, many existing summer water sources are becoming less reliable, as direct abstractions of groundwater for irrigation are vulnerable to the Section 57 cessation orders during droughts, particularly where they are considered to impact low flows or water levels in groundwater dependent ecosystems. A farmer given such an order to cease irrigating receives no compensation and so has major financial implications.

Farmers are therefore increasingly interested in constructing on-farm reservoirs, as once water is in a reservoir, it is the farmer's to do with as (s)he wishes, thus providing security of supply. Reservoirs are generally filled during the winter months, when groundwater levels and river flows are highest and abstraction charges are lowest- charges for winter abstraction are one-tenth of the cost of equivalent summer abstraction.

The number and volume of on-farm reservoirs has shown a steady increase since the mid 1970s (Figure 2). Weatherhead (2007) suggests that 42% of respondents in England had at least some on-farm water storage. There were 1069 licences in 2007 in the Anglian region for "spray irrigation storage", which together accounted for 41% of the total annual volume licenced for spray irrigation (Weatherhead et al., 2008).

5. Discussion

It is apparent from the preceding sections that a range of changes have been implemented at different scales by farmers and other stakeholders in East Anglia:

- National
  - i. Changes to the abstraction licencing system- enabling adaptive management;
  - ii. Changes to land management- reducing water quality threats to groundwater resources.
- Water resource management unit
  - i. Development of Water Abstractor Groups- improving adaptive capacity and social learning;
- Farm
  - i. Investment in more efficient irrigation technologies- reducing demand, demonstrating efficient use;
  - ii. Installation of on-farm reservoirs- diversifying supply, reducing summer abstraction demand, avoiding drought restrictions.

The question therefore becomes, to what extent are the practices consistent with purposeful adaptation? Do they build adaptive capacity and contribute to the development of resilient social systems (Carpenter et al., 2001)? And what barriers exist to further adaptation in groundwater management? Adaptation is not about returning to some prior state but about moving to some new acceptable alternative state, as all social and natural systems evolve or co-evolve over time.

Adger et al. (2005) suggest that most adaptation is reactive but that it can also be anticipatory when based on some assessment of future conditions. Given that the identified changes at farm to national scale are not in direct response to climate change, and nor is climate change currently factored into the decision-making process, it is unlikely that these changes can be considered as purposeful or anticipatory adaptation. The new practices are therefore discussed with regard to how they act to increase adaptive capacity.

5.1 National-level

The control of diffuse and point source pollution is needed to ensure the continued aquifer-wide utility of groundwater for public water supply, thus ensuring that irrigators do not lose out as public water companies seek new resources to replace those lost by pollution. The changes in land management that will be necessary in order to meet the requirements of the Nitrates Directive and the WFD are not intended as a means of adapting to climate change. However, because climate change is likely to lower rates of groundwater recharge, and consequently reduce the capacity of groundwater to dilute diffuse-source pollutants, the two are in fact closely related. Climate change is likely to make further modifications in practice necessary at the farm level, but the cyclical planning and review process for the two Directives allows an adaptive management approach to reducing pollution and increasing the utility of groundwater resources for future abstraction by farmers and, more generally, for ecosystem services.

5.2 Water resource management unit

Local individuals can often feel powerless within natural resource management systems, particularly due to the lack of access to high-level stakeholders and decision makers (Brown et al., 2001). The development of Water Abstractor Groups has been largely a reaction against this, and is a form of collective action whereby the efforts among groups of individuals is co-ordinated to achieve a common goal (Trawick 2008). However, the benefits of WAGs are greater than this, due to the capacity of social networks to enhance adaptive capacity (Tompkins and Adger, 2003).

WAGs in East Anglia have invested in commissioning and disseminating research to their membership on irrigation efficiency, training, benchmarking, and economic performance, all of which have helped to increase the capacity of their members to irrigate efficiently and derive improved economic returns. More mature WAG's such as the Lincoln Water Transfer Ltd have developed duties or responsibilities for the collective management of their water resources (Leathes et al. (2009), which is unique evidence of evolutionary change within a WAG in the UK.

The capacity for learning and adaptation is evident within the WAGs and the wider policy frameworks. The increasing utilization of scientific scheduling, water saving technologies and irrigator training encouraged by WAGs allows farmers to demonstrate good practice in their dealings with the Environment Agency. This in turn lends credibility to their lobbying position and adds legitimacy to their requests to be allowed to keep irrigating during dry periods. However, it would be advantageous for WAGS to be able to work out a set of institutions for cutting back their abstractions on their own during droughts, as irrigator groups in other parts of the world are often able to do (Trawick, 2008), as an alternative to having them cut back altogether by the regulator.

5.3 Farm-level

The ability of farms to buffer disturbances (i.e. droughts) is enhanced by reservoirs (which increase summer storage and allow irrigation demand and environmental demand to be increasingly de-linked and de-synchronised), by water trading, by improved irrigation efficiencies (through increasing utilization of scientific scheduling and water-saving technologies), and by improved communication between the regulator and the regulated, facilitated by WAGs. The improved information exchange between the regulator and irrigators is vital to avoid the significant economic losses associated with sudden (and largely unexpected) restrictions on licenses during droughts. Prior knowledge of the likelihood of restrictions (whether total or partial) allows farmers to apply coping strategies based on their individual circumstances (Knox et al., 2000). These can be either short-term seasonal plans, or longer-term strategic choices. Short-term plans might include re-scheduling the timing of abstraction to preserve available water, re-scheduling the allocation of water to prioritise specific high-value crops, or modifying the irrigation application (depth) and/or timing (interval between irrigations).

5.4 Barriers and limitations

All of the above activities are increasing the adaptive capacity of the groundwater irrigation sector to cope with anticipated climate change, but there are significant barriers or limitations. The construction of reservoirs and the installation of water saving technologies are long-term strategic developments and also major capital investments, which require confidence in the future availability of water, although reservoir-sharing has emerged as a means of spreading these costs and risks. Under the current abstraction licensing system, abstractors can be sure of their licence for no more than 12 years ahead. The combination of short-term economic uncertainties surrounding agricultural production, very limited state financial support for capital investment, and future uncertainty over water availability provides significant investment barriers for many farmers. Future increases in temperature are likely to lead to increased evaporative losses from such reservoirs which may not be recognised is current designs.

The sharing of water resources through water rights/allocation/entitlements trading has yet to develop in the UK, even though legislation allows it. This reflects in part uncertainty over the processes involved and the greater simplicity of existing informal practices, in which farmers simply rent or purchase land that has an abstraction licence, thus getting access to the associated water. The potential for water trading is large, as many abstraction licences are never or only partially used, so that water trading could enable farmers to exploit available water resources more efficiently in space, especially if water rights can be traded. The danger, however, is that in areas where water resources are already under pressure, the re-activation of so-called sleeper or unused licences could cause an even greater conflict between the interests of ‘the environment’ and those of the abstractors. Avoiding this will require very careful monitoring, and it may be necessary to revoke some licenses or prevent certain trades from taking place in order to stabilise abstractions at a sustainable level (Weatherhead et al., 2005).

The abstraction opportunities afforded by better conjunctive use of surface and groundwater require improved guidelines to make more use of the higher river flows in the “wetter” winters and saving groundwater for when rivers are low; and/or making better use of the difference in timing between high irrigation demand and low groundwater levels (Weatherhead et al., 2005).

Despite the many changes implemented, some irrigation is becoming more *sensitive* to climate change, as direct summer abstractors are increasingly subjected to time-limited licences and the setting of hands-off levels (which trigger the cessation of abstraction in severe droughts). However, it is unlikely that the changes already implemented will be sufficient to cope with the range of future water resource outcomes anticipated by climatic and socio-economic change (e.g. Holman et al., 2005).

5.6 Maladaptation

Despite abstraction licencing control to maintain resource sustainability, some potential maladaptation has emerged. Historically, trickle irrigation was exempt from the need for an abstraction licence, such that the use of trickle increased fivefold between 1990 and 2001, accounting for about 5% of the volume of irrigation abstraction (Knox and Weatherhead, 2005). This growth was driven by the commercial motivations, rather than the environmental benefits of water savings *per se*, but switching from spray to trickle irrigation was encouraged by government (Defra, 2002) and the regulator as a means of increasing water use efficiency. However, the increasing and unregulated volumes of water abstraction for trickle had implications for water resource management, as much of the growth in water-short catchments was on newly irrigated crops, for which a spray irrigation abstraction licence would not have been issued (Knox and Weatherhead, 2005). Given the potential importance of these unregulated abstractions on water resource management, trickle irrigation had to be brought into the regulatory system with the Water Act of 2003.

5.7 Wider lessons

Although this case study has assessed the irrigated sector of a single developed country, there are a number of lessons which have wider applicability:

1. Approaches to water abstraction management needed to integrated both horizontally (cross-sectoral harmonisation of policy and practice) and vertically (across the scales of governance involved in management, from the local upwards to the national).

2. The need for adaptive management – adapting for climate variability/climate change within the irrigated sector is not about a single action. Multiple approaches at different scales need to be embedded within an adaptive management framework which allows strategies and management decisions to be updated in the light of changing understanding or conditions (Figure 3)

3. Making best use of water resources which vary in space and time – water is not necessarily available in the quantities desired at the time or place it is needed. Actions which allow better use of resources by, for example, offsetting the timing of peak demand and the timing of least resources (e.g. reservoirs), reducing demand (e.g. improved efficiency) or spatially separating demand from supply (e.g. water transfers) are obviously beneficial. However, many other actions will contribute to the goal of making best use of water resources, such as good soil management and soil water conservation (to increase rooting depth, water infiltration,

soil water storage); rainwater harvesting; managed aquifer recharge (e.g. recharge dams) etc.

4. The need to control all significant abstractions within a sustainable resource management framework, whether at national (regulatory) or at local (collective action Water Abstractor Group) scales, that takes account of environmental needs;

5. Demonstrating efficient use of scarce resources – by adopting water saving technologies and improved irrigation scheduling, and carrying out water audits to calculate the benefits of irrigation, irrigators are able to demonstrate that they are efficiently and productively using a scarce natural resource – getting "more crop per drop". This provides legitimacy in irrigators' dealings with the authorities and reduces the risk of sudden abstraction restrictions, but can be done at both an individual and a group scale or level;

6. Collective action – the coming together of many irrigators into Water Abstractor Groups produces a number of benefits – a single point of contact for the authorities; increased lobbying power; increased potential for improving practice and increasing efficiency, whether through training, discussion, benchmarking etc; sharing of facilities/equipment; and the opportunity to develop institutions to proactively cut back abstractions during droughts etc (Fig. 3).

7. Reducing non-climate pressures – given the pressures of climate change, it is important that non-climate pressures, such as diffuse source pollution, which have the potential to reduce the utility of groundwater, are reduced.

6. Conclusions

Irrigation within the UK climate is predominantly supplemental, to ensure the high quality produce demanded by supermarkets and consumers. A range of important changes in groundwater management have been implemented at national to farm scales by the regulator and the regulated agribusinesses. At a national scale, groundwater abstractions are managed within the same regulatory framework as surface water, with a cyclical resource assessment framework which facilitates adaptive management. National strategies for controlling diffuse source pollution are reducing water quality threats to groundwater resources and ensuring future utility. At a water resource management unit scale, the development of Water Abstractor Groups is improving the adaptive capacity of rural agricultural businesses and empowering the irrigated agricultural sector within the water resource planning cycle. Finally, at farm scales, irrigators are investing in more efficient irrigation technologies and installing on-farm reservoirs to diversify supply and reduce summer abstraction demand. The implementation of these is not directly driven by climate change (although the publicity around climate change is certainly affecting expectations about future water availability), but all are increasing the adaptive capacity of the irrigation sector to cope with the anticipated but uncertain impacts of climate change.

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Figure captions

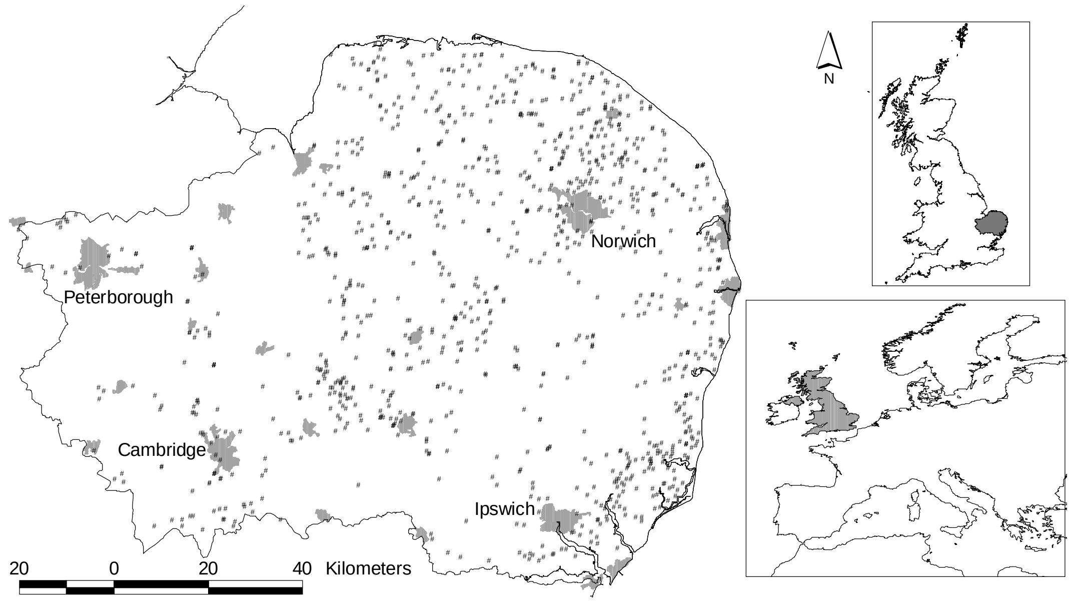

Figure 1 Distribution of agricultural spray irrigation licences using groundwater in East Anglia (Source: Environment Agency) and (inset) location of East Anglia and the United Kingdom

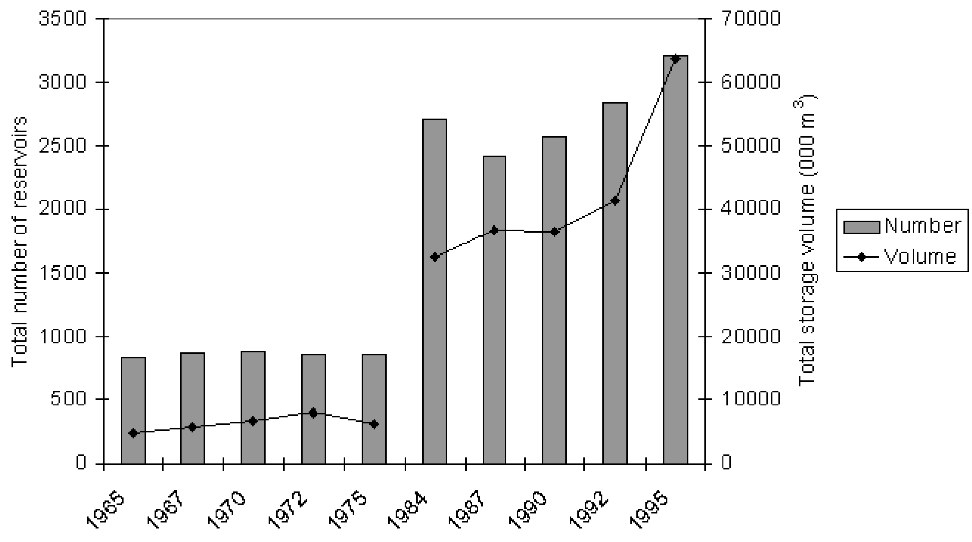

Figure 2 Growth in total number and total storage volume of on-farm reservoirs in England from 1965 to 1995 (adapted from Weatherhead et al., 2008)

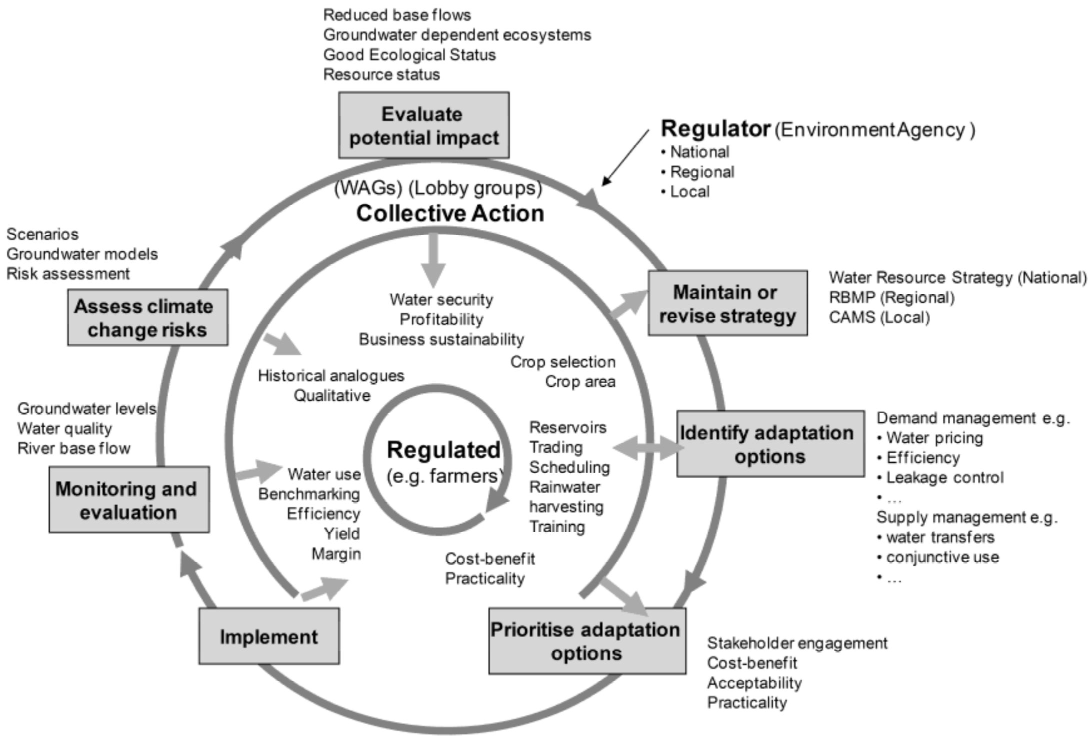

Figure 3 Multiscale adaptive management framework for groundwater. Dark grey arrows indicate the cyclical process of the regulator, Water Abstractor (collective action) group and the irrigated farmer; pale grey arrows indicate the directions of influence of the Water Abstractor Group