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Phase 2 final report

Research into water allocation through effective water trading

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Cover photograph: River Great Ouse in East Anglia

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Foreword

Globally the climate is changing and long term access to secure supplies of water is one of the most pressing challenges the world faces. At home our region is one of the fastest growing in the UK; water supplies are limited, and the east of England is one of the areas most vulnerable to the impacts of climate change.

Against this backdrop, and in a year of weather extremes, it has never been more important or timely to explore innovative and collaborative solutions for the allocation of our water resources. This year Anglian Water has joined forces with Defra to co-fund a piece of innovative research on water allocation in collaboration with the University of Cambridge Programme for Sustainability Leadership (CPSL) and a diverse range of project partners and stakeholders.

Using the Upper Ouse and Bedford Ouse catchment as a case study, the main aim of the research was to test water trading as a way to allocate water between stakeholders more effectively. Working with leading thinkers, experts and people on the ground we have explored the issues surrounding water allocation from each of their perspectives and developed a shared understanding of trading potential at a local level within environmental limits.

Using innovative methodologies the project sought to generate evidence to inform policy rather than seeking to make specific policy recommendations. It considered a variety of market and regulatory arrangements that could help to inform thinking on the methods through which water abstraction licences could be traded in the future in England and Wales.

At Anglian Water we have a strong record in managing supply and demand. And through Love Every Drop, our sustainability strategy, we are committed to changing fundamentally the way people value and engage with water, putting it at the heart of a whole new way of living.

However we recognise that we cannot address the significant challenges facing our region's water resources on our own. And we know it is only collective action and collaboration which will help us achieve sustainable and effective water allocation.

The strength of this project lies in the broad range of stakeholders and experts it brought to the table. The research project has been steered by a Working Group made up of local and national stakeholders including: Anglian Water, Department for Environment, Food and Rural Affairs (Defra), National Farmers Union, the Royal Agricultural Society of England, Natural England, the Environment Agency, Ofwat, WWF-UK, Association of Drainage Authorities, Cranfield University, Atkins, the Royal Society for the Protection of Birds and the Broads Authority.

Particular thanks must also go to HR Wallingford, an independent company that carries out research into the water environment and climate change, for leading the team; Collingwood Environmental Planning for the stakeholder engagement part of the project; Dr Julien Harou of University College London and Dr John Raffensperger of the University of Canterbury in New Zealand for looking at tools that can assist in promoting the trading of water and Professor Mike Young, Director of the Environment Institute at Adelaide University in Australia, who has provided expertise on water entitlement and water allocation systems used worldwide.

I hope that the work outlined in this report will inform the development of policy on water trading and that we continue to build on the collaborative approach that was so invaluable in testing the potential effectiveness of trading models.

Jean Spencer

Regulation Director, Anglian Water
Chair, Water Allocation Working Group for the University of Cambridge Programme for Sustainability Leadership

Executive summary

This report presents the findings from a collaborative research project that explored the feasibility and effectiveness of water trading systems and their implications for stakeholders concerned with sustainable water abstraction. The project was completed as part of the University of Cambridge Programme for Sustainability Leadership (CPSL) and the 'Collaboratory on Sustainable Water Stewardship'.

The objectives of the research were:

- To establish the feasibility of an effective trading system at a catchment level;
- To provide stakeholders with a shared, credible, evidence base about water trading at a catchment level;
- To generate evidence to inform policy rather than make policy recommendations.

The work was carried out in two Phases:

- Phase 1 – Engagement with the key stakeholders to document and assess their understanding of how water trading could work in the future;
- Phase 2 – The development of two demonstration water trading systems for the Upper Ouse and Bedford Ouse catchment to show to abstractors in the catchment how different types of water markets could work.

The drivers for this research at a policy level emanated from a number of sources including the Water White Paper and associated documents published by the Environment Agency and Ofwat on the "Case for change" in late December 2011. The White Paper commits the Government to reforming the abstraction management regime by the 2020s. Current licensing arrangements are unlikely to deal efficiently with extended periods of water scarcity, a long-term decline in availability, and greater volatility of supply. This research commenced at the beginning of May 2012 at a time when East Anglia had experienced a two year long drought. Although the onset of a very wet period from the beginning of April 2012 alleviated the drought, the issues of water allocation and water use efficiency were still very much at the forefront of most abstractors' minds. In October 2012 Paul Hammett, the National Farmers' Union's (NFU) environmental policy adviser in East Anglia, described the 2012 drought as a "near miss" for growers, but viewed it as an opportunity to improve the situation.

Our research has been focused on the Upper Ouse and Bedford Ouse Catchment Abstraction Management Strategy area in East Anglia.

Phase 1 of the research comprised interviews and focus groups with 27 stakeholders: abstractors holding abstraction licences in the catchment; innovators (who have implemented innovative water management techniques) and delivery agents such as the Environment Agency. The research focused on their views on water management in general and on two possible trading approaches (improved pair-wise and common pool). We report those views here without comment on their validity or economic wisdom. The main findings of the Phase 1 stakeholder engagement were the following:

- Within the study catchment, the interrelationship between the licence types and the abstraction timing complicates water management. As a result, each abstractor encounters a different set of challenges and opportunities in managing their water resources. This complexity will need to be taken into account in designing and operating trading systems;

- Currently, abstractors engage in a number of water management practices in order to ensure they have enough water at the right time and place for their businesses. This includes "informal" trading, between trusted sources at times of need;
- Some abstractors perceive that the introduction of a water market would 'force' them into trading;
- There is widespread lack of knowledge and awareness of water trading across all types of stakeholders. As a result, the opportunity exists to be able to discuss trading. We found no evidence of entrenched views: we saw neither outright rejection nor committed support for increased trading in water or a new system to facilitate it;
- Abstractors raised the issue of ring-fencing, specifically within agriculture. Farmers expressed a perception that they would lose out to larger abstractors if trading of licences were to be introduced;
- The Innovators appear to provide useful links between farmer abstractors and the Environment Agency or the Internal Drainage Boards.

In Phase 2, we developed and trialled two new trading systems:

- An improved pair-wise trading system;
- A smart market or common pool method.

Currently, pair-wise trades are possible; however, initiating a water trade and getting regulatory approval can take several months. The improved pair-wise system, as suggested, intends to increase the speed and flexibility of water trading, and, in some cases, pre-approve trades. To understand the impact of the improved pair-wise approach, a model was developed that provided illustrations of who would trade with whom based on the assumptions that (i) there were some pre-approved trades and (ii) trades happened on a short term temporary basis. Implementation of the improved pair-wise approach would require a bulletin board where people could indicate their willingness to trade, with an assessment of the environmental constraints in the catchment. Participants were shown some of the outputs from a model of pair-wise trading to aid discussions during the two workshops.

In the common pool method, abstractors would buy and sell water rights with a catchment manager (such as the Environment Agency). Users would place offers to sell or bids to buy on a web page, and the catchment manager would clear all trades simultaneously, using a water balance model, following a regular schedule (e.g. weekly or even daily). The water balance model would ensure that environmental flows were satisfied. Users could offer to sell or buy water for future weeks. Within minutes of the market-clearing, users would have firm rights for the immediate period and conditional rights for the future periods.

The common pool method relies on a model that optimises the allocation of water, based on water availability, environmental conditions and how much people are prepared to pay for the water. This project developed such a model for the Upper Ouse and Bedford Ouse catchment. Abstractors who came to the workshops were able pilot the approach using this model.

Both methods were demonstrated to 15 stakeholders (abstractors, innovators and regulators) in two workshops held in October 2012. Overall, this research has shown the potential benefits of new ways of water trading, highlighting some risks and challenges that need to be overcome to take this work forward. These are summarised below:

- **Flexibility** - We found general agreement that the common pool and pair-wise trading systems provided more flexibility than the current licensing system in facilitating short-term trading of water;

- **Weekly trading** - Most abstractors saw that a licensing system that allowed them to trade on a weekly basis would provide sufficient flexibility;
- **Improved information** - Most stakeholders saw that web pages and maps, showing where abstractors are willing to buy and sell water, would be useful;
- **Evolution of current approaches -** Short-term pair-wise trade, which involved primarily decreasing trade regulatory approval time, was generally seen as a relatively small change to the status quo;
- **Independence from new licensing systems** - Short-term trading would likely provide more benefits under a state-of-the-art licensing system (such as a shares system with future environmental flows being met), but short-term trading would still provide a large share of its benefits under the current licensing system (i.e. volumetric licences with hands off flow conditions);
- **Risks** – The research revealed the following risks with regards to:
  - **Certainty of supply** - This concerned some abstractors, such as the public water supply company who have a regulatory obligation to supply water. Abstractors perceived risks under the common pool method, if they bid below the clearing price then they will not obtain their quota;
  - **Allocation to high value water uses** - Some participants expressed concern that the proposed trading systems would allocate water to sectors considered to have a higher economic value or social value; this concern was reinforced by the pair-wise modelling which explicitly modelled trades by assuming lower willingness to pay users would trade to those abstractors willing and able to buy;
  - **Lack of water for low values users** - The purpose of water trading is to encourage water to move to higher value uses whilst protecting the environment. This shift could possibly lead to a lack of water for lower value users. This concern may need to be tackled by policy-makers to encourage water trading;
- **Challenges** going forward are as follows:
  - **Pricing bids** - In the common pool method, users had difficulty in choosing bids. This difficulty related to the associated lack of price history, the novelty of the market and also users' lack of knowledge about their own value for water;
  - **Learning processes** - Complex trading systems such as the common pool method involve a change of mind-set by abstractors and require a period of learning to understand them. Abstractors expressed some concern that they could lose money whilst learning how the system operated;
  - **Reliance on models** - Many stakeholders expressed a view that for any trading system to be trusted the underlying hydrological and optimization models would need to be reliable and accurate, and they would need to be convinced that this was the case.

The project has shown the potential for new forms of water allocation based on better information, participation of stakeholders and the use of economic water resource models. However, these results are based on engagement with a limited number of abstractors for a single catchment study. Broader engagement is required to confirm these results.

Glossary of terms

Abstraction – The removal of water from surface waters (i.e. lakes, reservoirs, rivers) and groundwater for agricultural, domestic, commercial, power and industrial uses.

Abstraction licence – A licence that gives the holder a right to take a certain quantity of water from a source of supply (e.g. inland waters such as rivers or streams or an aquifer). Many abstraction licences have restrictions defined by hands off flows or hands off water levels. In times of low flows the newest abstractors are restricted first, thereby protecting the environment and those with historical abstraction rights.

Abstractors – Holders of water abstraction licences within the Upper Ouse and Bedford Ouse catchment.

Assessment point – A location in a catchment at which the regulator measures the hydrological state, usually river flow rate, river level, or aquifer head. This provides an indicator of the local environmental health. If the state at this point is above a certain minimum (and also possibly below a certain maximum), at a given time, then the environmental obligations are considered satisfied in that local area, at that time.

Bonding capital – This is the social connectedness that uniquely follows when individuals from within a particular group relate closely to one another.

Bridging capital – This is the social connectedness that results when members of dissimilar groups engage with one another.

Catchment – The area of land drained by a watercourse or area recharging a specific groundwater aquifer.

Catchment Abstraction Management Strategies (CAMS) – A document produced at a catchment level in England and Wales by the Environment Agency to provide a consistent and structured approach to local water resources management, recognising the reasonable needs of abstractors and the needs of the environment.

Clearing price – The price at which the quantity supplied equals the quantity demanded. In the common pool method, the market manager determines the clearing price using an optimization model. In the improved pair-wise trading method, the two parties agree on a price.

Common pool method – A method of trading in which users trade water rights with a catchment manager, i.e. a many to one relationship, rather than via a pair-wise (one to one) relationship. The common pool method in this research differs sharply from ordinary auctions (in particular those used to trade water in Australia) in its use of a water balance model based on hydrological optimisation.

Delivery agent – An organisation that is currently responsible for water management and regulation in England and Wales such as the Environment Agency and Ofwat.

Drought – There is no single definition of drought. A drought is caused by a shortage of rainfall; however, the nature, timing and impacts will vary according to the location and the different sectors affected such as public water supply, agriculture and industry.

Ecosystem services – The benefits provided by a multitude of resources and processes that are supplied by natural ecosystems.

Environment Agency – The organisation responsible for managing and regulating water resources and the environment in England and Wales.

Externality – A cost imposed by one party's behaviour on other parties whose interests are ignored. In water trading, a trade between two parties could result in an externality in which a third party loses access to water, or in which the environment is negatively impacted.

Grandfathering of licences – This is when a previous regulation continues to apply to some existing licence holders, whilst a new regulation applies to all new and future licence holders.

Groundwater – Water that collects or flows beneath the earth's surface, filling the porous spaces in soil, sediment, and rocks. Groundwater originates from rain and from melting snow and ice and is the source of water for aquifers, springs, and wells. The upper surface of groundwater is the water table.

Hands off flow condition – Many abstraction licences contain conditions where the licence holder has to reduce or stop abstracting water once the river has dropped to a certain level or flow. These are known as hands off flow conditions and protect other river users and the environment. The hands off flow is the flow below which an abstraction licence holder cannot abstract water from a watercourse.

Innovators – Organisations and people with abstraction licences who are carrying out innovative water management practices and/or are interested in the trading of water rights.

Linking capital – This refers to the social connectedness of individuals or groups belonging to different "levels" of a society or organisation.

Market manager – A person or agency with the responsibility of clearing and managing the market. Market managers are not usually needed for most commodities, such as markets for corn, cell phones, and umbrellas, which need only normal regulation to operate. For complex commodities such as electricity and water, an active market manager can help the market function more efficiently.

Naturalised flow – The flow in a river in the absence of abstractions and discharges, i.e. the flow that would exist in a river without any anthropogenic impacts.

Optimization – A mathematical term, meaning the solution of a set of equations for a given set of data. "Optimal solution" is a strictly mathematical term, meaning that the given solution is the maximum or minimum that can be found given the data. The phrase is used in this report only in a mathematical sense. That is, in solving a real world problem with optimization, we do not claim that we have solved the real world problem to everyone's satisfaction, or even that we have modelled it correctly.

Pair-wise trading – Trading in which two separate parties have a one to one relationship, i.e. a bilateral trading arrangement.

Price signal – A message sent to stakeholders in the form of a price charged for a commodity, in this case water. This message is intended to produce a particular result, for example, increasing the cost of water during a drought is a price signal to abstractors to use less water.

Quota – A right to use a quantity of water for a relatively short fixed term, e.g. one week. This right is unbundled from other licence requirements (such as type of use) and is temporary, as well as being location-specific. The right may be firm, especially for the immediate period, or the right may be conditional, for future periods in which flows are uncertain. The holder may bear some or all the risk of the uncertainty in the supply.

Reservoir – A natural or artificial body of water used for the storage and regulation of water.

Ring-fencing – The act of putting restrictions on an abstraction licence or set of licences so that the associated water can be used only for a particular purpose, e.g. irrigation.

Sleeper licences – Abstraction licences which have been issued but have no recent history of water usage.

Spot market – A market in which participants trade a commodity for immediate or short-term use. This contrasts with the futures market, in which participants trade a commodity for delivery far into the future.

Surface water – Water naturally open to the atmosphere, i.e. water in streams, rivers, reservoirs, lakes, ponds, estuaries and seas.

Thin trading – A condition where the market has little trading activity, usually due to high transaction costs.

Tranche – A financial term meaning a section of a given transaction. In the central pool method a potential trader can bid to buy or sell different quantities of water at different prices. These different quantities and prices can reflect the user's real demand for water.

Water trading – The process of buying and selling entitlements to water. Defra and the Environment Agency define water abstraction licence trading as the transfer of licensable water rights from one party to another for benefit (Environment Agency, 2007).

1. Introduction

1.1. Background to the research

The University of Cambridge Programme for Sustainability Leadership (CPSL) has launched a Collaboratory on Sustainable Water Stewardship, chaired by Lord Selborne who is Treasurer of the UK Government's All Party Parliamentary Water Group (see www.cpsl.cam.ac.uk for more information on the Collaboratory). The objective of this Sustainable Water Stewardship Collaboratory is to improve the way in which the economic, environmental and social benefits of water are understood and valued, and to feed this learning into policy-making processes. One of the Collaboratory working groups is focused on water allocation through water trading. The overall goal of this Working Group is to address the question: "What is an effective water trading system and what are the implications for stakeholders concerned with sustainable water abstraction?" This piece of research for this Working Group commenced on 15 May 2012 and was completed on 2 November 2012.

1.2. Objectives and assumptions

1.2.1. Objectives

The objectives of the research were as follows:

- To establish the feasibility of an effective trading system at a catchment level;
- To provide stakeholders with a shared, credible, evidence base about water trading at a catchment level;
- To generate evidence to inform policy rather than make policy recommendations.

We carried out the research in two phases as follows:

- Phase 1 – Engagement with the key stakeholders to document their views and understanding of water trading in the context of current water management practices and how water trading could work in the future;
- Phase 2 – The setting up of demonstration water trading systems for the Upper Ouse and Bedford Ouse catchment to illustrate to abstractors in the catchment how different types of water markets could work. This used innovative methods to work with practitioners, opinion formers, and local abstractors to develop a shared understanding of the potential for water trading markets at a catchment level. The goal of this work was to generate evidence to inform policy rather than making specific policy recommendations.

1.2.2. Assumptions

At the outset of the research the Working Group steering the research formulated a number of assumptions, based on previous research, expert opinion, and abstractors' opinions in East Anglia relating to water trading. These were as follows:

- Effective water trading is affected by the number and diversity of abstractors to realise the full economic potential of the catchment and deliver security of supply over the long term;
- Both short-term and long-term trades would be possible to meet the flexible needs of abstractors;
- The availability of trusted information for abstractors will be a significant factor dictating interest and take-up of water trading;
- A cost-effective set of arrangements would probably use existing hydrological models rather than propose developing new ones;
- The more commonly applicable the method is, the more likely it is that any capital costs will be accepted and covered where necessary by other catchments over time;
- Trading potential is more promising where there is unmet agricultural demand;
- Downstream trades may be more viable than upstream trades and bring about more environmental benefits;
- There is an uncertainty regarding the ‘value of water’ by abstractors.

These assumptions have been investigated, as far as possible, as part of the research and are commented on as part of our findings.

1.3. Scope of the report

This report forms the final report, providing a summary of the Phase 1 work and full reporting of Phase 2. For further details of the stakeholder engagement, the Phase 1 report (HR Wallingford et al, 2012) should be consulted. This report focuses on the development of temporary short-term trading arrangements, in which the opportunity to abstract water is transferred to another party for a short period of time, and the long-term entitlement is not affected. This contrasts with permanent trading, whereby a licence holder agrees to permanently reduce the maximum amount of water they abstract, on the understanding that this water will be transferred to another licence holder.

1.4. Drivers for the research

The drivers for this research at a policy level emanated from a number of sources. The UK Government’s Natural Environment White Paper, published in June 2011, commits to halting biodiversity loss by 2020 and supports the economic valuing of the environment following the National Ecosystem Assessment. The Natural Environment White Paper is the first paper of its kind for 20 years and takes a bold look at the next 50 years. It calls for the protection of precious natural resources, such as water and it draws on new scientific tools to look at the value provided by ecosystems services. It aims to strengthen connections between people and nature, to the benefit of both.

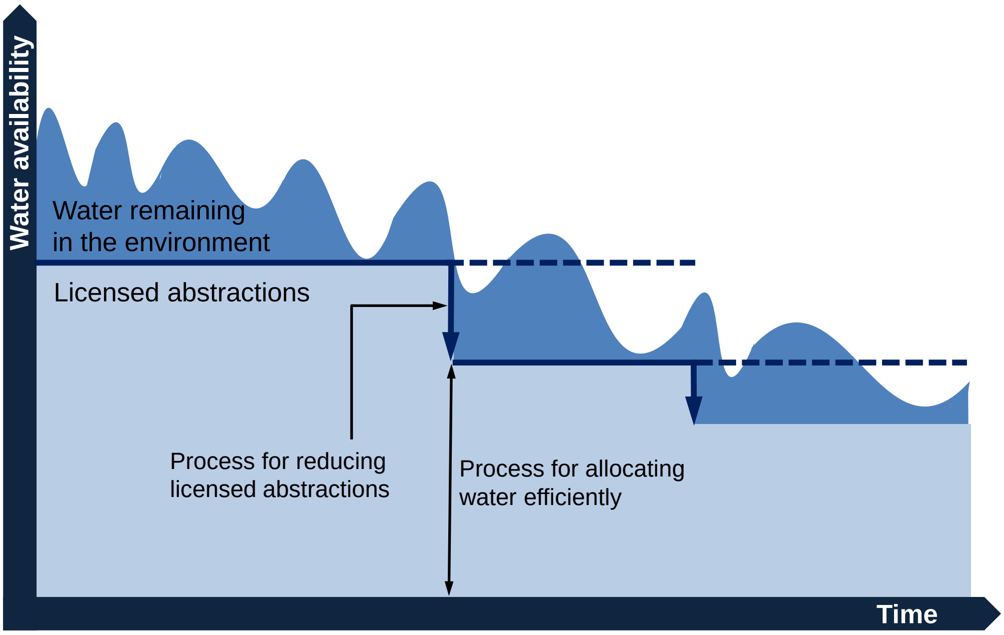
In late 2011, the UK Government launched its Water White Paper and associated documents published by the Environment Agency and Ofwat on the “Case for change”. The White Paper commits the Government to reforming the abstraction management regime by the 2020s. Our work explores options that could positively influence regime change at an implementation level.

Anglian Water's own research papers 'A right to water?' and 'Trading Theory for Practice' provide helpful contributions and useful regional context to the debate. East Anglia is facing acute short-term and long-term water resources issues (Anglian Water, 2010; Frontier Economics, 2011).

Water resources in parts of England and Wales are already under pressure, and many catchments are classified as 'over-abstracted'. Current levels of abstraction have been cited as a barrier to water trading and more specifically that a market would increase current abstraction levels by activating so called 'sleeper licences'. The Environment Agency is currently working to address unsustainable abstraction through its 'Reducing Sustainable Abstraction' programme (RSA) where abstraction levels are damaging important conservation sites. There are 68 RSA sites across the Anglian region (Environment Agency, 2012).

Current licensing arrangements are unlikely to deal efficiently with extended periods of water scarcity, a long-term decline in availability, and greater volatility of supply. To prevent damage to the environment, licensed abstractions may need to be reduced to balance water for the environment and consumptive uses. Good water allocation methods are thus all the more important for maximising the value of water (Frontier Economics, 2011). Figure 1.1 shows how these issues can emerge and how processes for reducing abstractions and allocating water more efficiently can assist in leaving sufficient water for the environment.

Figure 1.1: Methods for dealing with future water scarcity



Source: Frontier Economics, 2011

When this research was commissioned in April 2012, East Anglia and the south-east of England were officially in drought, with many water courses in East Anglia recording their lowest river levels in 110 years. The area had had two winters without the rainfall needed to recharge reservoirs and aquifers. At the time the research commenced the drought was having serious impacts on the environment and abstractors in East Anglia. On 12 March 2012 seven water companies (including Anglian Water) announced a hosepipe ban effective from 5 April 2012 and farmers, and some other abstractors agreed to reduce their abstractions by 20%. This was the first time in 20 years that Anglian Water had had to introduce a hosepipe ban (Anglian Water, 2012).

At the beginning of April 2012, a period of exceptionally wet weather commenced that increased flows in many rivers and largely refilled reservoirs hit hard by the two year long drought in East Anglia. The Centre for Ecology and Hydrology (CEH) in their April 2012 hydrological summary for the UK stated that "*Britain's climate is inherently capricious but there are few modern parallels to the hydrological contrasts experienced through the spring of 2012. March was exceptionally warm and recorded the lowest rainfall for the UK since 1953. April was the coldest since 1989 and the wettest in the last 100 years at least*" (CEH, 2012a). In East Anglian the monthly rainfall totals for April 2012, June 2012 and July 2012 were 260%, 192% and 218% respectively of the 1971 to 2000 monthly averages (in May 2012 the monthly Anglian rainfall equalled the average amount experienced in the recent past) (CEH, 2012a, 2012b, 2012c, 2012d).

Both May and June were relatively cool months. The persistent rain and low temperatures extended the recharge season of aquifers into the early summer. As a result of the wet period in late spring, Anglian Water lifted their hosepipe ban on 14 June 2012. By the beginning of the summer, many farmers in East Anglia were saying that it had been too wet.

At the start of the research, it was thought that the drought would create both risks and opportunities for the work. In March 2012, many abstractors, especially farmers, were concerned about their livelihoods, and that water allocation would be more important for them at a time of stress than during normal conditions. In April 2012 the fact that water scarcity was at the forefront of many people's minds encouraged positive engagement from abstractors. In March 2012, Andrew Alston of the Broadland Agricultural Water Abstractors Group (which represents more than 180 licensed abstractors) said that the prospects for irrigation were poor. "*We did not create this problem, but farming is at the forefront of any drought,*" he said. "*We know that the prospects for irrigation this year are poor and my advice to anyone in a stressed catchment area like the Wensum, Stiffkey and Glaven is to grow 80% of their normal irrigated crops this year. It is better to grow 80% well rather than 100% poorly. They should also think about cutting back on late-season irrigated crops like carrots as we cannot guarantee there will be water for them*" (EDP24, 2012).

Although the onset of a very wet period from the beginning of April 2012 alleviated the drought, the issues of water allocation and water use efficiency were still very much at the forefront of most abstractors' minds. In October 2012 Paul Hammett, the National Farmers' Union's (NFU) environmental policy adviser in East Anglia, described the 2012 drought as a "*near miss*" for growers, but viewed it as an opportunity to improve the situation. "*The drought has concentrated the minds of everyone involved. Farmers are looking again at the security of their water and government is listening,*" he said. "*The time is right to come up with some clear ideas about what we expect government and others to deliver and what we expect farmers to do for themselves*" (Water briefing, 2012).

1.5. Research team

The research was funded by Anglian Water and the Department for Environment, Food and Rural Affairs (Defra) as part of the Sustainable Water Stewardship Collaboratory. The research was guided by a Working Group that comprised Anglian Water, Defra, the National Farmers Union (NFU), Natural England, Cranfield University, the Royal Agricultural Society of England, the Royal Society for the Protection of Birds (RSPB), the Broads Authority, Association of Drainage Authorities, Environment Agency, Atkins, World Wide Fund for Nature (WWF), CPSL and the Water Services Regulation Authority (Ofwat).

HR Wallingford led a research team that comprised Collingwood Environmental Planning, who were responsible for stakeholder engagement, Dr Julien Harou of University College London and Dr John Raffensperger of the University of Canterbury in New Zealand, who developed tools for the Upper Ouse and Bedford Ouse catchment to assist in demonstrating the trading of water, and the University of Adelaide's Professor Mike Young, who provided expertise on water entitlement and water allocation systems used worldwide.

1.6. Current relevant research projects

A number of relevant, but separate, research projects are running in parallel to this work. Defra has recently commissioned a research project looking at the impacts of abstraction reform options on non-public and public water supply abstractors (http://www.defra.gov.uk/abstraction-reform/). This project is assessing the impacts that different reform options have on people and organisations that rely on water taken directly from rivers and groundwater focusing on seven case study catchments throughout England and Wales. The work is considering the different benefits, costs and risks of each regime option and, as far as possible, quantifying the level and distribution of these impacts (Defra, 2012). The research is combining hydrological models, which describe surface and ground water flows, with models of how individual abstractors may behave under different abstraction reform options.

Cranfield University is carrying out research called "Transforming water scarcity through trading" (http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/J005274/1). The objectives of this work are to:

- Inform the current move towards water markets;
- Show how active markets could transform the current water management system;
- Value the available water spatially and dynamically, revealing its opportunity cost;
- Identify the economic benefits of trading water licences at basin scale;
- Research the opportunities for novel engineering options for increasing supplies, such as distributed reservoirs, enhanced aquifer recharge, and rainwater harvesting, and how/whether they might be funded by downstream buyers;
- Investigate the rules and restrictions necessary to protect the environment and avoid unwanted consequences;
- Investigate options for incorporating payment for ecosystem services, to enhance environmental benefit (Cranfield University, 2012).

Both of these research projects are yet to formally report their results. However, some lessons learnt from these projects have been taken into account via members of the project team and members of the Working Group who are involved in the above research.

2. Water abstraction licensing and trading in England and Wales

2.1. The water abstraction licensing regime in England and Wales

The 1963 Water Act was the first to require that the right to abstract from surface or groundwater (with some exemptions) was subject to a licence. 'Permanent' licences conferring legal rights to take water were issued to riparian occupiers (whose right to water had hitherto been considered part of their right to land), on a 'first come, first served' basis, without formal guidelines for justification of required quantities. This reflected the perception of water as a free and plentiful resource, and followed the long established 'riparian rights' principle (Sowter and Howsam, 2008). This system of grandfathering abstraction rights was not designed to safeguard the environment or to manage competing demands. Grandfathering of existing abstractions as 'Licence of Rights' in the 1960s implicitly assumed practices that had gone unchallenged under common law were not impacting other legitimate users and were therefore acceptable. Licences were used in perpetuity without flow restrictions and authorised a volume of abstraction derived from evidence of the previous three years' abstraction. Although perpetual licences appeared to be pragmatic, this led to organisations inflating the amount of water that they used (Cunningham, 2002). Many changes have taken place since 1963; however, the legacy of the initial distribution of water rights on the current abstraction licensing system has limited the efficiency of water use (Cunningham, 2002).

The White Paper of 2002 entitled "Directing the flow" launched substantial changes to the arrangements for water abstraction rights. These changes were later encoded in the Water Act 2003 (Defra, 2012). The Environment Agency has described progress in implementing these and in the practice of abstraction trading within the current licence regime (Environment Agency and Ofwat, 2009). More recently, significant restructuring of the water industry was proposed, to expand the scope of upstream competition (Cave, 2009). The Government in its recent White Paper has chosen not to implement Cave's recommendations in full, but nevertheless is bringing forward significant proposals for market reform (Defra, 2011a, 2011b), to which this research contributes.

Across England and Wales, about 21,000 abstraction licences enable the holders to draw water from surface and groundwater sources. Excluding public water supply companies, the largest group of abstractors is the power generation sector; other industrial users are also large water abstractors. Agriculture accounts for around 1% of abstractions by volume on average across England and Wales, although this proportion varies considerably between regions and seasons (Environment Agency, 2009). In East Anglia agriculture usually accounts for around 5% of abstractions by volume, but this can rise on occasional days to over 60% of water being used for irrigation (EERF, 2007). This tends to coincide with the driest periods when overall demand from all users is at its highest. In East Anglia over 1,000 agri-businesses rely on irrigation to produce 30% of the UK's potatoes and 25% of all vegetables and fruit (EERF, 2007).

Water use in England and Wales is considerably higher than in many other developed countries. Climate change will result in an increase in average temperatures and changes in seasonal patterns of rainfall. Although potential changes in future rainfall patterns are harder to estimate, current climate projections (based on the Met Office UK Climate Projections 2009 (UKCP09), Met Office 2010a) suggest that the summers are most likely to have less rainfall and that drought conditions may become more common. A recent study by the Met Office suggests that England and Wales may experience ten times as many significant droughts by 2100 compared to today, with a drought like the one in 1975 to 1976 occurring on average every ten years (Met Office, 2010b). If these changes occur, the case is much greater for reforming abstraction licensing to enable water trading to take place more easily.

The abstraction licensing system has evolved in recent years, with some more modern licences requiring the amount of water abstracted to be reduced when the source of water is under pressure. However, little has changed for the majority of abstractors. A third of catchments are already estimated to be over-abstracted or have too much abstraction licensed; two-thirds of catchments are closed to new abstraction licences, and 1 in 10 rivers have environmental damage as a result of over-abstraction (Defra, 2011a).

Currently, abstraction licence costs do not reflect the relative scarcity of water in England and Wales. As a consequence, end users have little external incentives to save water, to manage climate variability, or to manage climate change on a least cost basis. Addressing the problem of over-abstraction under current arrangements is estimated to cost between £3.7 billion and £27 billion (Defra, 2011a). Some argue that achieving sustainable abstraction at current rates could take 45 to 335 years to achieve (Defra, 2011a), without accounting for trends such as population growth and changes to rainfall patterns.

As a consequence, Defra is committed to a reform of the current abstraction licensing system in England and Wales to help abstractors deal with the risks of future water scarcity. The licensing system must be able to cope with a water-stressed future and continue to deliver sufficient water to end users, as well as protect the environment. A future abstraction licence regime needs to:

- Be equitable;
- Drive efficiency;
- Be flexible;
- Meet reasonable end user demands without harming the environment.

We discuss these requirements briefly below in relation to water trading.

2.1.1. Equitability

The proposed markets would determine the traded quantities and the associated prices through voluntary and mutually beneficial operations. The issue of equity should refer to avoiding injuries to third parties, in what economists call externalities.

2.1.2. Efficiency

Efficiency here means three different but related things as follows:

- Trading systems should give good price signals, giving water value information to participants, informing them when and where to adjust their water use and infrastructure;
- Users should be able to execute trades easily and cost effectively, and the trading system itself must operate efficiently;
- The market should be competitive, i.e. no user or group of users should have the ability to push prices up or down for extra gain at the expense of others.

2.1.3. Flexibility

The trading system should not inhibit government from its rightful task of managing the common resource. Ideally, a good trading system would enable government to manage the resource more effectively and dynamically than it does now. In this sense, the management of the resource would be more flexible. In a separate report to Defra, Professor Mike Young proposed a framework that would increase the potential of both common pool and pair-wise trading to improve water use in England and Wales (Young, 2012b).

2.1.4. User needs and environmental requirements

A state-of-the-art trading system should meet reasonable users' demands without harming the environment. Trading should respect environmental requirements as those requirements currently stand. The trading system should have rules for changing those requirements. Users should be able to plan with reasonable certainty, while rules allow for adjusting rights in some fashion to match uncertain inflows. We assumed in the research that future environmental flow requirements as detailed in the Water Framework Directive would have to be met.

2.2. Current water trading system in England and Wales

In November 2003 the Water Act 2003 was passed. This Act simplified the administration for licence applications, as well as for transferring and renewing licences. The Act therefore reduced some of the barriers to the trading of water rights. Defra and the Environment Agency define water abstraction licence trading as the transfer of licensable water rights from one party to another for benefit (Environment Agency, 2007). The Environment Agency as the regulator remains impartial during trades, besides deciding whether the trade will cause unacceptable environmental consequences. The terms of the transaction are up to the parties involved and the Environment Agency does not gather information on pricing. The Environment Agency does not act as the broker. The current system is one of pair-wise trading with considerable transaction costs owing to the paper work involved and the time to complete a trade, which is typically six months. Administrative fees are only £135 (Environment Agency, 2011); however, hiring expertise to assist the trade and the time involved to complete it can add significantly to the transaction costs.

Many English and Welsh catchments are over-abstracted, so further licences cannot usually be obtained; or if they can, abstraction is allowed only infrequently and under tightly controlled conditions. However, even in dry years, less than half the licensed water is actually abstracted (Environment Agency, 2011a). Many agricultural licences have not been used for many years. In theory, farmers selling "spare" water to those needing additional short or long-term supplies would benefit both parties (Environment Agency and Ofwat, 2009).

Our Phase 1 document provides a stakeholder perspective (HR Wallingford et al, 2012), summarised in Chapter 3. Major barriers to trading include the complexity and time to get trades approved, and the fear that the Environment Agency will "claw back" any unused licensed volumes once a trade has taken place.

Tables 2.1 and 2.2 summarise trades that the Environment Agency approved from 2003 to 2008. Forty-eight trades were registered in that period, with 73% of all transactions occurring within the agricultural sector (52% of traded volume) and with a likely 50/50 split between permanent and temporary trades.

Table 2.1: Permanent versus temporary trades during the 2003 to 2008 period

Type of trade	Number	Percentage of trades by number	Volume of water traded (m^3/year)	Percentage of trades by volume
Temporary	23	48%	992,518	53%
Permanent	15	31%	456,995	24%
Unknown	10	21%	431,163	23%
Total	48	100%	1,880,676	100%

Source: Environment Agency, 2010a

Table 2.2: Trades by sectors during the 2003 to 2008 period

Donor to recipient	Number	Percentage of trades by number	Volume of water traded (m^3/year)	Percentage of trades by volume
Agriculture and farming to the same use	35	73%	980,880	52%
Water supply to the same use	4	8%	96,000	5%
Other	9	19%	803,796	43%

Source: Environment Agency, 2010a

Currently every trade must be approved by the Environment Agency, which deals with trades on a case by case basis. This results in high transaction costs and lengthy delays in completing the paperwork. The time to go through the process with the Environment Agency acts as a barrier to trading under the current system and has led to a thin market, (i.e. one where there is little trading activity), in abstraction licences.

Trading of water rights can be either permanent or temporary in England and Wales. In a permanent trade the seller gives up their licence. At the end of a temporary trade the seller keeps their licence and the abstraction right returns to them. The trading scenarios that are currently possible are outlined in Table 2.3.

Table 2.3: Current possible trading scenarios

Trading scenario	Description	How the trade is licensed	Who pays the Environment Agency
Whole, permanent	The whole of the seller's abstraction right is sold to the buyer on a permanent basis	Grant a new or varied licence to the buyer and revoke the seller's licence	The buyer
Whole, temporary	The whole of the seller's abstraction right is sold to the buyer on a temporary basis. The seller retains their licence, although they would not be allowed to use it for the period of the trade	Grant a new or varied licence to the buyer, and vary the seller's licence with a condition preventing the seller from using their licence for the duration of the trade	The buyer
Part, permanent	Part of the seller's abstraction right is sold to the buyer on a permanent basis	Grant a new or varied licence to the buyer, and reduce the quantities on the seller's licence	The buyer and seller
Part, temporary	Part of the seller's abstraction right is sold to the buyer on a temporary basis. The seller gets back all of their abstraction right at the end of the trade	Grant a new or varied licence to the buyer, and reduce the quantities on the seller's licence for the duration of the trade	The buyer and seller

Cost of trading is as follows: The buyer must pay a £135 application fee, the cost of the public notice, and a £100 advertising fee if the application is advertised (Source: Environment Agency, 2011)

Trading can take place only where surface water or groundwater link the seller's abstraction point to the buyer's proposed abstraction point, which may require each abstractor to be located in the same surface water catchment or the same groundwater aquifer. The water cannot be sold without this connection.

The approach to licensing, and therefore trading, is based on the water availability as defined by the Catchment Abstraction Management Strategies (CAMS). Where a CAMS shows "water availability", then trading of the licences' "used and unused water" is acceptable. However, where a water body is "over-abstracted", only the "used water" part of the abstraction licence may be traded. In over-abstracted reaches the Environment Agency will recover unused water for the environment as part of a trade (Environment Agency, 2011b)[1]. It is important to note that CAMS are not legally binding documents.

A buyer can apply to change the use of the abstracted water as part of the trading process. Changing the abstraction use may affect how much of the seller's right can be traded. The Environment Agency's water availability assessment takes into account the proportion of abstracted water that is returned to the environment, because it affects the environmental impact of an abstraction. The Environment Agency also considers the impact of where abstracted water is returned to the environment, as it may alter the

[1] This arrangement is in effect a tax on trading and, as a result, discourages trading. We have identified other ways to match licensed quantities to sustainable quantities, such as defining licences as a share of the total available for abstraction (Young, 2012b).

environmental impact of an abstraction because a new abstractor may return flow to a different part of the catchment or even a different catchment. Water returned may be beneficial to the environment in one instance, but detrimental in another. The Environment Agency may include different conditions on the buyer's licence. The conditions of a traded licence usually fall into two categories:

1. Those that provide catchment-wide protection for the environment and existing water uses;
2. Those that mitigate against local impacts.

Wherever possible the Environment Agency will license changes to a new location on the same terms as the existing licence. However, this depends on the conditions of the seller's licence, and whether the abstraction at the buyer's location impacts on the environment and on the rights of existing abstractors and water users. For part and temporary trading transactions, the seller's licence will revert to its existing terms and conditions when the trade ends (Environment Agency, 2011b). Trading groundwater abstraction rights is generally more complex than surface water, especially if the proposed location is near environmentally sensitive features or other abstractors.

The Environment Agency is legally required to limit the duration of all new licences arising from a water rights trade, even if the seller's licence does not have a time limit. The Environment Agency also puts time limits on licences that are varied, so that the licence reverts back to its original terms when the limit expires. The Environment Agency does not apply a time limit to a licence if it is varied to reduce the licensed quantities (Environment Agency, 2011b).

3. Methodology and approach

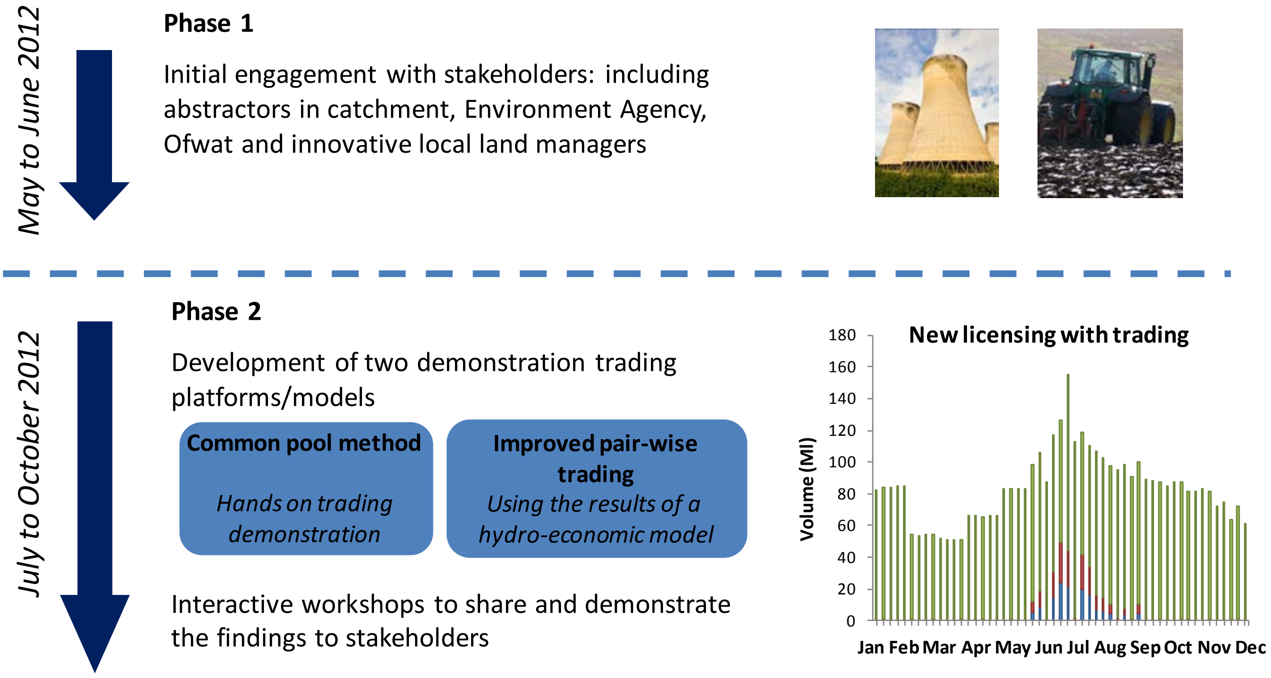
3.1. Approach

We undertook the research as follows:

- **Phase 1** Stakeholder engagement which is summarised below;
- **Phase 2** Development of trading systems and continued stakeholder engagement which included:
  - Hydrological modelling of the Upper Ouse and Bedford Ouse CAMS area;
  - Development of prototype trading systems;
  - Demonstration of systems to stakeholders;
  - Assessment of the feasibility and effectiveness of the trading systems;
  - Development of conclusions and recommendations.

The approach to the work is shown diagrammatically in Figure 3.1.

Figure 3.1: Approach to the research



3.2. Case study area

The research has been focused on the Upper Ouse and Bedford Ouse Catchment Abstraction Management Strategy (CAMS) area, shown in Figure 3.2. The case study catchment was selected by the Working Group. The criteria used to select the case study area included: the number, variety and concentration of abstractors; no significant environmental or political sensitivities; its location within Anglian Water's supply area; past experience of trading; recent experience of drought and a lack of atypical features which would make the catchment non-representative.

Over-abstraction is likely to affect East Anglia earlier than other parts of the country. Data for East Anglia shows approximately 66% of licensed groundwater and 69% of licensed surface water was actually abstracted. This compares to a figure of around half for England and Wales (Frontier Economics, 2011). Water resource assessments carried out by the Environment Agency indicate that pressures on abstraction, and the associated uncertainty and risks for security of supply in East Anglia, are likely to continue into the future; climate change will exacerbate these (Frontier Economics, 2011). By 2050 under an uncontrolled demand scenario, the Upper Ouse and Bedford Ouse catchment is unlikely to have sufficient water to meet current abstraction and environmental flows (Defra, 2011).

The Upper Ouse and Bedford Ouse CAMS area covers an area of approximately 3,000 km^2. The land varies from the gently rolling upper catchment to more extensive downstream river valley flood plains and flood meadows. The area is predominantly rural with development concentrated in established cities and towns. Major urban areas include Milton Keynes, Leighton Buzzard, Bedford, Hitchin, Huntingdon and Brackley (Environment Agency, 2005).

Natural flows in the catchment derive from surface runoff resulting from rainfall, surface or near surface drainage, and baseflow derived from spring flow and groundwater. Springs are found in the south-east of the area in the Woburn Sands and Chalk and in the north and west in the Great Oolite Group (Environment Agency, 2005). Rainfall is highest to the west of the catchment in the more upland areas. The long-term average rainfall varies from 670 mm in the west of the catchment to 540 mm in the fenland areas in the east. Generally the amount of rainfall in each month is fairly constant throughout the year. In summer, evaporation exceeds rainfall, giving a net loss from the catchment (Environment Agency, 2005). The main storage is Grafham Water Reservoir, located between St Neots and Huntingdon with a surface area of 9.3 km^2 and a maximum net volume of some 55 million m^3. Grafham Reservoir is filled by pumping water from the River Ouse at Offord. It is the eighth largest reservoir in England by volume and is one of Anglian Water's most important water supply assets. Grafham Reservoir is part of a partially integrated water supply system, known as the Ruthamford Water Resource Zone. This zone comprises the surface water reservoirs of Rutland Water, Pitsford, Ravensthorpe and Hollowell, an area several times larger than the Upper Ouse and Bedford Ouse CAMS area.

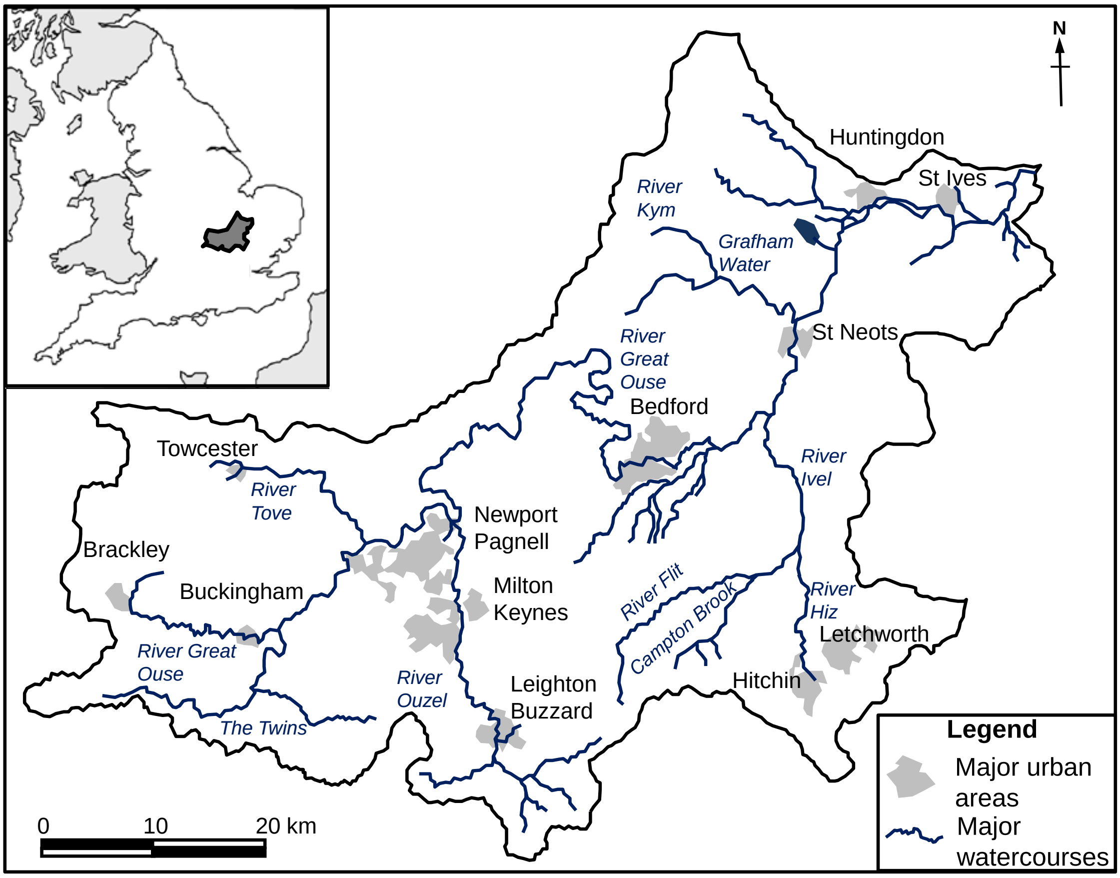
There are approximately 250 licences in the Upper Ouse and Bedford Ouse CAMS. Table 3.1 shows the distribution of these licences and the amount of water abstracted by sector.

Table 3.1: Details of the abstraction licences in the Upper Ouse and Bedford Ouse CAMS by sector in 2009

Sector	Distribution of the abstraction licences between sectors (%)	Volume of water abstracted (Ml/year)	Volume of water abstracted by sector (%)
Agriculture	73.8%	1,140	1.0%
Public water supply	4.9%	102,524	93.4%
Industry	12.0%	1,780	1.6%
Electricity production	0.5%	4,173	3.8%
Fish and aquaculture	0.3%	0	0.0%
Other	9.0%	120	0.1%

Source: Environment Agency, 2009

Figure 3.2: Location of the surface water abstraction licences in the Bedford Ouse and Upper Ouse CAMS area



3.3. Details of the trading systems researched

We researched the following new trading systems as part of this work:

- An improved pair-wise trading system to facilitate bilateral short term trades;
- A common pool trading method.

The improved pair-wise and common pool methods are described in Sections 3.3.1 and 3.3.2. These methods were demonstrated with users in the Upper Ouse and Bedford Ouse catchment.

3.3.1. Improved pair-wise trading

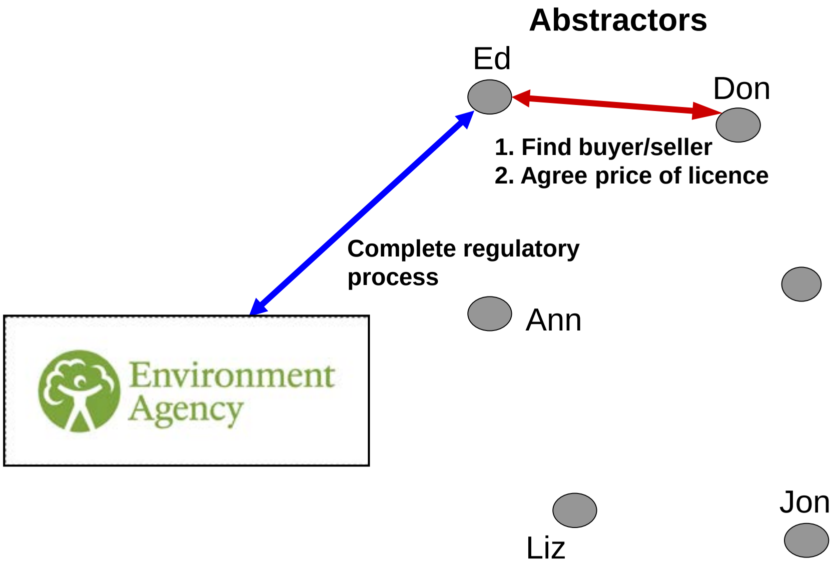
A pair-wise trade of abstraction licences has two steps:

- Step 1 - An abstractor wanting to buy or sell water rights must search for and make arrangements with another licence holder;
- Step 2 - The trade must be approved by a central regulator (e.g. the Environment Agency).

Currently initiating a trade and getting regulatory approval can take a long time (i.e. several months). By improving the current system, water rights trading would still be regulated, but could be less bureaucratic and time consuming than it is currently. In some catchments "pre-approved" trades could be facilitated provided that they did not result in any environmental damage. One way of improving efficiency could be through the use of an online management system. Users would place expressions of interest to sell or buy on a web page. An example of pair-wise trading is shown in Figure 3.3.

The improved pair-wise trading system may need interim licensing policies in place to reduce the time to complete a pair-wise trade. One pre-approval option would be to allow any licence holder to increase the amount of water they take or discharge without the need to amend the licence.

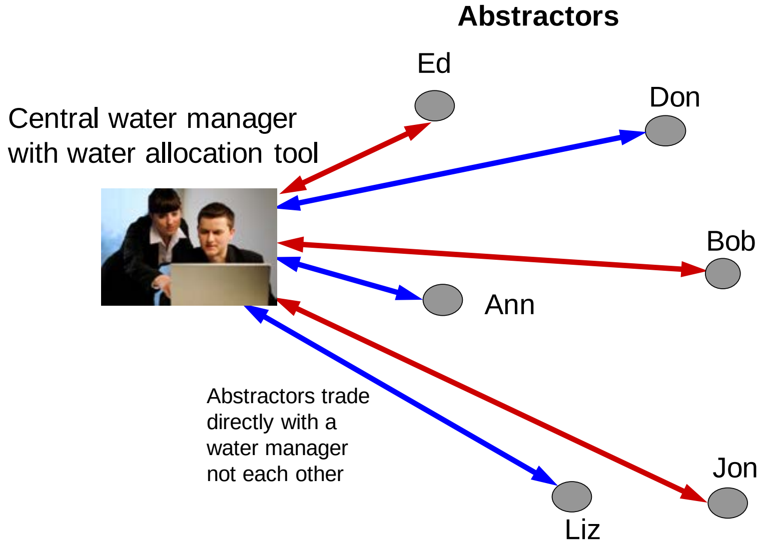
Figure 3.3: Pair-wise trading



3.3.2. Common pool method

In the common pool method, users would not make pair-wise trades with each other. Instead, users would periodically (e.g. weekly) buy and sell temporary water rights with a catchment manager (such as the Environment Agency) through a "common pool". Users would not need to search for a trading partner, write contracts, or wait long for approvals. Instead, users would place offers to sell or bids to buy on a web page, and the catchment manager would clear all trades at once, using a water balance model (based on hydrological optimisation), following a regular schedule (weekly or even daily). The water accounting system would ensure that environmental flows were satisfied. Users could offer to sell or buy water for future weeks. Within minutes of the market-clearing, users would have firm rights for the immediate period and conditional rights for the future periods. An illustration of the common pool method is shown in Figure 3.4.

Figure 3.4: Common pool method



3.4. Summary of Phase 1 - Engagement with stakeholders

3.4.1. Introduction

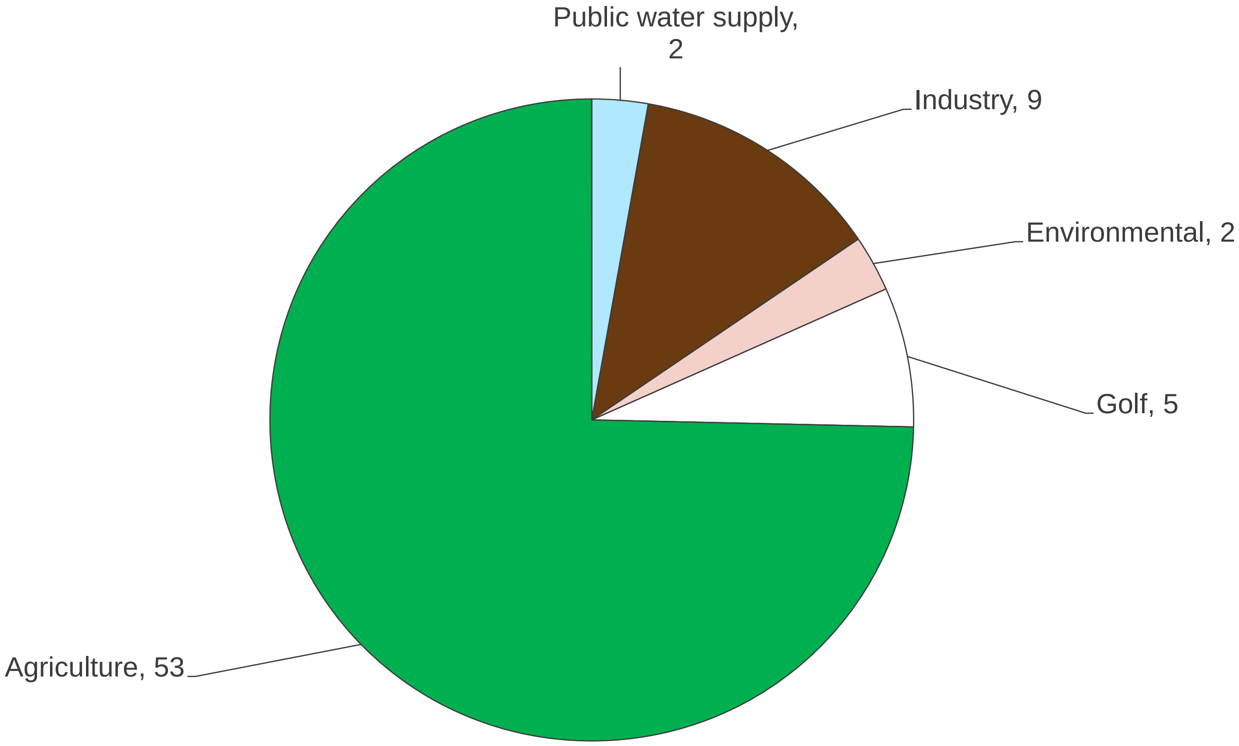
Phase 1 focused on understanding abstractors' perspectives, assumptions and appetite for water trading in the Upper Ouse and Bedford Ouse catchment; abstractors' views on barriers and opportunities to trading; and to obtain feedback on the two trading systems that were to be examined in Phase 2.

Three categories of stakeholder took part in Phase 1, categorised according to their role within or relationship with water management and trading:

- **Delivery Agents** – These were representatives of organisations currently involved in managing water resources both within and external to the Upper Ouse and Bedford Ouse catchment. These included the Environment Agency, Ofwat, Internal Drainage Boards and Natural England;
- **Abstractors** – These were holders of abstraction licences within the Upper Ouse and Bedford Ouse catchment; and
- **Innovators** – These were organisations carrying out innovative water management practices and/or interested in the trading of water rights. The innovators were not necessarily located within the Upper Ouse and Bedford Ouse catchment; however, most were abstraction licence holders located in East Anglia.

Of the 89 stakeholders we contacted as part of the research, 52 responded (58% of the total number contacted). Of those who responded to us, 39 stakeholders responded positively. A number indicated that they were interested in the study and its results but that they could not engage with the project. Reasons given were time constraints or that the relevant person within their organisation was not available to participate in the research. The 13 people who responded negatively explained that they were not interested in engaging with the project because they did not feel it was relevant to their organisation or interests. The number of abstractors contacted and the sector in which they operate are shown in Figure 3.5. In addition we contacted 11 delivery agents. Two focus groups were held in June 2012 and a number of face-to-face and telephone conversations were carried out and in total 17 abstractors, three innovators and seven delivery agents participated.

Figure 3.5: Number of stakeholders from different sectors contacted in Phase 1



3.4.2. Method

We used interviews and focus groups to explore the topics of interest. Schedules of semi-structured questions were developed for the focus groups and interviews. In each schedule we covered the same topics, but the questions were slightly different, tailored to the different roles and experience of the people involved. The questions were designed to encourage discussion and to explore views, generating qualitative findings. Table 3.2 provides an overview of the high-level topics under which specific questions were structured. The Abstractor topics were also the basis for discussions during the focus groups.

We held two focus groups with nine and three abstractors respectively. The first group was predominantly farmers and the second group was made up of abstractors from other sectors. Four interviews were carried out face-to-face and the rest were carried out by telephone. In addition we were able to carry out a structured discussion as part of the NFU Regional Abstractors Group meeting.

Table 3.2: Overview of interview schedule high-level topics

Innovators	Abstractors	Delivery agents
1. Setting the scene: your involvement in water abstraction and water trading today	1. Context – current and future water management practices	1. Setting the scene: the current context for water allocation and water trading
2. Barriers and opportunities for innovation in water allocation	2. Understanding, awareness and views on the concept and process of water trading, generally and in the catchment	2. Barriers and opportunities for effective water management in conditions of scarcity
3. Attitudes towards innovative systems of water trading: • Improved pair-wise • Common pool	3. Introduction to innovative approaches to water trading and exploration of views and enthusiasm for these approaches: • Improved pair-wise • Common pool	3. Attitudes towards innovative systems of water trading: • Improved pair-wise • Common pool
4. Any other comments	4. Any other comments	4. Any other comments

The interviews were analysed and the findings are described in full in the Phase 1 report and are not reproduced here. However, we briefly discuss the key findings.

3.4.3. Findings and discussion

Efficacy of the current mechanisms for abstraction licensing

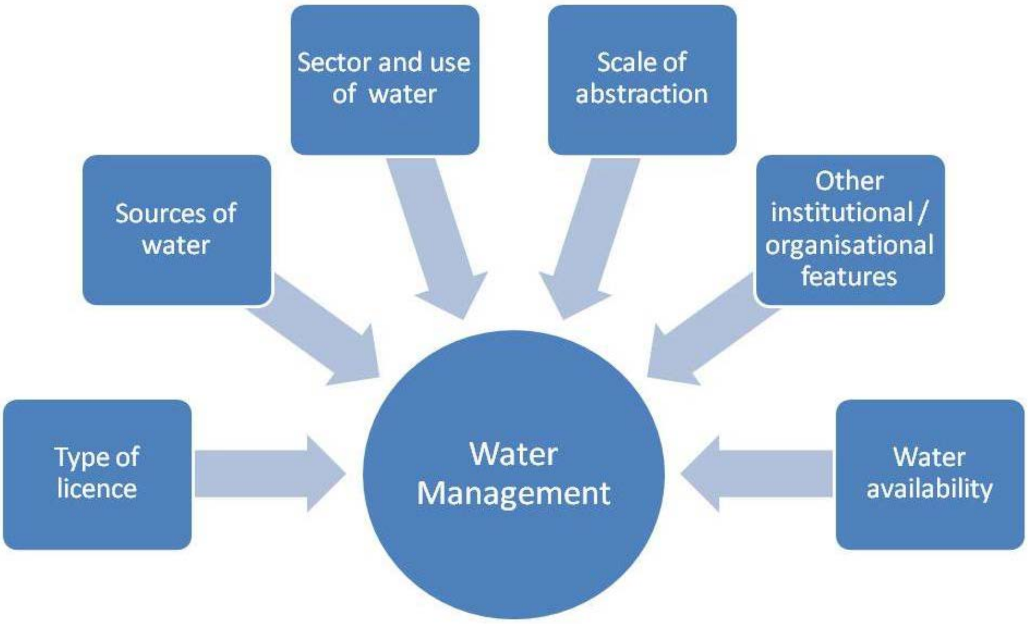
From the perspective of the delivery agents it was considered that the current water allocation system does not allow water to be allocated or managed efficiently, but rather it is just split up and licensed on a ‘first come first served’ basis as one Delivery Agent said *“...at the moment... no one has the authority or the responsibility to make decisions on where water is of best value, it is simply running a regulatory process which splits water between people and the environment and then allocates the water to people on a first come, first serve basis”.*

Abstractors made little comment on how the current system functions, but clearly abstractors’ situations and needs varied greatly. Licence terms and conditions vary. Needs vary between farmers (different crops or production) and between types of abstractors (e.g. public water supply, industry, leisure). This quote shows how these water management factors come together for one abstractor in the catchment:

“*Our main aim for the watering is consistency of going for horses and safety of the horses and the jockeys. I’ve only got 63,000 cubic metres at my disposal. So, I’m not a high user”.* **How do you irrigate it? “***We have towlines…. that’s a 20 year old towline with modern sprinklers on……So, with two of those we can do 440 yards at a time. And with the idea of that it gives me an option of timings…………”.***And what’s your pattern of watering them …?** “*Hopefully if nature helps itself we wouldn’t water…What we tend to do, no watering in the winter,…. just April, May and then perhaps a bit in October depending on the season. During* *the winter no watering at all and nothing really during the summer*." **And is your licence a…?** "*I've got an all year round. I was very lucky when I did mine"* (Focus group 2).

Because there are many factors influencing water management, shown in Figure 3.6, which can combine in a number of ways it means that the experience of water management varies considerably between different abstractors. It will be important to consider then how water trading impacts on different abstractors given this range of factors.

Figure 3.6: Influences on water management



However, it was clear that within the current system even when abstractors have enough water they do want to hold onto any unused licences in case they might need it elsewhere or for a different purpose:

"We have always felt that we have got sufficient licence volume for our operations at the moment anyway and we have tended to want to hold on to those in case we need them somewhere else for ourselves as opposed to necessarily wanting to give those up to others, albeit even on a temporary basis" Abstractor (aggregates).

This may or may not be a function of the current system, but it does raise the bigger issue of the perception of water as a commodity and how that perception may influence decisions to take part in water trading.

For the innovators, their concern focussed on the growing demand for water and increasingly unpredictable nature of supply and a realisation of the unreliability of historical rainfall patterns. *"We've got more people demanding more water, we're trying to grow more food and yet we're starting to think that the climate is going to take water away from us."* (Innovator).

Whilst this was not a direct criticism of the current system, this thinking does lead to questions about what sort of system would be most efficient given these changes in water supply.

Responses to drought

The Environment Agency made efforts to assist abstractors in coping with the drought by:

- Applying the current system as flexibly as possible, to assist abstractors, particularly farmers, to manage their water resources more effectively;
- Providing information to abstractors on trends in water availability;
- Moving away from thinking in terms of summer and winter abstraction, to periods of high and low flows;
- Introducing mechanisms for more informal agreements between abstractors, such as dispensation letters.

However, it was felt that the current system did not really support this approach and needed to be changed. One Delivery Agent said "*We're encouraging our staff to take the risks in the right way. Having said that, perpetually using a system where you're taking risks against the legal framework is not sustainable, so yes we look at what could change and be better in the long term*".

Across all the abstractors, those who had on-site storage infrastructure were in a better position to manage the drought than those who did not, but most reported that they had studied or implemented actions. Responses to the drought by non-farming abstractors ranged from implementing water efficiency programmes to reducing or closing down some of their activities.

The interviews and focus groups took place when it had already started raining and the drought was pretty much over, so farmers were perhaps more upbeat about having been able to manage the drought. However, it is clear that most of them had also taken or considered a number of measures to reduce the impact of drought on their businesses by:

- Reducing water consumption and increasing efficiency;
- Reducing the quality or quantity of production (e.g. not agreeing to as many irrigations of crops, reducing area planted): "*I think one thing we've done is where we have potatoes and we're growing them on contract, rather than six irrigations we'd normally guarantee we've got down to guaranteeing less, typically four irrigations, and we've shared the risk on that. That's now past but it's something we've struggled to guarantee"* (Focus group 1)*;*
- Introducing improvements such as wetting agents or night-time irrigation.

What also emerged was a difference between the larger farms that were tied into agreements with supermarkets and the smaller farms that had a diversity of outlets for their crops. The former expressed greater concern about the drought and its impacts, which would be more serious than for those with smaller farms who gave the impression of being able to manage during the drought and be more adaptable:

Participant 1: *"One thing I've noticed with looking back at applications per year – both potatoes and onions, I can't speak for cabbage, but we always end up irrigating probably five or six times a year through the crops".*

Interviewer: *"So fairly consistent".*

Participant 1: *"Fairly consistent".*

Participant 2: *"But interestingly not always the same periods".*

Participant 3: *"Not always the same period".*

Participant 1: *"I think one year all the irrigating was before the end of June and the next year all the irrigating was after the end of June."* (Focus Group 1)

Perhaps what singled the innovators out was their use of collective methods for addressing problems, e.g. catchment level associations; setting up groups to create joint storage facilities; networking with regulators to keep abreast of developments and identify opportunities, e.g. for funding for shared storage. Further they were involved in lobbying and influencing policy making (especially to promote interests of farmers). A range of responses to the drought emerged, with flexibility on the part of the delivery agents. and abstractors having a variety of options to secure their water needs.

Urgency of problems facing water abstraction system

The Environment Agency sees water abstraction as a problem waiting to happen, rather than one that has actually arrived. Other delivery agents considered reorganisation of the abstraction system as an opportunity for more holistic planning of catchments.

For the abstractors in the Upper Ouse and Bedford Ouse catchment water availability has not historically, and is not perceived currently, to be a major consideration, with the exception of some farmers. However, it is important to note that the research involved only people who already have abstraction licences and did not seek out people who are trying to obtain licences. The innovators were possibly more conscious of the looming problem of water shortages than the majority of abstractors. However, some innovators felt that water is still widely available: *"if there's water available you can go and apply for it yourself so why would you buy it?".* Overall, the drive for reform of the system appears to be mainly from the delivery agents rather than from the abstractors, but it should be noted that the research did not ask about issues with the current system directly.

3.4.4. General perceptions of water trading

Knowledge and concerns of abstractors

Overall, we found varied levels of knowledge and understanding of water trading amongst the stakeholders interviewed. It is clear that this is not a regular topic of conversation for many of the stakeholders. However, stakeholders were interested and curious about how it might work. This went hand in hand with a number of concerns, specifically from the abstractors, which are listed below:

- **Losing rights permanently** - Stakeholders had a strong sense that if you have a water licence it is important to keep hold of it even if it is not being used fully. The value of the licence was recognised, with a desire to keep what was regarded as owned by the participant, in particular when the water comes from what abstractors view as their property. "*And I think we tend to be quite traditional, it's mine, I've got it and I don't want anything to, you know, I don't want anybody interfering with it." (*Focus group 2);
- **Transaction costs and other barriers** - For example the time to complete trades which is currently around six months. The one person who was in the middle of a current trade said that it was taking a long time to do the paperwork and in fact the paperwork would not be finished until the next season, however, he has been allowed to have the water. *"It's just mind-blowing, it's bureaucracy".* (Focus group 1);
- **Price uncertainty** - The lack of agreed prices raised concerns around transparency and value for money. One abstractor stated that he had been offered a trade but did not want to bid as he had no idea

what the price would be. Discussions in the NFU abstractors group included an example of a farm being offered an abstraction licence for sale but no bid being made as there was uncertainty on what a "sensible" price was for the licence. Abstractors had *"no idea about what a reasonable offer (for a licence) is"* (NFU Regional Abstractors Group);

- **Uncertainty of water supplied, costs and outcomes** - Uncertainty was a key theme through discussions about trading, with respect to costs, process and outcome. Interviewees wondered, if there was not enough water, what would there be to trade.

  "Yes, it could be. Maybe if this drought carries on for another six months or ...But then what are we going to trade?" (Abstractor, water company)

- **Equity issues relating to 'winners' and 'losers'** - Farmers clearly agreed that sectors should be "ring-fenced", as they felt that industry or water companies would be the winners and agriculture the losers in any system. Ring-fencing would entail restrictions on certain abstraction licences so that they could only be used for a particular purpose.

  "Presumably if it was industry they'd want it for a longer basis than an annual basis, whereas agriculture is much more annually orientated, depending on your cropping for that year. Yes, the danger is though they can afford to pay far more for water and that's the way you're going to lose" (Focus group 1).

  There were also concerns that the ability of industry and public water supply to pay significant amounts of money for abstraction licences would mean that farms would sell their licences and close. This would have a very significant impact on rural communities. However, other abstractors felt that the benefits would be to agriculture rather than to the public water supply. One abstractor said *"I think it's going to be for agriculture [who benefits]… I'm struggling to see how public water supply is going to benefit significantly from opening up trading because I just don't….the scales I think are quite different*" (Abstractor, water company)

- **Issues related to large abstractors trading with small abstractors** - It was commented that given the relative amounts the water companies and other sectors abstract (roughly 80% vs. 20%) that the non-public water supply participants could not see how it would be worth anyone trading between sectors as what was a significant amount of water to one group was not relevant to the other.

- **The methods via which trading could be implemented** - Participants seemed to ponder how trading could work, especially if everyone wanted water at the same time, which is what happened in a drought. In addition, understanding constraints of location on how trading could work was raised.

  "If everyone say in this square mile or whatever buys all the licences and you all start abstracting out of the Ouse here from… How does that work because there's only a limited resource?

  "Yes, it's in the same catchment area isn't it?" (Focus group 1).

Responses to innovative methods of trading

With respect to the two innovative approaches to trading, most stakeholders expressed general interest in an improved system for trading water licences such as the common pool and improved pair-wise trading systems. However, many also indicated that they had not had time to fully understand, discuss and digest the systems proposed or that the information provided was too sketchy to enable them to properly assess the options. Very few stakeholders rejected the idea of water trading for reasons of principle. Those who expressed doubts tended to focus their queries on the way in which the system would work and on how it would fit in with the new system of regulating water abstraction.

Factors affecting willingness or not to trade

The perceived barriers to effective water trading were seen as follows:

- Size of market - Environment Agency staff argued that not enough trades were taking place to create a dynamic market. Abstractors like to hold onto their licences and have no incentive to sell them, because of the relatively low cost of retaining the licence by paying the annual fee;
- Understanding and expectations about how a market for water could work - Abstractors expressed a concern that under a new system they might be forced to trade;
- Social equity issues.

The different stakeholders were clearly open to discussions around trading, with views not appearing to be polarised either way regards trading in general or towards one method above another. Water trading was not perceived to be an urgent issue for many abstractors and none had a clear idea of what the price of water might be, although many seemed to think that it was likely to be low. The issue of ring-fencing (i.e. whether trading could occur across different sectors) was raised by a number of the abstractors, in particular farmers. The engagement process allowed the factors that would influence abstractors' decisions about whether to enter the water market, either as a seller or a buyer to be summarised. These are presented in the Table 3.3.

Table 3.3: Factors likely to affect willingness of abstractors to trade water

Factor	Buyers	Sellers
Volume of water traded	For those needing large amounts of water, there would be little interest in making multiple purchases of small amounts.	Given the price of water, high volumes would be needed to justify the costs involved in trading.
	Would need to be able to trade large volumes freely, not just occasionally or subject to restrictions.	
Price of water	Price needs to be lower than the fine for exceeding licence conditions.	Price would have to be high enough to justify the costs involved in trading.
	For abstractors with access to water from the mains supply, prices would need to be lower than that of mains water.	
Process for participating in trading		The process for providing information about available water surpluses and for completing transactions would have to be simple and quick, avoiding additional costs.

Source: HR Wallingford et al, 2012

3.5. Phase 2: Introduction

Phase 2 had two key strands which came together in the workshops to test out the two innovative trading systems:

1. Engagement with stakeholders and;
2. Development of trading models for the Upper Ouse and Bedford Ouse catchment.

We sent all the stakeholders who we had engaged with in Phase 1, a letter of thanks and an update on Phase 2. For Phase 2 the stakeholder engagement consisted of short telephone interviews around costs for water and two workshops with abstractors and the Environment Agency. The aim of the interviews was to provide some information for the two trading models being developed, to try to give an indication of what price people might be willing to buy and sell water for. We developed a short interview schedule that covered the following aspects:

- Details of abstraction licences held, water demand and costs to their business of buying a licence;
- Costs and losses to business associated with reducing water consumption, increasing abstraction, and lack of water availability.

In total we interviewed five abstractors from a range of sectors including agricultural and industrial. The questions related to the value of water and the amount of money abstractors would be willing to pay for water in particular circumstances. Details of the questions that were asked are given in Appendix E. The findings from these interviews were interesting, but overall those interviewed found the questions very difficult to answer. We suggest this was partly because of the wording of the questions but also partly to do with the topic area which many abstractors are unfamiliar with and therefore they were not able to answer the questions meaningfully.

3.6. Development of trading models for the Upper Ouse and Bedford Ouse CAMS area

3.6.1. Introduction

This section describes the assumptions and development of the proposed improved pair-wise trading and common pool trading markets for the Upper Ouse and Bedford Ouse CAMS area. We developed and tested these within the two stakeholder workshops which are discussed in Chapter 4. We made the following institutional and regulatory assumptions about the scenario under which water trading could take place in this catchment:

- The market operates under the rule of law, i.e. the market manager (most likely the Environment Agency) and the government have the means and will to enforce the relevant rules and regulations;
- Existing institutions continue in their current roles, and these roles will not change significantly over the course of the modelled horizon;
- The Environment Agency will remain the regulator for users of the environment and would manage the common pool and improved pair-wise trading systems;
- Every trade constitutes an enforceable contract between two parties. In the case of improved pair-wise trading, the two parties are the two users. In the case of the common pool trading, each abstractor makes a contract with the market manager. Further, these contracts are obligations, not options;
- Users offer to sell or bid to buy on a voluntary basis;
- Trading is only between holders of existing licences.
- Abstraction licences are valid at least over the current year;
- Sufficient data are available to develop the required hydrological models and to monitor surface water flows;
- Environmental flow requirements must be met as constraints on the market;
- Water abstraction is metered and meters are read with sufficient frequency to ensure compliance.

This research focused on surface water although the use of complex hydro-geological models could allow the same trading systems to be set up for groundwater.

3.6.2. Improved pair-wise trading

Introduction

The proposed improved pair-wise trading system is intended to improve the current water trading system in England and Wales. The improved system would include better information and a faster processing of trade applications. It would provide abstractors with more information concerning where potential buyers and sellers of water are located in the catchment and the price of water. The approval of a proposed trade should be faster in many instances and less costly, thus addressing the current major barriers to abstraction licence trading[2].

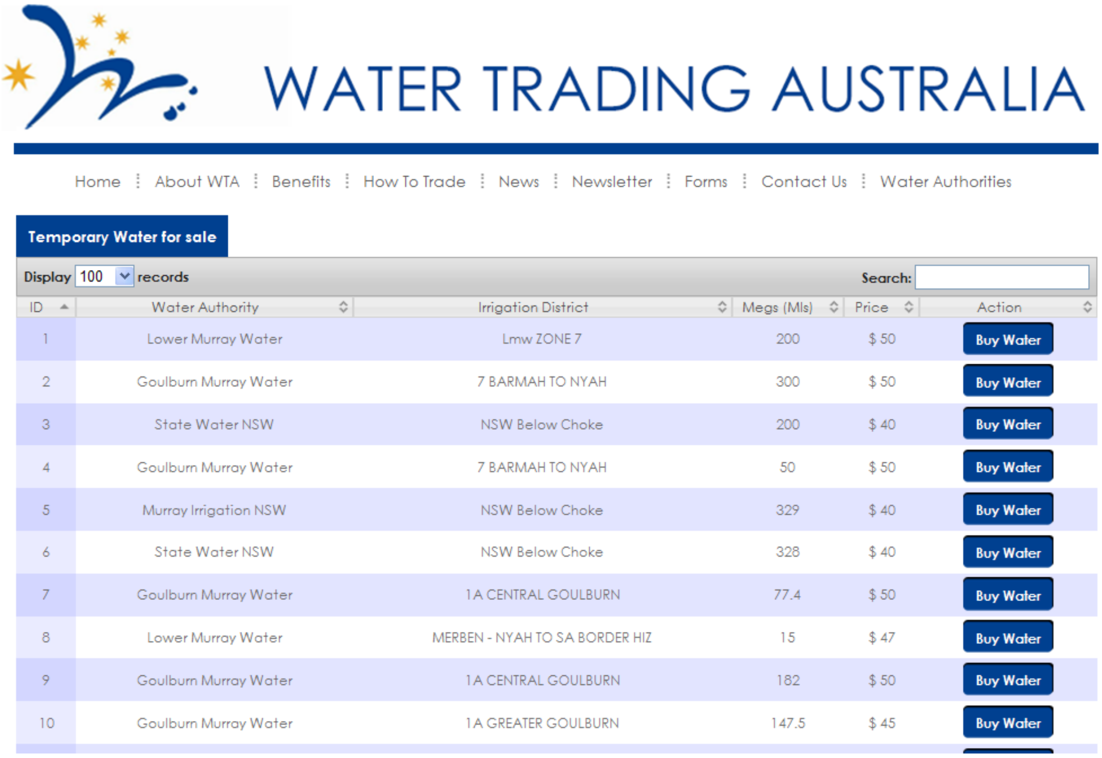
Currently abstractors have no simple method to ascertain who in their catchment is willing to trade. Often discussion on trades are initiated via informal communication (e.g. word of mouth, phone calls). This search for a buyer or seller is a significant component of the transaction 'friction', i.e. the factors that tend to reduce water trading. More trades might occur if potential buyers and sellers knew of each other's interest in a potential transaction. One way to achieve this is through a water trading bulletin board, maintained for example by the Environment Agency or a third party, that would post offers to buy or sell water (i.e. certain volumes at certain times). The website could be public or accessible only to registered abstractors. An example of a water trading web site from Australia is shown in Figure 3.7.

Streamlined approval of pair-wise trades

In the improved pair-wise trading system, trades with a low likelihood of adverse effects (as established by an appropriate hydrological analysis) could be pre-approved or approved quickly. Trades could be arranged hierarchically, depending on the time and effort it takes to approve them. Table 3.4 shows an example of a hierarchy of trades. Pre-approved trades could be linked to a trading bulletin board with a data-base of pre-approved trades that would facilitate the processing of trade requests. The bulletin board could have geographically based visualisation tools, an example of which is shown in Figure 3.8, to assist regulators and traders.

[2] Professor Young has proposed a transition to an administrative regime that may help remove some of these barriers (see Young, 2012b).

Figure 3.7: Example of an Australian water trading web site



ID	Water Authority	Irrigation District	Megs (Mls)	Price	Action
1	Lower Murray Water	Lmw ZONE 7	200	$ 50	Buy Water
2	Goulburn Murray Water	7 BARMAH TO NYAH	300	$ 50	Buy Water
3	State Water NSW	NSW Below Choke	200	$ 40	Buy Water
4	Goulburn Murray Water	7 BARMAH TO NYAH	50	$ 50	Buy Water
5	Murray Irrigation NSW	NSW Below Choke	329	$ 40	Buy Water
6	State Water NSW	NSW Below Choke	328	$ 40	Buy Water
7	Goulburn Murray Water	1A CENTRAL GOULBURN	77.4	$ 50	Buy Water
8	Lower Murray Water	MERBEN - NYAH TO SA BORDER HIZ	15	$ 47	Buy Water
9	Goulburn Murray Water	1A CENTRAL GOULBURN	182	$ 50	Buy Water
10	Goulburn Murray Water	1A GREATER GOULBURN	147.5	$ 45	Buy Water

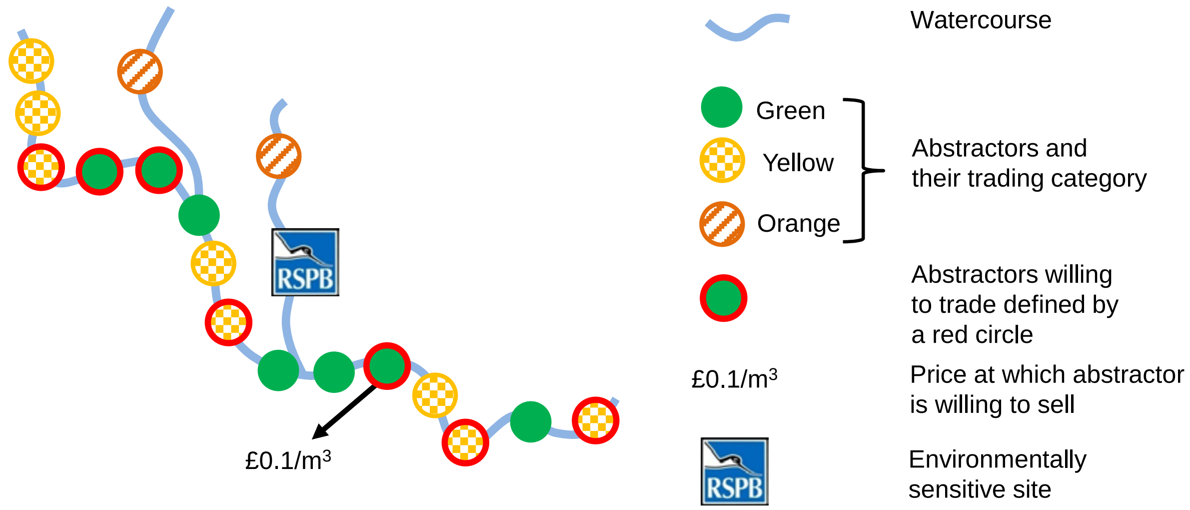
Source: Water Trading Australia (2012)

Table 3.4: Example of a possible hierarchy of pre-approved trades

Category of trade	Details of the trade	Approval time	Duration for which the trade is valid
Green	The buyer is downstream of the seller in an area where water is available and the buyer has an equal or inferior level of water consumptiveness. Negligible probability of environmental damage.	Approved automatically	Up to three months
Yellow	The buyer is downstream of the seller in an area where water is available and the buyer has an equal or inferior level of water consumptiveness. Low probability of environmental damage.	Approved automatically for short term trades	Up to one week
Orange	Similar to the existing system of trading abstraction licences. Requirement for a hydrological and environmental investigation	Full investigation required before the trade is approved	Dependent on the nature of the trade once it is approved it could be temporary or permanent and for a portion or all of the licence

Such a system could adapt in response to evidence based on how trades affect other abstractors and the environment. The system does not rely heavily on the use of sophisticated models run on short time-scales. The system would require regulations that would enable the Environment Agency to prevent trades that may have adverse effects. Hydrological models would still be used to investigate the 'orange' type trades.

Figure 3.8: Example of a schematic diagram of an improved pair-wise trading scheme that could be used to facilitate trading via a web site



3.6.3. Modelling improved pair-wise trading

Introduction

To investigate the potential hydrological and water management impacts of a short-term trading system, we built a mathematical model to simulate the current surface water abstraction system and how it could change if short-term trading were pervasive. We used a model to explore how the current system works, and how it could be improved if it were made possible to trade over short periods (i.e. one week). The model represents each surface water abstraction point each week over a possible future drought year. The model represents the actions of each individual abstractor and the relationships between abstractors to build a collective system-wide view at the catchment scale. Abstractors have an influence on each other through their impact on stream flows via abstraction, discharge, storage, or trading. The model accounts for the discharge in each part of the river system, the discharge upstream and downstream of each abstractor is estimated each week. This allows the model to implement different systems of environmental minimum flows. The model can account for storage in reservoirs and their interaction with abstractions.

The propensity of abstractors to engage in trading is modelled using abstractor-specific or sector-specific rules and economic demand curves that express how much water is worth to the abstractor in a given week. Unless the model has a rule for an abstractor included in the model that prevents it, an upstream abstractor will sell water to one or more downstream users if their value of water during that week is sufficiently higher than the upstream abstractor's to overcome the costs of the transaction.

Model assumptions

The improved pair-wise trading simulation used the following assumptions:

- **Abstractions** – These were based on historical abstraction patterns for the period 2006 to 2011 for all abstractors, apart from Anglian Water who provided data for the period 2002 to 2011. Abstractions were limited by weekly and annual maximum licence abstractions. The individual hands off flow conditions of each licence represent a constraint when an abstraction point must become inactive owing to environmental conditions;
- **Value of water** – Simple linear estimates of the value of water for each abstractor each week of the year were made. The curve provides different willingness-to-pay estimates for different tranches (i.e. “buckets”) of water (e.g. I’d pay this much for my essential requirements, then a bit less for water for less essential tasks). The curves were built based on historical monthly water use data for abstractors, an assumed marginal value of water for each sector and a literature value on how different sectors’ water use typically responds to water price;
- **Trading** – Each holder of an abstraction licence can buy or sell water unless an environmental condition on their licence prevents them from doing so. Transactions are limited to a duration of one week in length. Transactions can be repeated week after week. Simulated abstractors evaluate whether to abstract based on a weekly economic demand curve for water which quantifies how much the abstractor would be willing to pay per mega-litre for different ‘blocks’ of water that week. Trades will go forward if the difference in water value between a potential seller and buyer is sufficiently large to overcome the cost of the transaction. The trading partners and volumes are selected in such a way to maximise the total economic benefits generated weekly. No abstractor can trade more than half of their average annual use, this rule is to prevent abstractors from “trading themselves out of business”;
- **Consumptiveness** – The consumptiveness of different sectors was taken from Environment Agency data and are given in Table 3.5;
- **Licensed volumes** – These were based on information obtained from the Environment Agency;
- **Transaction costs** – Fixed and variable costs depending on abstractors’ relative consumptiveness have been assumed. Fixed costs were set to 10% of the current trading administrative fee which is currently £135 (Environment Agency, 2011) i.e. £13.50 for each trade. The volumetric charges were developed by assuming the regulator could impose a tax on trades where the consumptive use increases. Table 3.6 shows these charges which were developed based on the ratio of the consumptiveness of the buyer to the consumptiveness of seller;
- **Operation of Grafham Reservoir** – To ensure Grafham Reservoir performs in reasonable fashion, a function was added to the model to penalise deviations from Anglian Water’s monthly storage targets. If Grafham Reservoir is less than half full it was assumed that Anglian Water would start to reduce abstractions from Grafham Reservoir and not fully meet its target deliveries. Once this occurs no other Anglian Water site where there is an abstraction licence can engage in selling water to other sectors;
- **Reductions to agricultural abstractions, Section 57** – If flows at one of the Environment Agency’s flow gauges is less than the 95 percentile flow (Q95), Section 57 will be invoked and weekly maximum amounts for agricultural licences are reduced by 50%.

Table 3.5: Environment Agency CAMS consumption factors

Type	Consumptiveness
Water supply	60%
Agriculture (including spray irrigation)	100%
Industrial	60%
Energy	3%

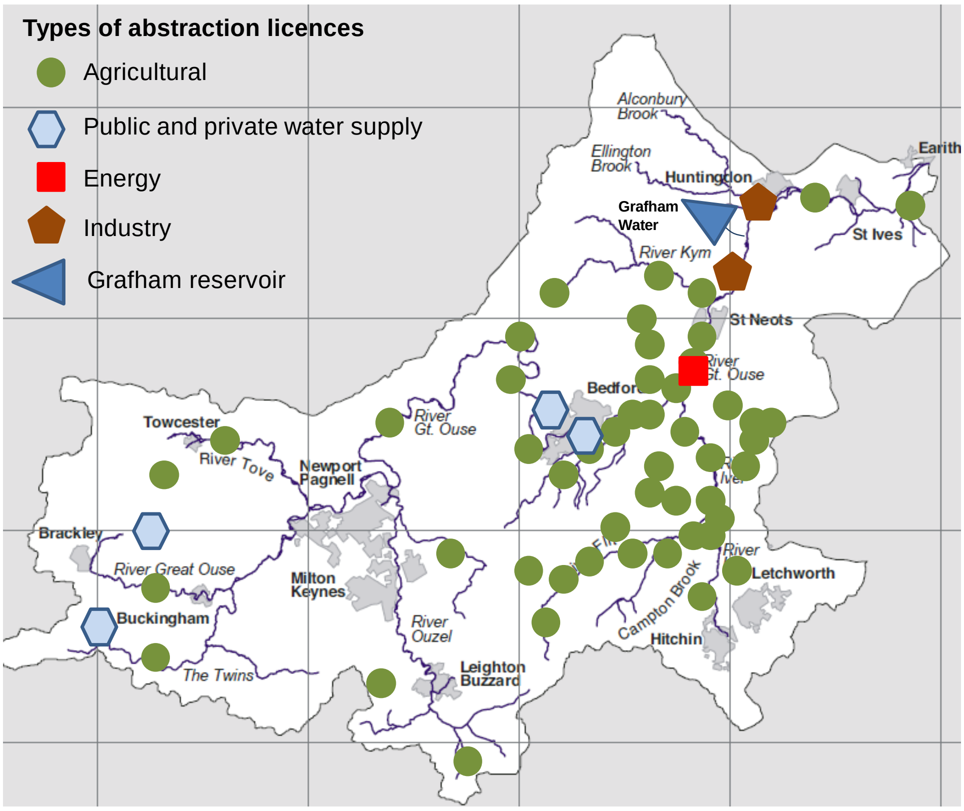
Table 3.6: Volumetric charges between sectors assumed in the improved pair-wise trading modelling

	Volumetric charge (£/Ml)			
Buyer/seller	Agriculture	Public water supply	Industry	Energy
Agriculture	12.5	21.0	21.0	417.0
Water supply	7.5	12.5	12.5	250.0
Industrial	7.5	12.5	12.5	250.0
Energy	0.4	0.6	0.6	12.5

Application to the Upper Ouse and Bedford Ouse CAMS area

The model was applied to the surface water abstractors located in the Bedford Ouse and Upper Ouse CAMS area. Almost half of the abstractors, (111 out of the 205 existing licences), registered no observed abstractions with the Environment Agency over the period 2006 to 2011. These licences were assumed dormant and excluded from the analysis; the remaining 94 licences were used in the model and are displayed in Figure 3.9 along with the catchment outline and river network.

Figure 3.9: Bedford Ouse and Upper Ouse CAMS area showing the active surface water licences



Modelled scenarios

Three scenarios were modelled to investigate improved pair-wise trading using hydrological inflows based on a possible future drought scenario (based on historical flow data for the catchment). These were:

- Scenario 1 Current licensing i.e. with volumetric based licences, hands off flows and no short-term trading taking place;
- Scenario 2 Current licensing with short-term trading;
- Scenario 3 Future licensing where a 'shares' licensing system is in place in which licensed abstractions are scaled in low flow conditions and where the percentage of water allocated to the environment changes depending on hydrological conditions. The ability to carry out short-term trading was included in the model.

Model results

The model results were used to demonstrate to stakeholders how water management improvements (such as the ability to approve trades quickly and a "shared" licensing system) could facilitate trading of abstraction licences and what effect this would have on abstractors, river flows and storage. The improved pair-wise trading model showed that under the no trading scenario in certain weeks, the river would not have enough water for many abstractors to obtain their required amounts of water, particularly those with newer licences that have more stringent hands off flow conditions than older ones issued under the 1963 Water Act. This situation is somewhat alleviated when short-term trading is enabled. The non-public water supply sectors are generally subject to less favourable hands off flow licence conditions under the current licensing regime, particularly the licence for the 680 MW gas-fired power station at Little Barford. Short-term trading helps to remediate the problem of hands off flow conditions, which otherwise prevent users from abstracting in periods when they place a high value on water.

Short-term trading injects flexibility into the system, such that abstractors who require water at certain times can obtain it from upstream abstractors if they are willing and able to pay for it. Because the diversity of water uses and licences leads to different sectors placing different values on water at different times, the model results show a large quantity and diversity of buyers and sellers. The agriculture sector would be both a frequent buyer and seller of licences. The third scenario showed that implementing a state-of-the art abstraction licensing system (using 'shares' and adaptable environmental flows) led to reliable water markets and reliable environmental protection. Further details of the improved pair-wise trading modelling are given in Appendices A, B and C.

Testing improved pair-wise trading with stakeholders

Participants in the Phase 2 workshops were given a short presentation on the improved pair-wise approach to trading, and then shown some of the outputs of the modelling so that they could get a sense of what might happen with this system. The list of outputs shown to the participants can be found in Appendix A.

3.6.4. Common pool method

Introduction

The second approach to water trading developed in this project was the common pool approach. The common pool market system comprises an on-line auction with a water balance model (an optimization model which serves as the market clearing engine) and it requires a market manager (such as the Environment Agency) to act as an "honest broker". Users trade only with the market manager, so they do not need to find trading partners. The market manager manages the available water as a common pool.

The market manager would be responsible for developing, maintaining and solving the optimisation model and the associated website and databases, ensuring market order and transparency, and carrying out financial transactions. The market manager would also be responsible for enforcing market rules, such as ensuring the accuracy and reliability of users' meters. The market manager's key role would be to "clear the market", which is the process of accepting users' bids over the internet, solving the optimization model, notifying users of the results, taking money from buyers, and paying the sellers.

Users would be able to trade every week, so this allows them a chance to change their allocation weekly. They could adjust their complete schedule of water every week, for every week remaining in the year. The common pool method would allocate all water in the given catchment for every remaining period in the hydrological year in every auction. Users would be able to lease out excess water a week at a time and get paid. They would be able to buy in extra water only for weeks when they needed it. The market manager would allocate all the water in the catchment simultaneously.

In this approach a type of uniform pricing would be used, in which all users of a given type (i.e. consumptive or non-consumptive) at a given location would face the same price. Furthermore, the market would allow multi-part bids to lower users' risk further, as they would be able to bid high for a block of water they needed, and bid low for a "nice-to-have block" of water. This would avoid the "winner takes all" type of risk seen in other types of markets. Environmental flows would be automatically satisfied through the water balance model.

The water balance model within the common pool approach works to maximize the sum of users' value for allocated water, whilst ensuring that the water flows satisfy the hydrological physics (e.g. conservation of mass at all points), and that the environmental flow requirements are satisfied. This model is a set of simultaneous equations and can be solved with standard optimization techniques. The solution to the model specifies the quantity of water that each user should be allocated, and the price that each user should face.

The common pool market would be a "spot market," in that current licence holders would lease out some or all of their licensed quantity for a short time, a day or a week. After the auction period ends (e.g. a year), each user's licensed quantity would return to them in whole. The market manager would need permission to operate what is essentially a monopoly, as entry of other common pool markets in the same catchment would be inadvisable. Hence, the establishment and regulation of the market manager requires a higher level authority, such as the Competition Commission or Ofwat which are independent of the Environment Agency.

Trading under a common pool system

Once the market is established, the market manager would have to be able to enforce the market rules on users. If the market manager were the Environment Agency (or a delegate), then they would have substantial new responsibilities.

A trade would be represented by a contract of some kind between two parties. A water licence typically includes an option to take water from a particular location for a particular purpose during a particular period. Hence quantities of water in different places at different points in time constitute different commodities, even if used for the same purpose. This is because water abstracted from different locations in a catchment can have different effects on neighbouring users and on the environment. If someone buys land from someone else who holds an abstraction licence associated with that land, the buyer will obtain the abstraction licence, under the current licensing system. This exchange may be viewed as a trade of the water licence, which is time-consuming and permanent.

If someone borrows an hour's worth of irrigation water from a nearby neighbour's hose, perhaps in exchange for another commodity or service, this exchange may be viewed as a trade of water licence. This type of trade is temporary, easy, and can be arranged at short notice. Such a trade requires the buyer's and seller's locations to be close, or for the associated water to be fully controlled, as with reservoirs and canals. The participants should have a contractual understanding, however informal. The trade need not be for the whole of a seller's licence, either in quantity, in duration, or in its conditions. This buyer gets something different, compared to the case where the buyer takes the whole licence along with the land, and the difference is more than quantity. Hence it is not strictly licences that are traded under the common pool method, because market participants do not trade the many conditions associated with their abstraction licences.

The licence is not getting traded, but rather a fraction of the licensed quantity is getting "leased" for a short time. This is a spot trade. Traders in a spot market want to trade only the water quantity, and only for a short amount of time. Hence rather than call the traded commodity a "licence", we shall refer to it as a quota.

The proposed common pool trading system would enable a spot market for contracts in water quota. A contract for quota would specify a quantity of water for a specific period of time, offered by a licence holder or the market manager, where the buyer agrees to take, transfer, or release the specified quantity over the specified period of time, for the buyer's specified use.

The spot market would have to allow simultaneous trades in quota for both current and future periods, because users would want assurance of future rights for their own planning, and also because water use in the current period affects water availability in future periods. However, the nature of the current and future rights have to be somewhat different. Users need to know what they are allowed to do immediately, so this right has to be firm. However, the uncertainty of natural inflows increases into the future, so the market manager could not always offer a firm future right.

Therefore, the common pool market would trade contracts for quota, which is a conditional obligation to take, release or transfer water, based on forecasted inflows, and subject to rules for adjustment as the inflows become known. Each trade constitutes a contract between the market manager and the user. The quota for the immediate period are considered firm, and users are expected to use their allocated water (i.e. follow their contractual agreement). Quota for periods beyond the immediate period are conditional, subject to possible scaling to match the surface water discharges.

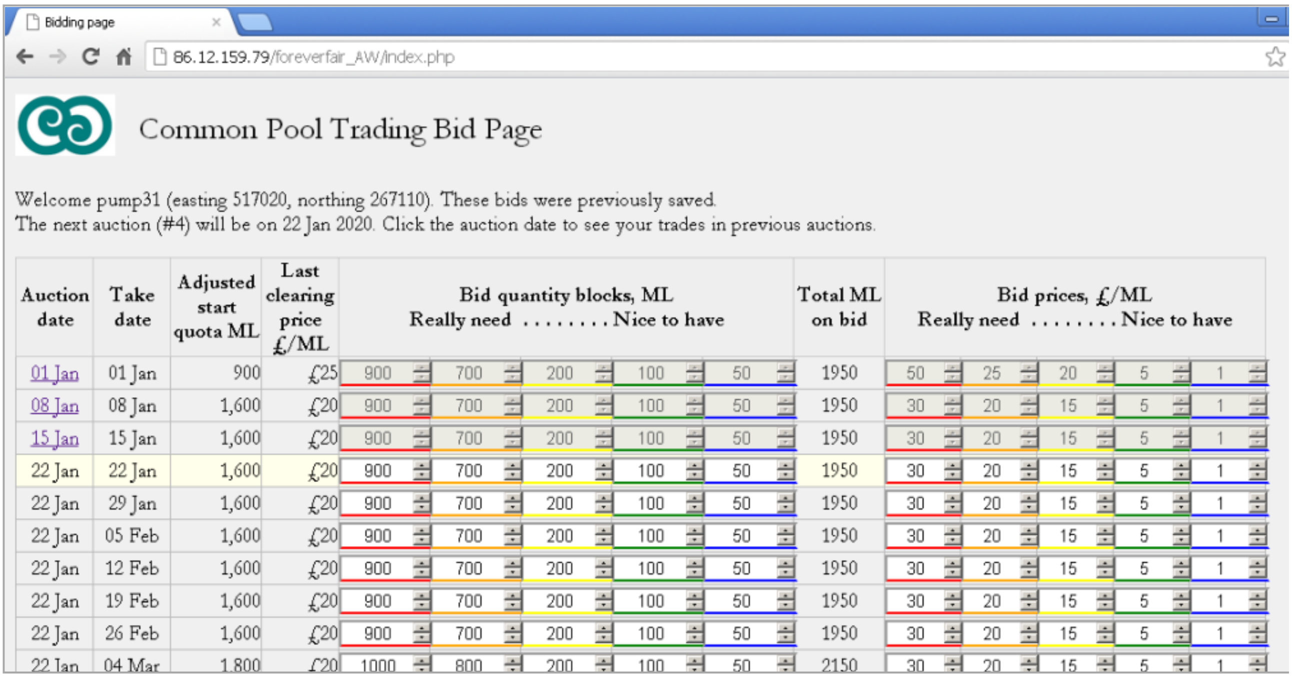
The demonstration of the common pool approach for this project needed an optimization model to clear the market, connected to the market database and a hydrology database, and an associated auction manager's web page to set up auctions and to control the market clearing. Appendix D gives a full description of the common pool model development. The optimisation calculates the optimal allocation from users' bids, maximising the total value of the water, i.e. the model will try to allocate water to users who bid highest (using the default bid curves as described in Appendix C for users who did not participate in the demonstrations), while satisfying the physical and environmental requirements. Following optimisation, the web server calculates trades based on users' initial rights and final allocations.

User interface for the common pool system

The demonstration required development of a reasonably user-friendly web interface, including a log-in page shown in Figure 3.10. Figure 3.11 shows the user's web interface. Each user's web interface automatically saves the user's bids to the market database on the server. Figure 3.12 shows the market manager's web page, which is used to initialize and clear each auction.

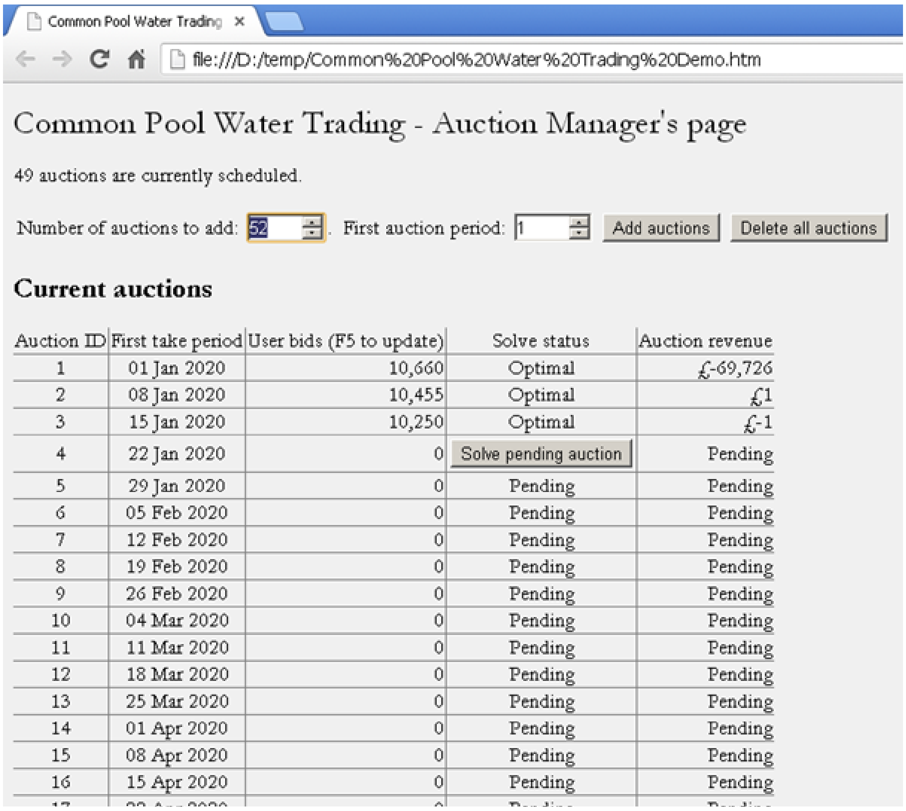
Figure 3.10: User's log in page for the common pool trading system

Figure 3.11: Part of the user's bidding page



Auction date	Take date	Adjusted start quota ML	Last clearing price £/ML	Bid quantity blocks, ML Really need .... Nice to have					Total ML on bid	Bid prices, £/ML Really need .... Nice to have				
01 Jan	01 Jan	900	£25	900	700	200	100	50	1950	50	25	20	5	1
08 Jan	08 Jan	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
15 Jan	15 Jan	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	22 Jan	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	29 Jan	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	05 Feb	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	12 Feb	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	19 Feb	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	26 Feb	1,600	£20	900	700	200	100	50	1950	30	20	15	5	1
22 Jan	04 Mar	1,800	£20	1000	800	200	100	50	2150	30	20	15	5	1

Figure 3.12: Part of the auction's manager's page



Auction ID	First take period	User bids (F5 to update)	Solve status	Auction revenue
1	01 Jan 2020	10,660	Optimal	£-69,726
2	08 Jan 2020	10,455	Optimal	£1
3	15 Jan 2020	10,250	Optimal	£-1
4	22 Jan 2020	0	Solve pending auction	Pending
5	29 Jan 2020	0	Pending	Pending
6	05 Feb 2020	0	Pending	Pending
7	12 Feb 2020	0	Pending	Pending
8	19 Feb 2020	0	Pending	Pending
9	26 Feb 2020	0	Pending	Pending
10	04 Mar 2020	0	Pending	Pending
11	11 Mar 2020	0	Pending	Pending
12	18 Mar 2020	0	Pending	Pending
13	25 Mar 2020	0	Pending	Pending
14	01 Apr 2020	0	Pending	Pending
15	08 Apr 2020	0	Pending	Pending
16	15 Apr 2020	0	Pending	Pending

This shows that three auctions have been completed.
The next pending auction is for 22 January 2020.

Limitations of the common pool method

Some simplifying assumptions had to be made owing to the limited time for this project. These limitations apply only to the demonstration and not to the common pool method generally. The limitations of the modelling carried out were as follows:

- The complexity of the Water Resource Zone was not modelled fully. Groundwater was omitted and abstraction was assumed not to affect river flows over periods shorter than a week.
- Sewage treatment return flows were modelled as constant flows; however they actually depend on sewer flows, rainfall, seepage and Anglian Water's operations.
- "Perfect foresight" of inflows was assumed in the demonstration. This was also partly to simplify the demonstration for the users. For implementation, the system would require weekly quota to be scaled in some way to match the inflows.
- Consumption factors were binary i.e. a user was either consumptive (i.e. used 100% of the water they abstracted) or non-consumptive (i.e. all their abstracted water returned to the river).

3.6.5. Workshops

As noted above, to test the two trading approaches developed for the project, two workshops were carried out on 9 and 16 October 2012. They lasted from 10.00 to 16.00. The aim of the workshops was to gauge users' responses to the improved pair-wise and common pool trading systems in the Upper Ouse and Bedford Ouse catchment. These were workshops aimed at encouraging participants to understand and to engage with the approaches and to give feedback. They were not controlled experiments, and the sample size was very small. Given this, findings about users' responses should be regarded as exploratory.

Participants

We invited participants from the pool of stakeholders with whom we had engaged in Phase 1. We included all those who had shown an interest in the project and those who had attended a focus group or taken part in an interview. We approached participants initially via email or letter, and then followed up by telephone calls until we spoke with the abstractor or were able to leave a message. In total we made contact with approximately 60 abstractors. Of these, 15 attended the workshops, eight at the first workshop and seven at the second workshop. Unfortunately, we found it difficult to attract agricultural abstractors, many of whom were in the middle of harvesting their crop and were not able to afford a day out from their work. Table 3.7 indicates which sectors the participants were from.

Table 3.7: Workshop participants

Type of participant	Workshop 1	Workshop 2
Agricultural abstractors	4	1
Public water supply abstractors	2	2
Industrial abstractors	1	1
Regulators	1	1
Researchers	-	1
Total	8	7

Method

The morning was spent on the common pool method which was explained and demonstrated, then participants had the opportunity to try out the method for "real". Each participant was given a laptop computer and was able to take part in a "live" auction. In the afternoon, participants were introduced to the Improved pair-wise model through a presentation. This was followed by small group discussions around model outputs that simulated what might happen if this approach were implemented in the Upper Ouse and Bedford Ouse catchment.

Participants filled in three short questionnaires which are included in Appendix F covering:

1. Their views on trading (given out at the beginning of the workshop);
2. Their views on the common pool approach (given out after the first session);
3. Their views on the improved pair-wise approach (given out after the last session).

In addition participants were asked to fill in a short form to evaluate the workshop as a whole. Throughout the workshop, the project team took notes and recorded plenary discussions on flip charts. All notes and flip charts were written up after the workshop and form part of the findings of this research.

4. Findings from workshops

4.1. Introduction

This section presents the findings from the workshops gathered through the questionnaire and the notes/flip charts. These stakeholders' views and opinions are based on their workshop experience and their pre-existing views. The findings provide a useful view of how stakeholders made sense of the two approaches. These workshops were only exploratory, so the findings need to be verified with a larger sample.

4.2. Knowledge and experience of trading

As discussed in the Phase 1 research, many of the abstractors had little knowledge or experience of the current water trading system. Of the 15 participants, 13 filled in the knowledge and experience forms. The participants self-assessed knowledge of trading ranged from very little to considerable, with most identifying with the middle point on the scale as can be seen in Table 4.1.

Table 4.1: Participants' description of their knowledge of water trading

	Numbers of participants				
Question	**Very little knowledge 1**	**2**	**3**	**4**	**Considerable knowledge 5**
How would you describe your knowledge of water trading?	2	2	5	2	2

With respect to their involvement with water trading most participants either had some indirect experience or some experience of informal trades as detailed in Table 4.2.

Table 4.2: Participants' description of their involvement in water trading

Level of involvement with water trading	Number of participants
Never been involved in water trading	2
Some indirect experience of water trading through friends, colleagues, research	5
Carried out/advised on informal trades	4
Carried out/been involved with a trade through the Environment Agency	2

In response to the open question, a range of views about trading were expressed which can be summarised into three categories:

1. Interested, trading regarded as a useful additional tool to improve water management, could help to get a sustainable solution and seen as the best way to allocate water for society (4 responses)

2. Interested, but with questions about:
    a. Equity ("*curious about how to ensure it's equitable*") (2 responses);
    b. Ring-fencing ("*good for agriculture as long as it stays in agriculture*") (1 response);
    c. Practicality and political appetite for necessary reforms (1 response);
    d. The need for greater flexibility (1 response);
3. Interested, negative with comments about:
    a. Cost and timing ("*trading is expensive and takes a long time from start to finish*") (2 responses);
    b. General anxiety ("*nervous*") (1 response);
    c. Doubt that a new system is needed ("*not sure that a new system is really required?*") (1 response).

Overall, stakeholders had a positive interest in trading, but those who were positive had questions that need to be addressed for them to feel comfortable with water trading, plus there were four negative comments around trading. This range of interest and comments echoes the Phase 1 research showing views are not so entrenched as to make discussion around water trading difficult. However, for that to happen, more knowledge and engagement with trading and its role in water management is needed. Finally, all participants hoped to get information from the workshop around water trading, the current abstraction reforms, and the project in general.

4.3. Reactions to the common pool approach

This section presents the findings from the individual questionnaires and discussions in the plenary sessions. Table 4.3 shows the answers extracted from the questionnaires given out after the common pool demonstration. The range of responses showed no consensus on this approach, although overall most people were nearer the "definitely" end for engaging with the approach than the "very unlikely" end. The comments made on the questionnaires alongside each question are discussed below with relevant comments raised in the plenary sessions.

4.3.1. Fairness

Twelve comments were made on the questionnaire about fairness, and it was discussed in the workshops. On the questionnaires participants felt that "big players" had the potential to dominate and that rules would be needed to ensure fairness; these comments link to comments about the need to protect food production and a suggestion that small farmers may be sceptical of trading. This issue was also raised in the workshops, it was felt that land might be taken out of irrigated vegetable production and that could lead eventually to some agricultural sectors disappearing. This was linked to the issue of "ring-fencing", keeping the trades within sectors, although it was raised that ring-fencing undermines overall trading and would reduce flexibility of the pool. Respondents were concerned that public water consumption is considered to have a higher value of water than agriculture, and given its dominance in the catchment the public water supply would be able to drive the price of water across the catchment. Finally, the issue of those who can pay most getting the water was raised.

Table 4.3: Reactions to the common pool approach

Question		1	2	3	4	5	
How fair or unfair do you think the common pool approach is? (12 responses)	Completely fair	0	4	3	3	2	Completely unfair
How flexible or inflexible do you think the common pool approach is? (12 responses)	Completely flexible	3	4	2	2	1	Completely inflexible
How efficient or inefficient do you think the bidding page for the common pool is? (11 responses)	Very efficient	0	2	6	3	0	Very inefficient
How do you think the common pool approach would affect the efficiency of water use in the catchment? (13 responses)	Make it much more efficient	4	3	4	2	0	Make it much less efficient
If you had access to the common pool approach can you see yourself engaging with it? (11 responses)	Definitely	4	4	3	0	0	Very unlikely

Note: Total number of responses varied between 11 to 13 as not all participants answered all the questions.

From the questionnaires, respondents suggested that it was hard to tell whether the common pool system would be fair or unfair. It could be both, and someone commented that the economically optimum solution was not necessarily the socially optimum solution. In the plenary session it was suggested that it would be fair for the environment to be able to bid for water so that it was represented in the system and therefore would have a voice. Finally, it was felt that more transparency in the system would be helpful.

4.3.2. Flexibility

Respondents gave fewer comments (5) on the questionnaire about flexibility. The weekly time steps appeared to provide plenty of flexibility, the approach was flexible but complicated; and people would need to practise to get the benefit of the flexibility. It was also suggested that it would free up unused water when it is needed. How abstractors would manage their money if they were trading each week was discussed at one of the workshops. Would it mean that money would be going in and out every week? If so given that they would be paying each week for a year it could mean a lot of money being exchanged on a weekly basis, money that a smaller abstractor might not have.

4.3.3. Efficiency of the bidding page

The participants had an hour or so presentation and demonstration of the common pool system before they took part in the auction. In a key part of the demonstration users were asked come up with a value that they would be prepared to bid for their water. In the first workshop participants were asked to think of a value, which proved to be quite a challenge in the abstract. In the second workshop they were given some boundaries and also the cost of water for the public water supply and that worked better. The participants did take time to understand the bidding page, which was quite complex.

In the plenary session participants suggested that it would need a period of learning to understand how the system worked, and that they could lose quite a lot of money in the process of learning. In one round of the auction the public water supply company had only enough water if they had paid enough money that would have “bankrupted the company”. In another auction the public water supply company and a smaller private water supply abstractor did not receive sufficient water which could have left people without water until the next round of bidding. It was not clear how that had happened, but it was felt that more time was needed to make sense of the process for some abstractors. A further comment was made that someone had overbid and bought water that they did not need, again highlighting the need for learning. It was expressed that they were unclear as to what was being traded, the concept of a quota rather than a licence took a little time for people to comprehend. In addition, the changing of values on the interface was found to be a little cumbersome (if you change one value all the ones below changed which helped in one way but not if you wanted different values further on in the year).

From the questionnaires it was suggested that more work on the page would be useful, specifically that the page could have fewer “buckets” (i.e. tranches), the web page could be made more intuitive and differentiate more between buying and selling. These issues were echoed in the workshops with a suggestion that three “buckets” may be enough and that having “buy” and “sell” columns would be more helpful on the interface.

4.3.4. Efficiency of water use in the catchment

Overall the comments (7) on the questionnaire were sceptical as to whether it would improve efficiency across the catchment; it was thought it would take time and people would have to learn to use it.

4.3.5. Engagement with the approach

The participants discussed their potential engagement with the approach and were positive but cautious, suggesting they would engage with a simpler system. Of the different sectors, the public water supply sector felt if certainty of supply was guaranteed then they could use the system. The RSPB felt it could help the management of their reserves and provide an income stream for them and it was felt that businesses would be interested if water did not cost as much as it does currently. Again the issue of ring-fencing for agriculture was raised. In addition, a bigger issue of the governance of water was raised; it was felt that stakeholders should be engaged with the planning process and the setting of environmental flows and that this common pool approach might encourage a more collective approach to managing the water in the catchment.

From the questionnaires (5 comments), participants felt they would engage in times of water shortage and if it became the tool for water allocation, but it was expressed that some older/smaller producers would need guidance to engage with it and one person found it hard to see the advantage if you need most of your licence most of the year.

4.3.6. Conditions for engaging with the common pool approach

Overall, for people to engage with the approach there would firstly need to be more time spent learning and engaging with the system, as it was clear from the workshops that as people engaged more with it they raised more questions for consideration. Key questions that were raised were the following:

1. How does the system value consumptive and non-consumptive use?
2. Is it necessary to have monetary transactions running over a year or could you pay for part of a year at a time?
3. Would trading result in abstractors needing to justify the licence they hold?
4. If you sell part of the licence will this result in a reduction of the licence?
5. How much would the new system cost?
6. Will the market allow for speculation? Will speculators be able to join the market?
7. Would it be possible to trade discharge rather than licensed water e.g. treated water released into the river?
8. If trading was between sectors and therefore uses how would the system take account of the fact that some uses have greater impacts on the environment than others?
9. How would this work with storage?
10. To what extent would those who benefit be determined by location in the catchment?
11. Wouldn't this need financial brokers?

On the questionnaires participants commented (9) that it would need to be simpler to access and navigate; that the winter licensing regime would need changing; that there should be a guaranteed quota for basic need; that costs could be passed to the consumer if needed; and there would need to be confidence in the hydrological modelling.

4.3.7. Overall benefits and limitations of the common pool system

Benefits

On the questionnaires, participants indicated that the common pool system had the following benefits:

- Flexible, and rapid, good for short term trades;
- Clear and transparent;
- Make better use of the resource and take into account all the needs of the catchment;
- Able to put a meaningful value on water.

From the general discussions of benefits of the common pool system, it was felt that it would help abstractors to understand the value of water, make the price more transparent which would lead to improving water management, making water a commodity that has to be actively managed. The system was felt to be open and that abstractors would get more of a sense of where people value water and when they value water. In addition, it was felt that it could help when making decisions as to whether to abstract from the river or build a reservoir, which was considered very useful.

Limitations

The participants indicated that they thought the common pool system had the following limitations:

- Raises equity concerns, that agriculture may risk losing water, or that selling water might be more profitable than farming;

- Turns water into a commodity like gas and oil, but where does that leave basic rights about access to water;
- Might mean abstractors did not get their minimum amount of water and go bankrupt;
- Would need to have very good underlying hydrological modelling.

From the workshop discussions the limitations revolved mostly around understanding more about the system, the concern that smaller abstractors might lose out, that it was complex to engage with and that large reforms and institutional changes would need to be made for it to be implemented. Some people also felt that there was a policy issue around where food would be grown if all agricultural licences were sold. Finally, participants expressed that many abstractors would be sceptical of the system and that leaders of various sectors would need to give a very strong steer that it would work, this would include the public water supply sector who would need to be convinced that the complex hydrology would work. It was felt that from a business perspective it would mean employing extra resources to run the system, which implies an additional cost.

4.4. Reactions to the improved pair-wise trading approach

In this section we present the findings gathered from the individual questionnaires together from the discussions in the plenary sessions at the workshops. From the questionnaires given out after the improved pair-wise presentation and small group discussions the answers detailed in Table 4.4 were extracted.

4.4.1. Fairness

The few comments on the questionnaires (2) suggested that the improved pair-wise trading system appeared to have greater transparency than the current system, but fairness would depend on whether scaling was introduced and it needed to be clear that environmental considerations are taken into account. In workshop discussions, issues of fairness were raised in relation to location, would it be more beneficial to people in certain locations? It was also felt that it was not clear how this system would help new users.

4.4.2. Flexibility

Participants (5) did not feel it was very flexible but could see the potential. Two participants thought it less flexible than the common pool approach. However, in the workshop discussion there were felt to be considerable benefits due to the pre-approved trades allowing the ability to trade at short notice.

Table 4.4: Reactions to the improved pair-wise trading approach

Question		1	2	3	4	5	
How fair or unfair do you think the improved pair-wise approach is?	Completely fair	0	6	3	1	0	Completely unfair
How flexible or inflexible do you think the improved pair-wise approach is?	Completely flexible	0	5	5	2	0	Completely inflexible
How do you think the improved pair-wise approach would affect the efficiency of water use in the catchment?	Make it much more efficient	1	4	4	2	0	Make it much less efficient
From what you have heard today, do you think the improved pair-wise approach has the potential to make your business or organisation better off?	Definitely	0	4	3	2	1	Very unlikely
If you had access to the improved pair-wise approach, can you see yourself engaging with it)?	Definitely	7	0	1	0	1	Very unlikely

4.4.3. Efficiency

Participants on their questionnaires (5) gave mixed responses over efficiency, with the view expressed that it might make it more efficient but this might be at the expense of agriculture, it might increase the use of unused licences through to the view that it would be efficient if the regulatory regime were sensible and regulatory action constrained. In the workshop discussions, it was felt that efficiency would increase use of licences that currently were unused and that it should encourage improvements in water demand management.

4.4.4. Improving business

Participants felt there was limited potential to make their businesses better off; however, some recognized the benefit of short term trades. This topic was not discussed or raised in the workshop.

4.4.5. Engagement with the approach

Participants in their comments (2) said they would engage with the approach on a short term basis and it would depend on location. Overall, the workshops again indicated cautious enthusiasm for the approach and engaging with it, with seven participants stating if they had access to an improved pair-wise trading approach that they would definitely engage with it.

4.4.6. Conditions for engaging with improved pair-wise approach

Participants (7) in their questionnaire responses commented that the approach needed to be clear and transparent and understandable, that they would need to have a better understanding of their own water use; that the science would need to be trusted; they mentioned ring-fencing of agricultural water bodies as well.

In the workshop it was discussed that abstractors would need to change their behaviour and thinking about water, and people would need to have greater trust in the system to engage with it. It was felt that protecting some sectors would be important, and agriculture was considered in need of ring-fencing, although it was also suggested that ring-fencing could undermine trade.

As with the common pool approach, participants raised questions that would need to be answered for people to engage with the system:

1. Would the prices be transparent? (e.g. to inform bids on bulletin boards)
2. How would trades be “policed”?

4.4.7. Overall benefits and limitations of the pair-wise approach

Benefits

As noted above, the idea of pre-approved trades was welcomed, as environmental studies would not be needed as they are currently. The fact that it puts buyers and sellers together was seen as a benefit. In addition it was felt that relationships between abstractors would develop over time and that was seen as a benefit. It was also felt that abstractors would have control over their licences and enable them to plan ahead.

Participants indicated that they thought the improved pair-wise approach had the following benefits:

- Flexible (i.e. able to get involved when you want to);
- Easy to understand;
- More efficient water use;
- Better than the existing system;
- Improved relationships between abstractors.

Limitations

Participants indicated that they thought the improved pair-wise approach had the following limitations:

- Still would not solve the availability of water issues;
- Would need to include groundwater and discharges from sewage treatment works;
- Would not be best for large volume traders.

5. Discussion

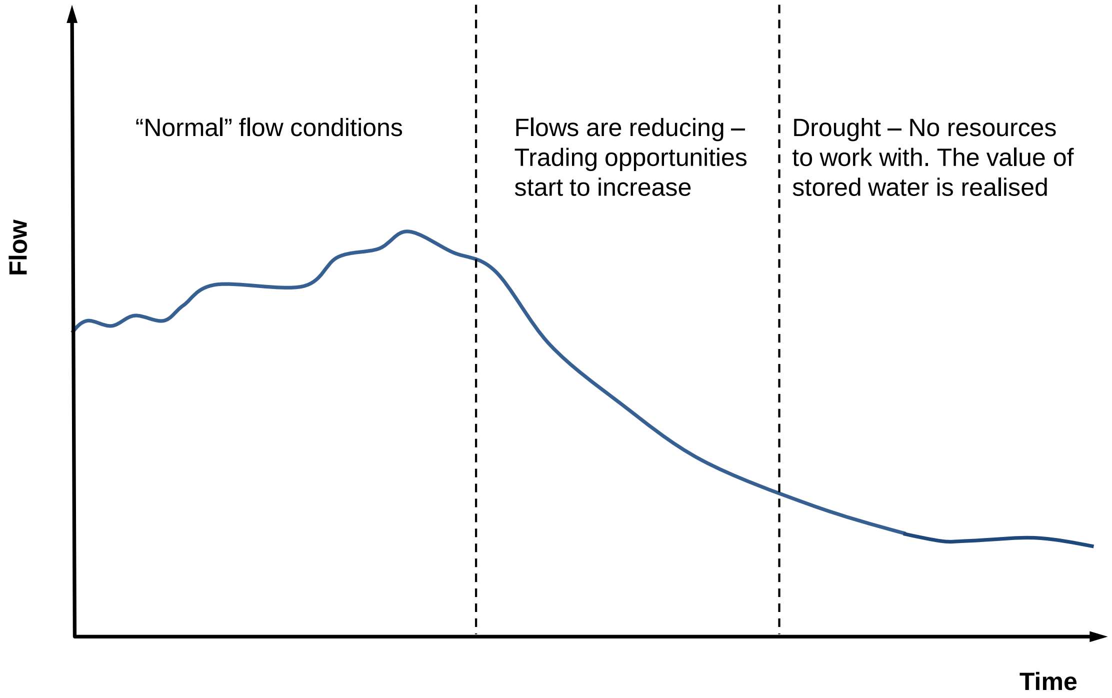
5.1. Current system

The abstraction regime in England and Wales was historically based on common law riparian rights with “riparianism” considered to be an adequate basis for the management of water until the introduction of recent reforms. In 2011 Defra investigated the unmet demand for abstraction licences in catchments across England and Wales. That study found that only a small number of sectors currently face problems with unmet demand, but the problem is expected to worsen in the future owing to the expansion of production activities, climate change and population growth (Defra, 2011d). However, new users have difficulty entering the market in over-licensed or over-abstracted catchments and new abstractors are often forced to buy or lease a property that has an existing abstraction licence.

For trading of abstraction licences to be active, a catchment needs a degree of both resource stress and unmet demand (either on a permanent or temporary basis). If plenty of water is available, trading will not generally take place (Defra, 2011c). An active market within a hydrological or hydro-geological area requires a sufficient number of abstraction licence holders, depending on the transaction costs.

The time to complete a trade currently is one of the main barriers to trading of abstraction licences. Improving the way water can be traded or shared will bring significant benefits during the initial stages of a drought, as shown in Figure 5.1.

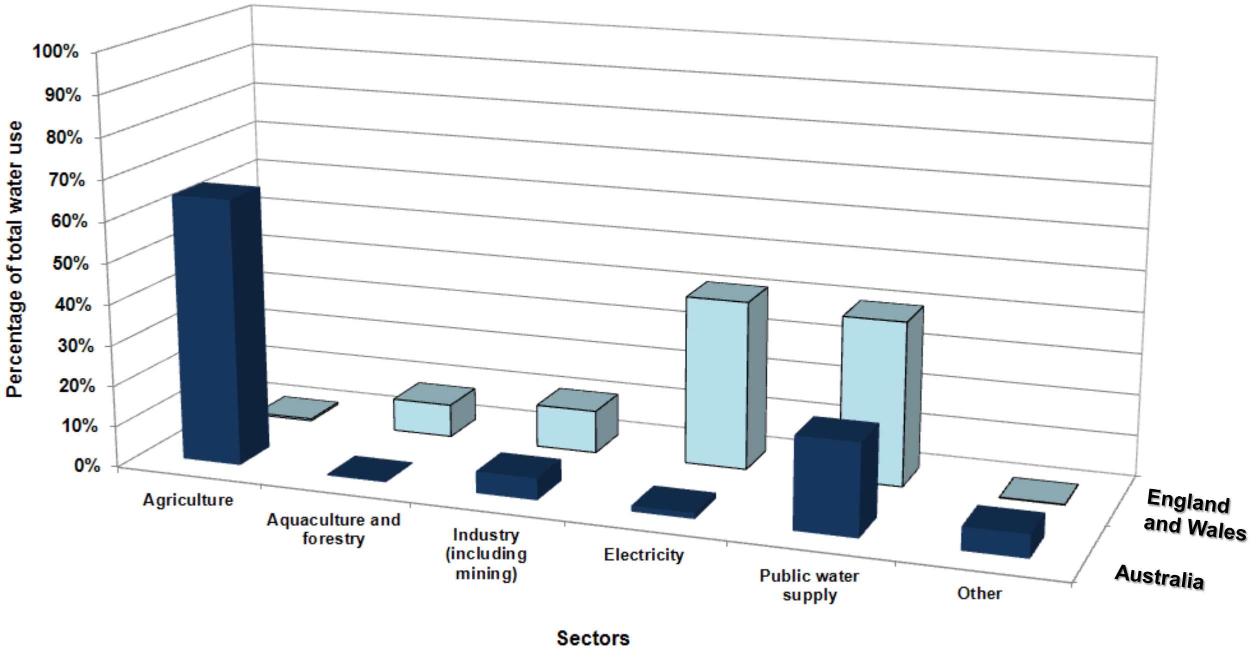
Figure 5.1: Illustration of how reducing flows increase trading opportunities and the value of stored water



5.2. Lessons from Australia

The development of water markets in Australia has occurred through a gradual, learning and adaptive process, allowing stakeholders to "*be brought along for the journey*" through participation (in regionally controlled situations) in the market (Slayter and Cvijanovic, 2012). In addition, water markets have been developed in consultation with state and territory governments at both policy and implementation levels, and feedback loops were established to ensure lessons learnt were captured and amendments to policy enacted accordingly in a timely manner to respond to market needs. Regular reviews of policy, implementation and trends have also been a key feature of water markets operating in Australia. It is important to note that when comparing Australia with England and Wales that the agricultural sector abstracts, as a percentage of total abstractions, are significantly more than in England and Wales as Figure 5.2 shows.

Figure 5.2: Comparison of water use between Australia and England and Wales



Source: Australian Bureau of Statistics, 2012; Defra, 2012

Based on the Australian experience, key things to consider when introducing water trading into a new market include:

- Being confident that the underlying policy is adaptive and flexible enough to allow lessons learnt to be incorporated quickly (through feedback loops with implementers) so that water trading rules are ahead of market developments;
- Considering, as early as possible, any matters that may become a barrier to water trade across jurisdictional boundaries, and address them quickly;
- Being mindful that climatic conditions can vary and affect the operation of water trading rules. It should be remembered that broader water management rules may in some cases override water trading rules when extreme conditions occur, and the rules surrounding a water market should be established to allow the market to operate during such conditions. For example, during drought conditions, unless a river system falls below its required environmental flow, water trading should not be ceased because of water management issues.

(National Water Commission, 2011; Slayter and Cvijanovic, 2012).

Introducing water trading in England and Wales needs an incremental approach. Australia has refined its approach over a 20 year period. This has been found to help to manage uncertainty and the concerns of stakeholders (National Water Commission, 2011). There needs to be market rules and complementary policies to prevent adverse environmental and social impacts. In the case of the environment Defra is committed to implementing the Water Framework Directive by 2025 which will increase environmental flows in currently over-abstracted catchments.

In many cases the diversity of water needs increases the effectiveness of trade. It is important to note that in Australia where water trading was introduced some 20 years ago, water markets are continuing to develop and difficulties are still being ironed out (Slayter and Cvijanovic, 2012). In Australia water markets have been used extensively during recent droughts as a key tool to manage scarce water resources (National Water Commission, 2011). The research has shown that water trading can be effective in allocating water to its highest value use.

5.3. Research assumptions and related findings

At the commencement of the research the Working Group formulated a number of assumptions, based on previous research, expert opinion, and abstractors' opinions in East Anglia relating to water trading. Each of these assumptions is addressed below in the light of the findings from this research.

5.3.1. Number and diversity of abstractors

Assumption 1 "*Effectiveness of water trading is affected by the number and diversity of abstractors in order to realise the full economic potential of the catchment, and deliver security of supply over the long term*".

In Phase 1 of the research Environment Agency staff argued that there were not enough trades taking place to create a dynamic market (HR Wallingford et al., 2012). Currently abstractors like to hold onto their licences and there is no incentive to sell them because the cost of retaining the licence is relatively low. In Phase 1 the innovators mentioned the need for a "big enough market" to make trading financially interesting, whilst the abstractors argued that there was little trading because there was little information about trading and few had much idea of what it would involve.

Both the improved pair-wise and common pool methods demonstrated that a high degree of trading could, under the correct conditions, take place within the Upper Ouse and Bedford Ouse catchment. However, in terms of volume of water abstracted the market place is dominated by Anglian Water. Further, more detailed work would be required to assess the "real power" Anglian Water wields in this catchment. A comparison with a catchment such as the Cam and Ely Ouse where agricultural abstractions are considerably higher, both volumetrically and in terms of number of licences, than the Upper Ouse and Bedford Ouse would be useful.

5.3.2. Usefulness of short-term and long-term trades

Assumption 2 "*Both short-term and long-term trades would be possible to meet the flexible needs of abstractors*".

The abstractors engaged in the research commented that in terms of the "short-term", trading on a weekly basis provided them with sufficient flexibility. However, under certain trading systems (e.g. an improved pair-wise system) both "long-term" trades as they currently exist would be necessary to meet the requirements of some abstractors (e.g. those who would want to sell or to lease their licences over a periods of greater than six months). Research in England and Wales has indicated that a faster system for approving trades would help to encourage short-term trades (Defra, 2011c).

5.3.3. Availability of trusted information

Assumption 3 "*The availability of trusted information for abstractors will be a significant factor dictating interest and take-up of water trading*"

In Phase 1 of the research it was found that currently, abstractors engage in a number of water management practices in order to ensure they have enough water at the right time and place for their businesses. This includes "informal" trading, between trusted sources at times of need (HR Wallingford et al., 2012).

Phase 1 found that across the case study catchment, there is evidence of the existence of valuable social capital including:

- **Bonding capital** (i.e. close knit groups with support from family/friends) found in river-level farmers' associations such as the River Lark Abstractors' Group and in informal cooperation between farmers to share water;
- **Bridging capital** (i.e. wider networks, bringing people involved in different groups together providing access to wider resources) through associations like the NFU which facilitates coordination between farmers across the region and between regions;
- **Linking capital** (i.e. hierarchical networks between people in local areas and organisations with power and influence): innovators appear to provide links between farmer abstractors and regional or national delivery agents such as the Environment Agency or the Internal Drainage Boards.

The availability of trusted information to abstractors from the limited engagement that we carried out would appear to be important and thus could be an important factor in the uptake of water trading and particular water trading platforms.

5.3.4. Use of existing hydrological models

Assumption 4 "*A cost-effective set of arrangements would probably use existing hydrological models rather than propose developing new ones*"

In Phase 1 of the research it was found that there is scepticism amongst certain abstractors as to whether hydrological and hydro-geological processes are represented accurately enough in CAMS to allow water trading to take place (HR Wallingford et al., 2012). There is a definite requirement to both improve and develop new hydrological models of catchments where trading is going to take place. In many cases existing hydrological models are unlikely to be sufficiently robust or sophisticated enough for use by water trading platforms. At the same time there is a need to improve the quality of data related to both actual quantities of water abstracted, abstraction licences and return flows.

5.3.5. Applicability of the method and the effect on capital costs

Assumption 5 "*The more commonly applicable the method is, the more likely it is that any capital costs will be accepted and covered where necessary by other catchments over time*"

This assumption was not explicitly explored as part of this research. However, the capital costs of implementing a trading system in suitable catchments are likely to be relatively low compared to the potential benefits as has been demonstrated by the implementation of the improved pair-wise trading systems, the full details of which are given in Appendix A of this report.

5.3.6. The relationship between trading potential and agricultural demand

Assumption 6 "*Trading potential is more promising where there is unmet agricultural demand*"

Research by the National Water Commission in Australia (National Water Commission, 2011) and Defra in England and Wales (Defra, 2011) has indicated that trading potential is more promising where there is unmet agricultural demand. Of the 51 abstraction licensing trades that occurred between 2003 and 2011, 13 of these occurred in the Cam and Ely Ouse catchment where there are a large number of agricultural licences and at certain times of the year there is an unmet agricultural demand.

5.3.7. The viability of downstream versus upstream trades

Assumption 7 "*Downstream trades may be more viable than upstream trades and bring about more environmental benefits*"

In general downstream trades are likely to be more viable than upstream trades and there is a possibility that these could bring about environmental benefits. However, the common pool and improved pair-wise trading methods do not preclude upstream trades whilst maintaining environmental flows.

5.3.8. Uncertainty amongst abstractors regarding the value of water

Assumption 8 "*There is an uncertainty regarding the 'value of water' by abstractors*"

The fact that there are no agreed market prices for water means there are issues relating to the uncertainty of the value of water by abstractors. When undertaking the common pool demonstration where stakeholders had to bid for water, many struggled to place a value on water. Workshops held by Defra in seven case study catchments throughout England and Wales, as part of an on-going abstraction reform project in September and October 2012 also confirmed this finding (Pocock, 2012). In Phase 1 of the work, one abstractor stated that "*I think that people don't have a feel for how much it's* [water] *going to cost and that's a genuine "blocker" when people are investigating the alternatives*" (HR Wallingford, 2012).

5.4. How stakeholders' concerns could be addressed

5.4.1. Ring-fencing and equity concerns

Stakeholders raised the issue of ring-fencing of water for agricultural use, to protect farmers' abstraction rights. However, ring-fencing of agricultural water could have the following effects:

- Skew the market, by keeping some non-agricultural users out of part of the market;
- Remove resilience from the trading system;
- Inhibit farmers from investing in water storage in partnership with other users;

- Eliminating the highest value trades (which would be between sectors, which would have larger differences in water values);
- Restrict farmers' ability to buy, store and sell water on the open market when conditions allowed.

In Australia it has also been found that measures that may stifle the market (e.g. ring-fencing) or impede it have in some cases been found to have unintended consequences (National Water Commission, 2011). It is clear that some education may be useful about the disadvantages of ring-fencing agricultural licences.

Anglian Water abstracts annually between 80% to 90% of the surface water in the Upper Ouse and Bedford Ouse CAMS area. The trading systems we have tested need piloting in catchments less dominated by public water supply and where agricultural abstractions are relatively larger. The Cam and Ely Ouse CAMS area is one such catchment in East Anglia.

Stakeholders concerns about equity and bankruptcy may have the same core issue as ring-fencing: fear of loss. However, trading should be voluntary, with both parties enjoying benefits. This is an area that needs further research.

5.4.2. Making water a commodity, ignores rights to access

Whilst some abstractors we engaged used the language of commodities to talk about their water resources, referring to assets, pricing, volumes traded; others talked about needing to be sure that they could get their water back if they agreed to trade it temporarily, for example one abstractor said "...*OK so you put water in ... what if you wanted to put that in for a temporary period of time, how do you ensure you are going to get it back?*"

This suggests that different abstractors have a different perception of their abstraction licences. Potentially, these kinds of social or emotional understandings of the value of water could act as barriers to water abstractors becoming involved in a water market. Some abstractors need to be assured that under a water trading system they would not necessarily have to trade and that water would be allocated in an equitable manner.

The research found that amongst many abstractors there was a clear recognition and awareness that water and its use has a value. Overall the stakeholders expressed the general view that water can be viewed as a commodity, or asset that is clearly valued (and therefore can be seen to have an economic value). One abstractor said *"I think there is an appeal in being able to trade water because as … it is an asset and it's a commodity that could be traded*" (HR Wallingford et al., 2012) . Furthermore some interest was expressed in the potential to benefit economically from a potentially improved market in water licence trading, for example one abstractor said that: "*Yes, there is the potential of earning a few pounds. I'm just looking at it from an economic point of view there, but ... yes; there is a bit of potential there*".

Although this interest is clearly shown, another abstractor indicated a "change of mind-set" was required in order to see licences and water as "tradable assets". There will need to be on-going training and capacity building to assist with changing the mind-set of abstractors.

5.4.3. Adequate hydrological modelling

Water is allocated now with models that are much less sophisticated than the ones we used, and still less sophisticated than the ones we envisage should be used. Further, other types of common pool markets (especially wholesale electricity) already operate with much higher reliability and security than would be required for water. There remains a real need to improve the hydrological and hydro-geological modelling of catchments and improve the quality of the data that these models rely on.

5.5. Requirements for effective water trading

The effectiveness of water trading, as it relates to the number, diversity and size of water users, is similar to many other commodities. Large numbers of diverse abstractors of varying sizes add to liquidity, in-turn allowing for more potential buyers and sellers to meet. Our research confirmed that for a market design to be successful the following are required:

- Transaction costs must be low. It is the large transaction costs that inhibit trade now. We showed that the common pool system and improved pair-wise systems can do this;
- Market participants need to take account of all the costs and benefits generated by their actions (i.e. any externalities are internalised). This is best done with price signals available from a market;
- There should not be barriers that prevent abstractors entering the market.

The prerequisites for a sustainable water market include:

- Setting a suitable cap on how much water can be abstracted from surface and groundwater. These caps are currently in place via the on-going implementation of the Water Framework Directive. We showed that both the common pool and improved pair-wise systems could incorporate complex environmental flow requirements;
- Establishment of clearly specified water entitlements;
- Establishment of a sound regulatory and governance framework;
- A comprehensive and robust system of metering and water accounting.

The research has shown that the challenges to setting up a successful market at a catchment level are: technical; political; social; cultural; and managerial. However, it is important to note that in Australia it was found that the new participants in the water market "*learnt quickly and made decisions based on the rules that were in place*" (National Water Commission, 2011).

In Australia the following were carried out to help ensure the success of water trading:

- A determination of the balance between consumptive and environmental water use;
- Development of regulations for the market (e.g. registers, water accounting and compliance and enforcement regulations);
- The development of trading platforms;
- The development of institutional and governance arrangements.

In 2000 the DETR carried out some research on the use of economic instruments and water abstraction. They carried out a survey of abstractors and it is interesting to note that 12 years ago 55% of the respondents indicated an interest in trading, although most were unable to indicate the volumes or prices at which they would sell or buy (DETR, 2000). In summary, the creation of markets in transferable abstraction rights should be feasible in those catchments where there is currently an unmet demand.

6. Summary of the findings

This research was based on engagement with a limited number of abstractors over a short period of time. Broader engagement is required to obtain more meaningful insight into stakeholders' views on water trading and the two trading systems that we researched. Raw water is relatively inexpensive in England and Wales and consequently many abstractors other than public water supply companies, farmers and power companies do not place water high up their agenda. This section provides a summary of the findings of the research.

6.1. Stakeholders' views

- All types of stakeholders lack knowledge and awareness of water trading. Certain abstractor groups felt that little information was available to them about the trading of water rights. As a result, an opportunity exists to discuss trading. We found neither outright rejection nor committed support for increased trading in water or a new system to facilitate it. Even people who did not want to participate in the research, when invited indicated that this was because they could not see its relevance (often because the quantities of water they used were "small"), not because they were opposed to it;
- Many participants mentioned ring-fencing. Some perceived that farmers would lose out to larger abstractors such as water companies, and that owing to their relatively small size of agricultural abstraction that larger abstractors would not be willing to make small trades with farmers;
- Abstractors raised issues relating to certainty of supply. Using the common pool method, an abstractor will not obtain their quota of water if they bid below the clearing price;
- Participants generally agreed that the common pool and pair-wise trading systems provided more flexibility than the current licensing system in facilitating short-term trading of water;
- Most stakeholders engaged in the research saw as useful web pages and maps showing where abstractors are willing to buy and sell water;
- Some participants expressed concern that under the proposed trading systems water would be allocated to sectors considered to have a higher economic value or social value;
- A licensing system that allowed abstractors to trade on a weekly basis was seen by most abstractors to be provide sufficient flexibility to meet their requirements;
- In the common pool method users had difficulty in choosing bids. This difficulty had to do with the associated lack of price history, the novelty of the market and also users' lack of knowledge about their own value for water;
- Complex trading systems such as the common pool method involve a change of mind-set by abstractors and require a period of learning to understand them. Some abstractors expressed some concern that they could lose money whilst learning how the system operated;
- Many stakeholders expressed the view that for any trading system to be trusted the underlying hydrological and optimization models would need to be reliable and accurate, and they would need to be convinced that this was the case;

6.2. Technical findings

- While the improved pair-wise trading system was not demonstrated live with users, we show that such a system, if built, could plausibly improve on the current system;
- We demonstrated that the common pool system and improved pair-wise trading systems could be built and operated in an East Anglian catcthment;
- We gave strong evidence that the common pool system could enable active trading, as we simulated 10,000 trades over a few minutes, when in England and Wales there were only 48 trades were approved from 2003 to 2008;
- We gave strong evidence that the common pool and improved pair-wise trading systems would ensure environmental flows as required by the Water Framework Directive.

7. Recommendations

The recommendations from the research have been grouped into the following sub-headings: trading platforms and water management; social science and institution building. Within those lists, recommendations are listed in order of decreasing priority.

7.1. Trading platforms and water management

- For the common pool method more work is required to research how abstractors would be scaled to ensure that the market has revenue neutrality;
- A "trading laboratory" could be set up using the model currently developed for the common pool. This would allow further investigation of how the platform works in different catchments with a different mix of abstractors. The Cam and Ely Ouse CAMS area could make a good case study, because it has about 700 agricultural licences, and the agricultural sector abstracts approximately 20% of the water by volume compared to only 1% in the Upper Ouse and Bedford Ouse catchment. This additional case study would give further evidence to Defra's on-going abstraction licence reform process;
- Further research is needed to investigate how groundwater and surface water can be traded. In this work we only looked at surface water and for a complete picture it will be necessary to look at how trading of groundwater could affect surface water flows, especially in catchments where there is a strong interaction between the two;
- The research utilised a very dry year, which provoked an active market. An "average year" needs to be simulated to determine how often the market would be of use both for the common pool and improved pair-wise methods. The market may not be of use most of the time, but we do not know if this is the case. The value of the market, and perhaps the urgency in implementation, depends on how active it would be. This study could be done in conjunction with the trading laboratory suggested above;
- The common pool and improved pair-wise demonstrations omitted groundwater, and treated sewage treatment return flows as constants. A study is needed to determine the potential economic value of return flows from Anglian Water's sewage treatment plants. Adding these to the model is important, but would require considerably more development;
- The common pool method interface and model could be improved to use "buy" and "sell" columns.

- The improved pair-wise trading system would benefit from another case study area (e.g. the Cam and Ely Ouse catchment) to assess how the hierarchy of trading options could be implemented in practice, and to obtain the views of the agricultural licence holders, Anglian Water, the Environment Agency and other key stakeholders on the practicalities of implementing this in practice;
- The common pool and improved pair-wise methods allocate water on a weekly basis. However, the time of travel of surface water raises concerns that certain timings of abstractions over a given week could dry out a river reach. The market rules could address this in a variety of ways (e.g. by planning abstraction by day or even hour). However, currently we do not know whether this would be a problem, and it would be worth further investigation;
- The manager of both the common pool and improved pair-wise trading methods would require an improved hydrological forecasting model, to determine the reliability of future rights. This forecasting model should be developed and integrated into the models to assist with allocating and adjusting users' future rights;
- Research is required to gauge the robustness and accuracy of current methods employed by CAMS to assess water resources with catchments within a context where water trading takes place on a regular basis, because there is scepticism amongst certain abstractors as to whether hydrological and hydro-geological processes are represented accurately enough in CAMS to allow water trading to take place;
- Further work is required to assess the sensitivity of the pair-wise trading model to transaction costs. Transaction costs are often cited by abstractors as being a barrier to trading. Further work is required to ascertain at above what level trading starts to decrease significantly as a result of these costs;
- To allow trades to complete in days rather than months, research is necessary to consider the hydrological and hydrogeological monitoring requirements, as well as effective methods to monitor abstractions;
- Owing to Anglian Water abstracting the majority of the water in the catchment further work is required to establish their impact on the market during the model development and in the demonstrations. The market could incorporate Grafham Reservoir, or Anglian Water could be required to manage Grafham Reservoir directly as now;
- Under a common pool system, deciding how much to bid for water is not just a case of simply learning the trading interface. Users, especially large abstractors such as the power station and Anglian Water, will need to dedicate some resources for bid planning. Further research is needed to assess the resources that would be required by such abstractors.
- Models need to be peer reviewed and validated. More engagement and transparency is needed with the stakeholders with regards to the models used for the common pool and improved pair-wise trading.

7.2. Social science

It is recommended that the following are carried out in the future:

- Investigating the social equity implications of water trading within a catchment with a range of large and small abstractors.
- Investigating the institutional and governance issues for trading to be effective, credible and trusted. What new resources and technical capacity would current water management institutions require?

- There is need to gather evidence to consider the interplay between potential trading in future and storage options. For example, if a farmer has invested in an on-farm reservoir are they more or less likely to trade their water rights;
- Research into the perception of the value of abstraction licences and water to different abstractors.

7.3. Institution building

- We envisage that the Environment Agency would operate any trading platform. However, before this would be possible there would need to be a significant investment in improving the database of abstraction licences and also in improving the monitoring of the quantities of water abstracted by users from rivers and aquifers.
- Further work is required to engage Environment Agency and Defra staff so that they have the opportunity to learn how the market mechanism would be set up, how the market operates, and what the Environment Agency obligation would be in market operations. This would take the form of workshops for staff in the Environment Agency and Defra, to explain:
  - How the two markets work;
  - Details of the data requirements, and how the models are developed and used;
  - The role and responsibilities of the regulator in each case;
  - The advantages and disadvantages to the regulator;
  - Longer term issues, such as how permanent licences are ultimately renewed;
- We have studied only temporary reallocation. Research is needed on how to lower the transaction cost of permanent trades. Research is also needed on how the Environment Agency should allocate permanent licences initially.
- Transition arrangements should be studied to move from the current abstraction licensing system to a more sophisticated and less bureaucratic system in the future, and the time period and costs to put these arrangements in place.

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Appendices

A. Improved pair-wise trading - Illustrative results for three policy scenarios

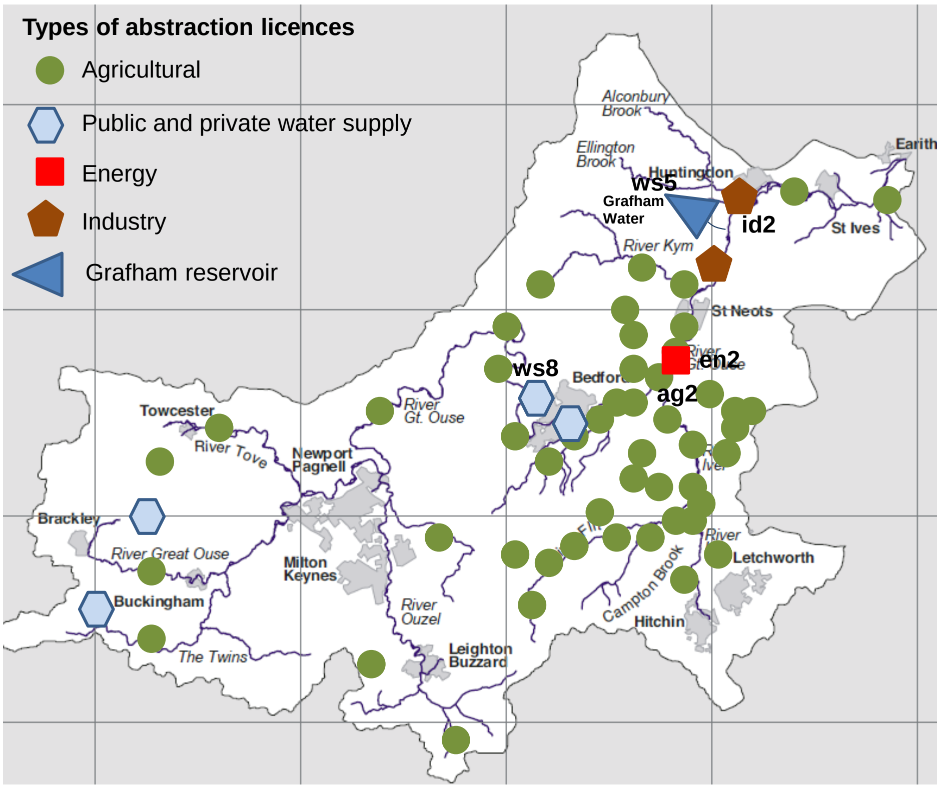
A.1. Introduction

Three scenarios were modelled to investigate improved pair-wise trading using hydrological inflows based on a drought year scenario. These were:

- Scenario 1 Current licensing with no short-term trading;
- Scenario 2 Current licensing with short-term trading;Scenario 3 Future licensing where a 'shares' licensing system is in place in which licensed abstractions are scaled in low flow conditions and where the percentage of water allocated to the environment changes depending on hydrological conditions. The ability to carry out short-term trading was included in the model.

Model results include for each time step abstractions, buying or selling of licences, reservoir storages and flow through each river reach (link between two nodes). This information can be exported for each of the three scenarios resulting in a large quantity of results. In several plots the name of specific abstraction points is evoked, these are displayed in Figure A1.1.

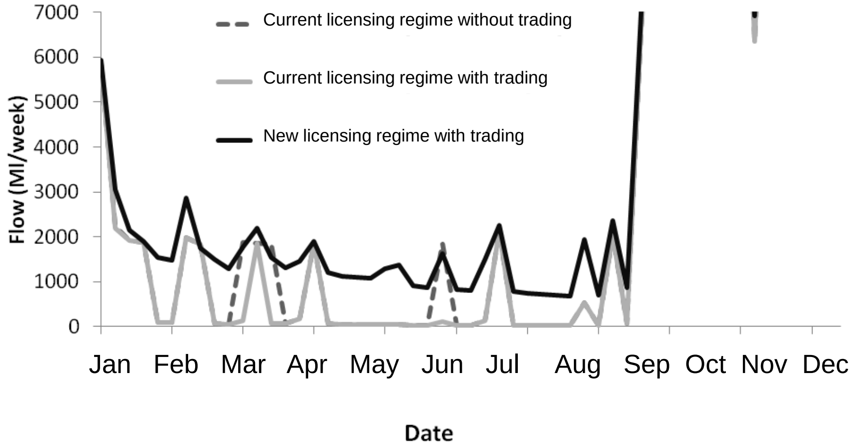
Figure A1.1: Location of the surface water abstraction licences in the Bedford Ouse and Upper Ouse CAMS area



A.2. Maintaining environmental flows

Figure A2.1 shows the contrast between how the different licensing system can ultimately guarantee river flows during periods of low inflows. Ultimately, because the Environmental Agency can only invoke Section 57 agricultural reductions during periods of extreme drought under the current licensing system, the system is unable to maintain basic environmental flows during the worst drought events. Figure A2.1 shows how under the scenarios with the current licensing system, flows nearly reach zero on multiple occasions during the dry year.

Figure A2.1: Flow at the downstream end of the Bedford Ouse and Upper Ouse CAMS area Earith for the three modelled scenarios



A.3. Abstraction by different sectors

Figure A3.1 shows the public water supply sector and Figure A3.2 shows the other sectors (i.e. agriculture, industry and energy) under three modelled scenarios. Anglian Water possesses two robust licences at Clapham and Grafham Reservoir with only modest hands off flow conditions. This means under the current licensing regime, Anglian Water is able to maintain a relatively constant schedule of abstractions. Under the no trading scenario, certain weeks simply do not have enough water in the river to abstract the required amount or anything at all; this is somewhat alleviated when short-term trading is included as shown in View b of Figure A3.1 thus avoiding weeks when no water can be abstracted. View c of Figure A3.1 shows the shares system. Owing to the fact that it maintains basic environmental flows, and the way it was converted to shares in this study (i.e. without allowing for Anglian Water's favourable hands off flow and licensing conditions), causes a major reduction in Anglian Water's abstractions although it too avoids zero abstraction weeks.

The non-public water supply sector is subject to less favourable hands off flow licence conditions under the current licensing regime, particularly the licence for the 680 MW gas-fired power station at Little Barford. Short-term trading shown in Views b and c of Figure A3.2 strongly remediate the problem and allow this high willingness-to-pay energy sector to obtain the water it needs for cooling. Agricultural and energy abstractions are strongly reduced in Scenario 3 towards during the wet period of the final three months. This is because Anglian Water is unwilling to sell water from its Clapham licence when Grafham Reservoir is less than half full owing to the Anglian Water's operational rules described in report (no trading whilst Grafham Reservoir is less than half full).

Figure A3.1: Abstractions by Anglian Water from the River Ouse at Clapham intake (ws8) and for Grafham (ws5) near the Offord flow gauge.

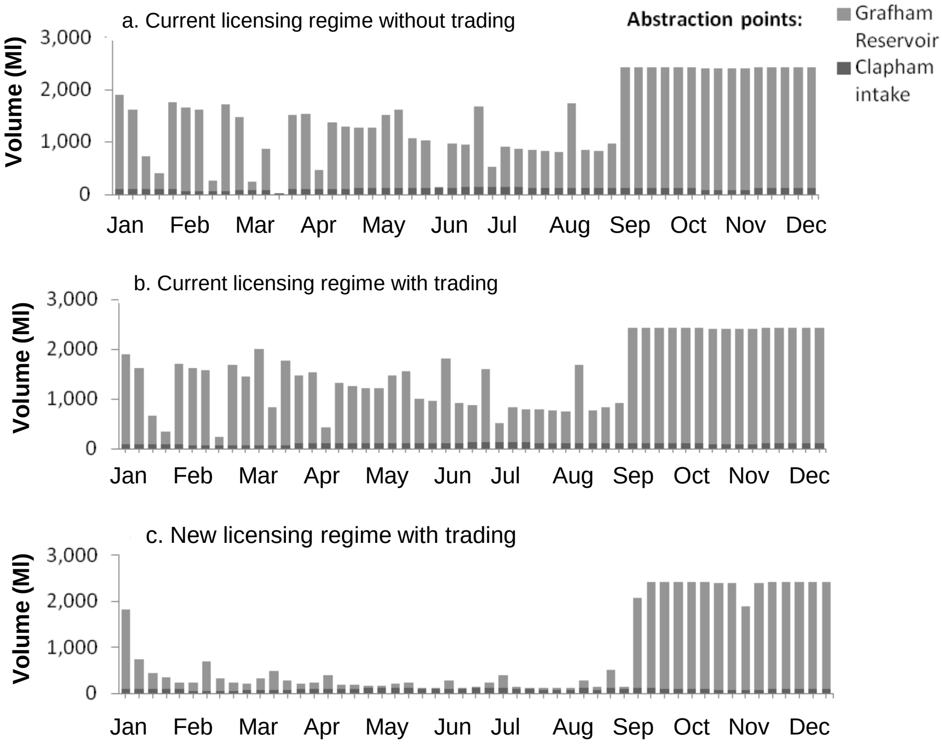
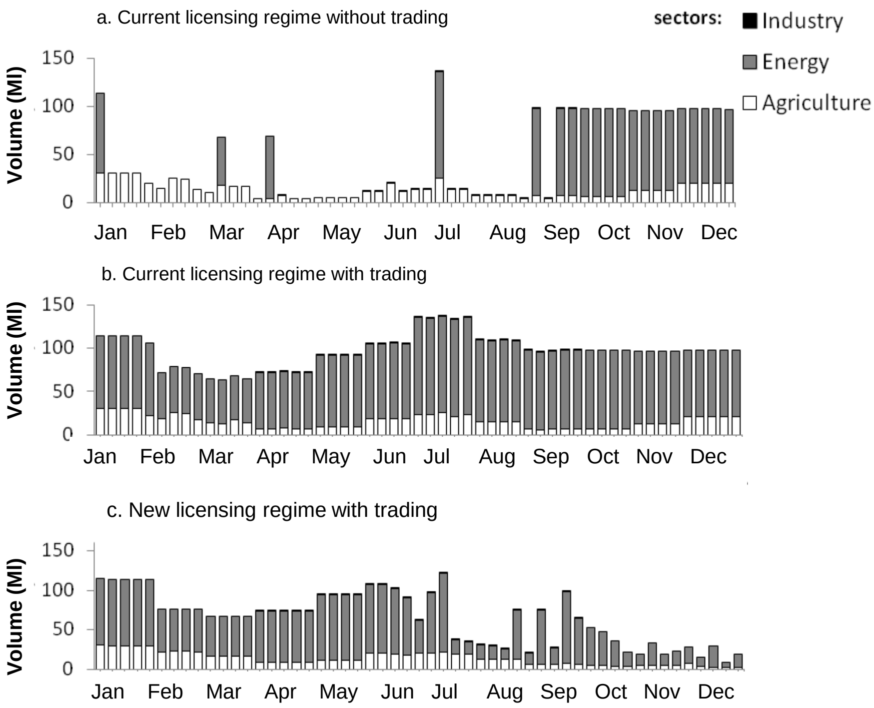


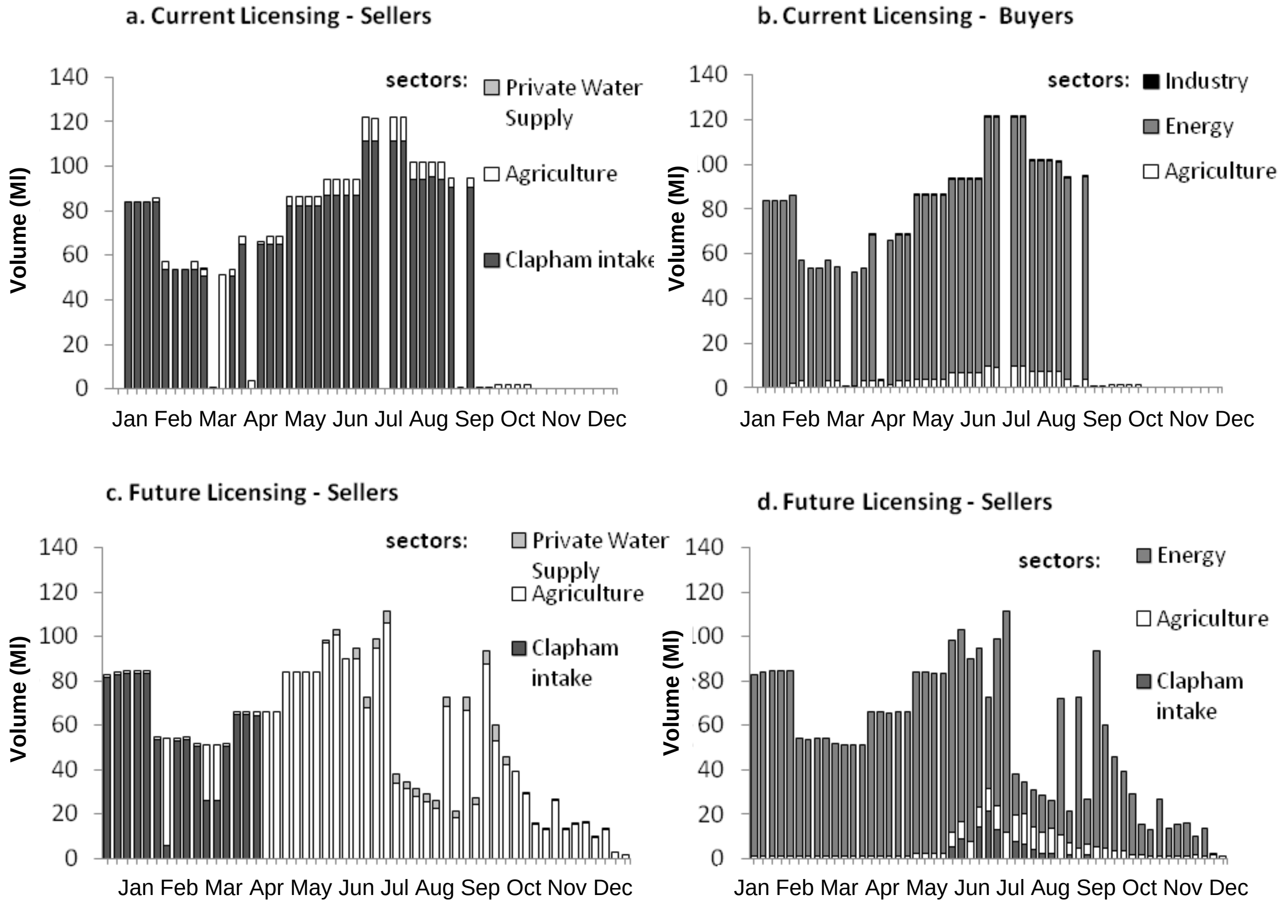
Figure A3.2: Abstraction by non-public water supply licences (agriculture, industries and energy sector) under the three scenarios



A.4. Trading

Figure A4.1 show how the shares system produces a more reliable market, with no weeks with zero trades. The current licensing (i.e. Scenario 2) has almost no trading in the wet last three months because most sectors can abstract enough; whereas in Scenario 3 Anglian Water must refill Grafham Reservoir so less water is available and trade continues in the final wet months. In late April Grafham Reservoir falls below 50% volume which triggers reduced deliveries and cause Anglian Water to stop selling water; this is why the agriculture sector suddenly starts selling at this point in Scenario 3. This is illustrated by View c of Figure A4.1.

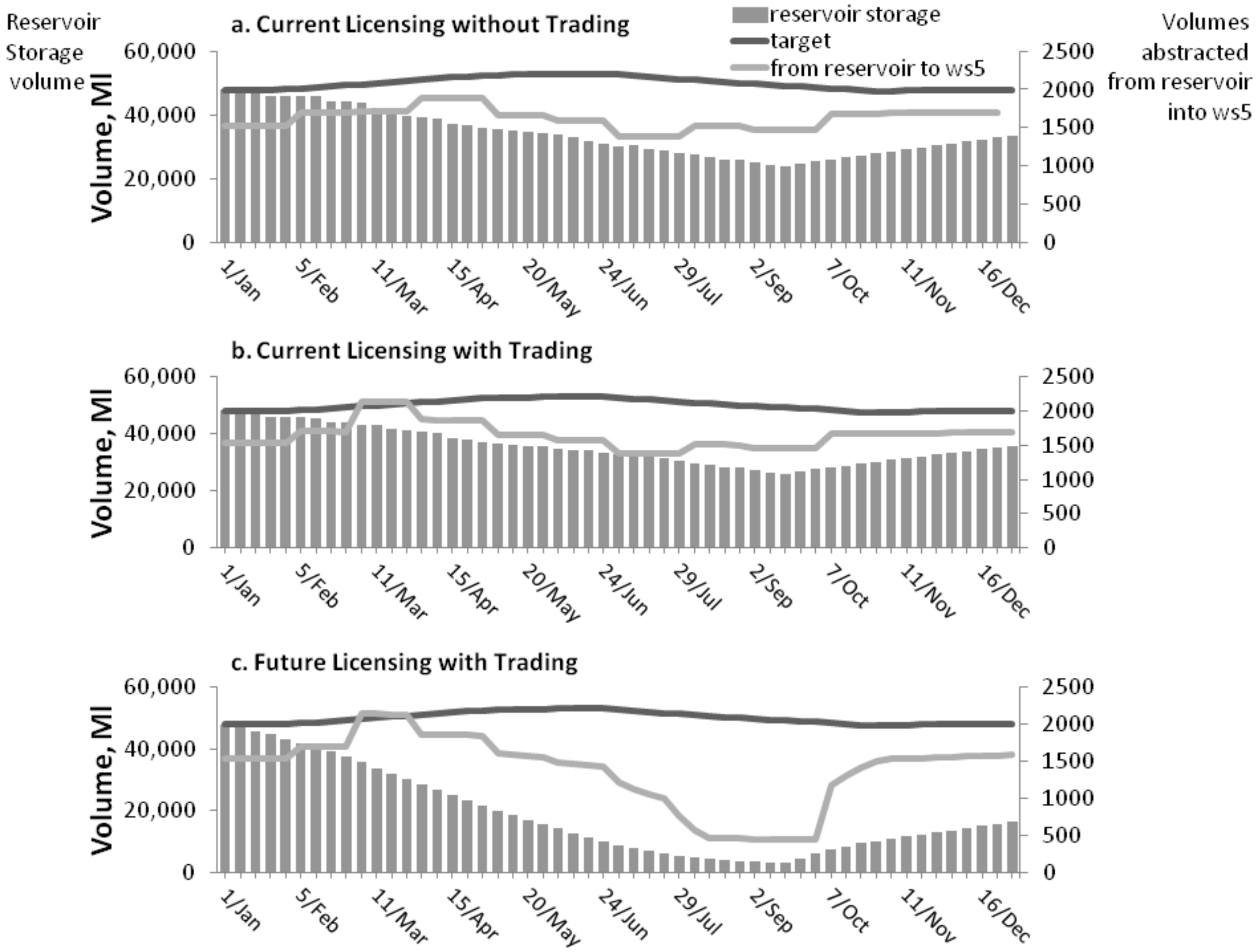
Figure A4.1: Volumes of water traded by buyers and sellers by sector for trading scenarios 2 and 3



A.5. Reservoir levels

Figure A5.1 shows reservoir levels, the Figure shows how the reduced abstractions in Scenario 3 owing to the greater environmental protection, drawdown Grafham storage which causes a more severe drawdown than the other scenarios.

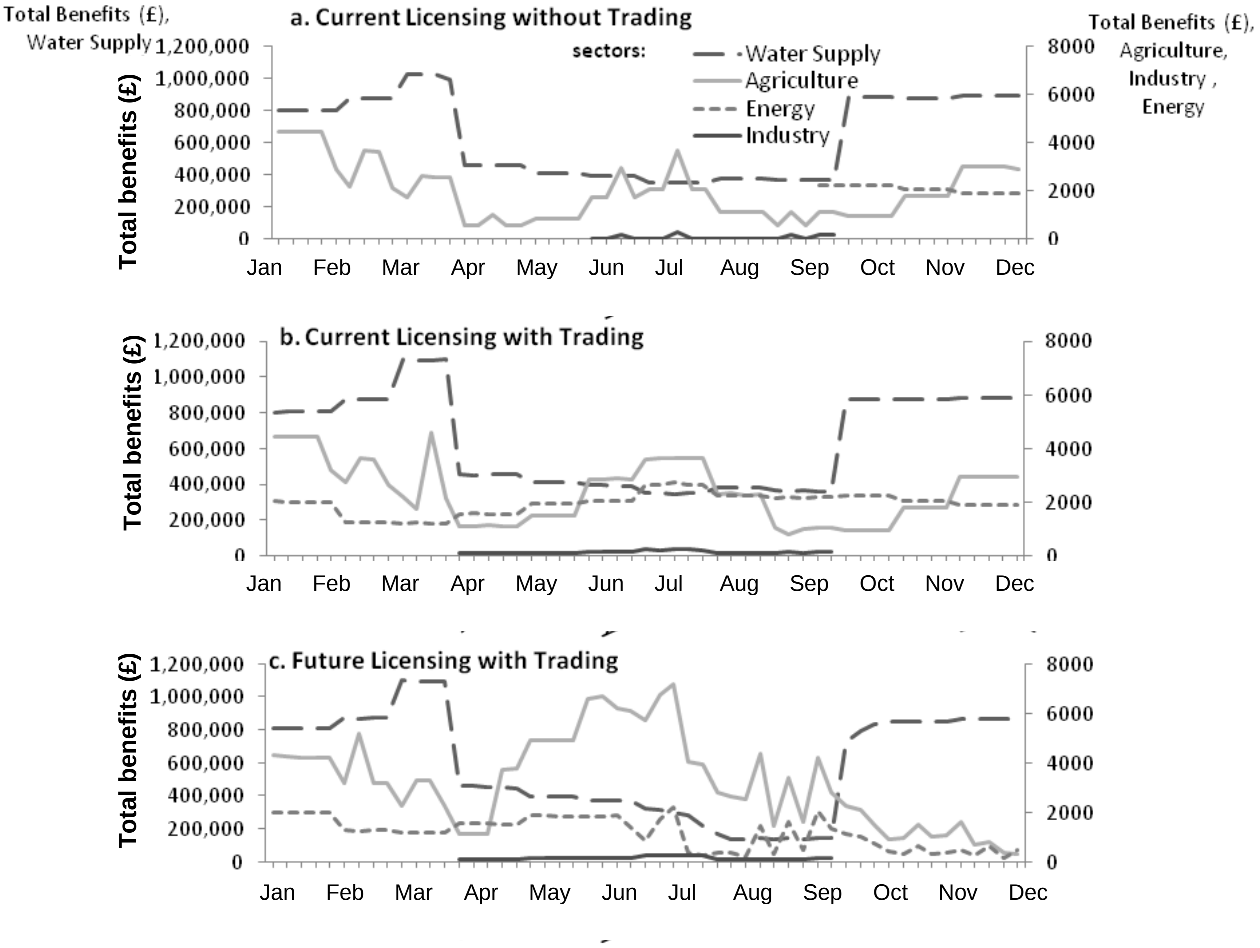
Figure A5.1: Comparison of Grafham Reservoir Water levels under different trading conditions



A.6. Economic benefits by sector

Below is a preliminary plot of economic benefits generated from water use by each sector for the three scenarios. These plots do not consider water substitutes (e.g. air cooling for energy) and so do not reflect the absolute benefits per sector, but only those benefits generated by water abstraction and use. The plot is provisional as the methodology to attribute economic benefits when water is traded has not yet been settled. To be settled in a final way, the price of water would need to be known but in a pair-wise trade market, where transactions are agreed between people and organisations, prices cannot be predicted so it will never be possible to attribute final and exact benefit estimates per sector. In Figure A6.1 water supply benefits are relatively constant because of public water supply's favourable licence conditions. This is not the case with other sectors such as agriculture, energy and industry which abstract comparatively little in Scenario 1 (View a, current system without trading). Benefits are more stable under both trading scenarios. In Scenario 3 (View c) the agriculture sector makes money from selling water to other sectors who have had their licensed volumes scaled by the new system. The figure is significant because it indicates that water management changes which include trading water could potentially make the agricultural sector better off. This observation is backed by empirical evidence from the Western regions of the USA and Australia where certain farmers and irrigations districts have profited from water trading, although it should be noted in the catchments where this has happened the agricultural sector tends to be the largest abstractor.

Figure A6.1: Illustrative plots showing the economic benefits generated from water use by each sector in the three scenarios



A.7. Impacts of assumptions and limitations

As with all modelling exercises, model results reflect reality in some measure the appropriateness of the model assumptions and data inputs. Several key assumptions used here should be noted and perhaps improved upon in future work.

A first limitation of the study is that groundwater is not included; this somewhat limits results because groundwater is a source of alternate supplies to some surface water abstractors who may manage both resources conjunctively in complex ways not represented here, and groundwater abstractions can impact stream flows in ways not considered in this exercise. There are some mitigating factors on this limitation; the study assumes groundwater management is not changed in a way that would impact surface waters. This does not mean groundwater is not traded, it could be as long as its management does not change the groundwater contributions to stream flows that is assumed in our hydrological modelling. Assuming that groundwater extraction would not be allowed to place further burden on the surface water system is reasonable.

The model results can be considered best case results of what a short-term water licence market could achieve given the transaction costs that were used. However, because we use a single regional objective function (maximise regional economic benefits) to model the whole system, the trades that occur are the ones that most benefit the region rather than the ones that most benefit particular traders. In a well-functioning market, it is generally recognised that trades that maximise individual's welfare will also maximise the region's welfare. However, because water markets are never perfectly efficient, this theory will not hold, therefore the results can be considered a "best case result" i.e. we have shown the best the licence market could do to lower society's water scarcity cost. In reality, some traders will prefer different transactions for firm-specific or other specific reasons and not all licence holders will engage in the market. It should be noted that our agent rule stipulating that all traders would only realistically be willing to sell water amounting to half of their typically annual use already resulted in a major loss of efficiency; had this rule not been included, economic gains from trades would have been higher.

The abstractors' economic demand and benefit functions are important in that, along with transaction costs, they are the drivers of modelled trades. The demand curves were derived in a simple way using assumed marginal value of water by sector (taken from values averaged across the USA) and generic elastic estimates. To exactly reflect the propensity of different abstractors to buy and sell water over time, more detailed information would need to be known on an abstractor by abstractor basis. The possible use of water substitutes is an important factor which determines willingness to pay for water. These were not considered in our first order demand estimation exercise. This is significant for energy for example, the energy abstractor (Little Barford power station) was a major buyer of water on the market. The availability of an alternate air cooling system for example would mean willingness to pay for water could likely decrease. Because our linear demand curves were integrated to produce quadratic benefit functions, the time-series plot of economic benefits (Figure A.6.1) generated by water would be different if the valuation exercise were more sophisticated and reflected the exact practices and specificity of each catchment abstractor in each month of the year.

The fact that the shares licences (scenario 3) did not "grandfather" in the relative security of existing licences is relevant. Scenario 3 was strongly impacted by the fact that Anglian Water would face a scaled licence and need to drawdown on its reserves at Grafham Reservoir. There have been suggestions that the new licence regime should contain licences with different priorities or reliabilities; this has not been considered in the current modelling exercise.

Finally, some model limitations did not limit this particular study but can still be considered general limitations of the proposed model. For example, strategic use of several licences in unison by a single organisation is not represented in a general way in the model. Such behaviour can be represented by extra 'agent rules' such as the rule that ensures Anglian Water does not sell water on the market (e.g. from its Clapham abstraction point) whilst its reservoir (Grafham) is less than half full (which we have assumed triggers rationing). In our case study only Anglian Water had two licences, so it was not necessary to represent this complexity in the model in a general way for widespread application. If the model were extended to groundwater use, a more general way to represent strategic use of resource across licences would be needed.

B. Optimisation based formulation for pair-wise trading for the Upper Ouse and Bedford Ouse CAMS area

B.1. Nomenclature

NT	Scenario where trading is not allowed between the licence holders
HoF	Scenario where hands off flows are applied in which users can no longer abstract or trade water
EFI	Environmental flow indicator taken as future licensing where the sharing system is introduced
$\boldsymbol{Junction}$	No-demand and non-storage nodes which join two or more links in the network
$\boldsymbol{User}$	The set of all licensed river abstractors
$\boldsymbol{WT}$	Water type' (WT) set which includes all members of set User, the river links and the reservoirs are the water owners based on their licences
$\boldsymbol{x_{ij}^k}$	Decision variable, the water flowing from node i to j with licence holder k
$\boldsymbol{inFl_i}$	External hydrological inflow nflow at junction node i
$\boldsymbol{CO_{ij}}$	Connectivity table which contains a one if node i is connected to node j, 0 if no connection
$\boldsymbol{pRes_j^k}$	Reservoir j storage carried over from previous time step with water licence k
$\boldsymbol{Res_j^k}$	Reservoir j storage with water licence k
$\boldsymbol{tRes_j}$	Reservoir j target
$\boldsymbol{Keep_i^k}$	Water consumed by user i which is either bought from owner k or abstracted from river using user i's licence
$\boldsymbol{Trade_i^{k \in river}}$	Water licence leased for one time-step by user i
$\boldsymbol{ReturnFlow_i}$	Water returned back to the river based on the consumption factor of user i
$\boldsymbol{Discharge_j}$	Discharge sink j at the mouth of the river
$\boldsymbol{WkLi_i}$	Weekly licence allowance for user i to abstract water from river
$\boldsymbol{Deviation_j}$	Deviation of reservoir j from its target storage volume
$\boldsymbol{MinFlow_j}$	Minimum flow at gauge j
$\boldsymbol{JuGA_{ij}}$	Connectivity information which equals one if junction node i is connected to gauge j
$\boldsymbol{flGA_j}$	Flow at gauge j
$\boldsymbol{AlGA_j}$	Allowable flow at gauge j
$\boldsymbol{RuGA_{ij}}$	Information with regards to the hands of flow condition which equals one if user i abstraction is controlled with the level of flow at gauge j

$\boldsymbol{Q95GA_j}$	Q95 flow level at gauge j
$\boldsymbol{UpGA_{ij}}$	Agriculture user i which is upstream of gauge j
$\boldsymbol{LevelRule_j}$	Hedging rule for reservoir j
$\boldsymbol{DemandRule_i}$	Demand reduction for user i based on the hedging rule
$\boldsymbol{YlSl_i}$	Yearly abstraction expectation for user i
$\boldsymbol{nFlGA_j}$	Natural flow at gauge j
$\boldsymbol{WlGA_{ij}}$	Information with regards to the shares licensing system which equals one if user i has the gauge j in its immediate downstream
$\boldsymbol{ConsFactor_i}$	Consumption factor of user i
α	Reservoir deviation penalty factor

B.2. Model description

B.2.1. Objective function

The objective is to maximise the total economic benefits derived from water use and the weekly trade of water licences and minimise the deviation of reservoir storages from their weekly targets. The total benefits are compiled using the benefit functions for each user in each time step and the transaction costs for each trade transaction.

$$NetBenefit = \sum_{i \in User} totalBenefit_i - \sum_{i \in User} totalCost_i - \alpha \left| tRes_j - \sum_{k \in owner} Res_j^k \right|$$

where *totalCost* is the trading fixed cost and the *totalBenefit* is the quadratic benefit function for user i. In addition, | | is the absolute value of the deviation of the reservoir level from its given target multiplied by a penalty factor α.

This objective is subject to the following constraints detailed below.

B.2.2. Constraints

Mass balance at junction nodes

Water entering junction node i plus the inflows at the same node equals the water leaving the node i.

$$\sum_{\substack{j \\ CO_{ji}=1}} x_{ji}^k = \sum_{\substack{j \\ CO_{ij}=1}} x_{ij}^k + inFl_i \qquad \forall i \in Junction, \qquad k \in Owner$$

Storage balance

Water entering the reservoir j plus the water already in the reservoir is carried over to the next time step minus what leaves the reservoir.

$$\sum_{\substack{i \\ CO_{ij}=1}} x_{ij}^{k} + pRes_j^k = Res_j^k + \sum_{\substack{i \\ CO_{ji}=1}} x_{ji}^{k} \qquad \forall j \in Reservoir, \quad k \in Owner$$

Abstraction balance

The user node consumes (Keep) the receiving water as part of demand satisfaction and sells the rest of its licence to others (Trade). The fraction that is not consumed leaves the user node as well (i.e. the return flow).

$$\sum_{\substack{j \\ CO_{ji}=1}} x_{ji}^{k} = \sum_{\substack{j \\ CO_{ij}=1}} x_{ij}^{k} + Keep_i^k + Trade_i^{k \in river} \qquad \forall i \in User, \quad k \in Owner$$

where:

$$\sum_{k \in Owner} \sum_{\substack{j \\ CO_{ij}=1}} x_{ij}^{k} = ReturnFlow_i \qquad \forall i \in User$$

$$ReturnFlow_i = \sum_{k \in Owner} (1 - consFactor_i)\ Keep_i^k \qquad \forall i \in User$$

and

$$Trade_i^{k \in river} = \sum_{\substack{j \\ CO_{ij}=1}} x_{ij}^{i} \qquad \forall i \in User$$

Mass balance at discharge zone

$$\sum_{k \in river} \sum_{\substack{i \\ CO_{ij}=1}} x_{ij}^{k} = Discharge_j \qquad \forall j \in Discharge$$

Licence constraint

The weekly licence limits total weekly abstracting and selling for each user node i.

$$Keep_i^k + Trade_i^k \leq WkLi_i \qquad \forall i \in User, \quad k \in river$$

Storage capacity

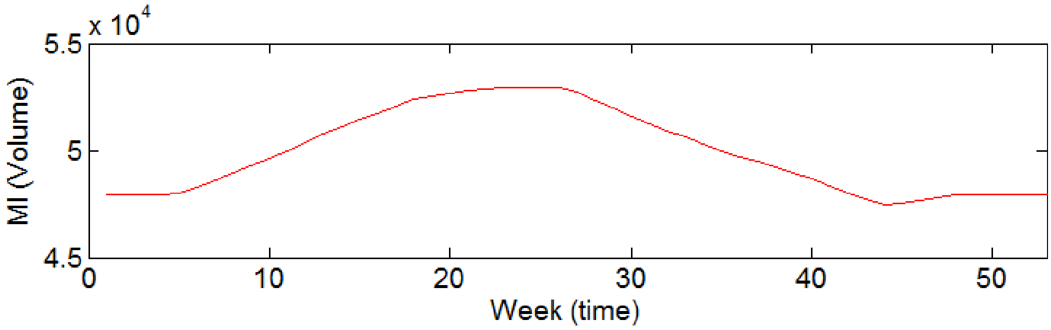
Reservoirs have both the minimum and maximum capacity.

$$2627 \leq \sum_{k \in Owner} Res_j^k \leq 55450 \qquad \forall j \in Reservoir$$

Reservoir deviation

Reservoirs have a target profile; for Grafham the curve is shown in Figure B2.1.

Figure B.1: Reservoir target profile



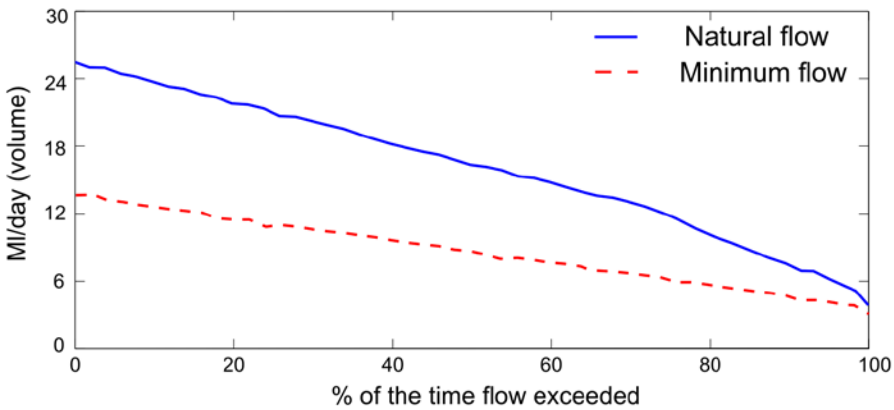
$$Deviation_j = \left| \sum_{k \in Owner} Res_j^k - tRes_j \right|$$

B.2.3. Extra constraints and rules

Minimum environmental flow at gauges (Environmental Flow Indicators approach for Scenario 3)

Minimum environmental flows are calculated by the Environmental Flow Indicators (EFI) approach to support good ecological status. This is based on the natural flow recorded at the gauges. An example of the Environmental Flow Indicator is shown in Figure B2.2.

Figure B.2: Environmental flow indicator (EFI)



$$\sum_{k \in river} \sum_{\substack{i \\ co_{il}=1}} x_{il}^k + inFl_l \geq MinFlow_j \qquad \forall l \in Junction, j \in Gauge,$$

Hands of flow rules at local and Offord gauges (for Hands-off flow (Hof) and NT scenarios)

If the flow at the gauges is less than the allowable amount, the user is not allowed to abstract from river or sell its licence.

$$\left(flGA_j \leq AlGA_j \right) \longrightarrow \left(Keep_i^{k \in river} + Trade_i^{k \in river} \leq 0 \right)$$

$$\forall i \in user, j \in Gauge, \qquad RuGA_{ij} = 1$$

Section 57 rules for agriculture (HoF and NT)

Under section 57, if the flow at the gauges is less than the value of the river flow which is exceeded on average for 95% of the time (Q95), the agricultural weekly abstraction allowance is cut down by 50%. The agricultural users who face the cut down in their licence are upstream of the corresponding gauge.

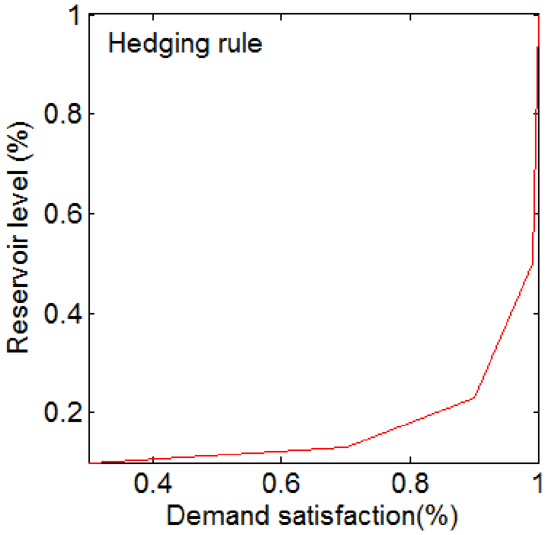
$$\left(flGA_j \;\le\; Q95GA_j \right) \;\longrightarrow\; \left(Keep_i^{k\in river} \;+\; Trade_i^{k\in river} \le 0.5 \times WkLi_i \right)$$

$$\forall i \in Agriculture, j \in Gauge, \qquad UpGA_{ij} = 1$$

Reservoir Hedging

Anglian water abstraction from Grafham reservoir is reduced based on a hedging rule in addition to the fact that reservoir abstractions will be lowered to avoid the penalised deviation from Grafham Reservoir storage target. This rule is shown in Figure B2.3.

Figure B2.3: Hedging rule for satisfying Anglian Water demands using Grafham reservoir



$$\left(\sum_{k\in Owner} Res_j^k \;\rightarrow\; LevelRule_j \right) \;\longrightarrow\; \left(Keep_i^l \;\le\; DemandRule_i \right) \forall i \in user, \quad l \in Reservoir, \quad CO_{li} = 1$$

Clapham selling restriction

Clapham user will not sell its extra licence if Grafham Reservoir level is less than 50% of its target.

$$\left(\sum_{k\in Owner} Res_j^k \;\le\; 0.5 \times tRes_j \right) \;\longrightarrow\; \left(Trade_{i\in Clapham}^{l\in river} \;\le\; 0 \right) \qquad \forall j \in Reservoir$$

Selling limit (EFI)

Users are limited to selling only half of their yearly abstraction before they've abstract water for their consumption. This avoids users selling their entire licence at the beginning of the year ignoring the fact they'll need water later in the future.

$$Trade_i^{k \in river} \quad \leq \quad 0.5 \times \ YlSl_i \qquad\qquad \forall i \in user$$

Share system (EFI)

Under the EFI scenario, each user belongs to a sub-catchment defined by the downstream gauge. The water available for abstraction at each gauge is divided between the shareholders in that sub-catchment proportionally to their shares.

$$Keep_i^{k \in river} \quad \leq \quad \begin{cases} \theta_{\ j} \times WkLi_i \ , & nFlGA_j - MinFlow_j \quad \leq \quad \sum\limits_{\substack{k \\ WlGA_{kj}=1}} WkLi_k \\ \\ WkLi_i \ , & o.w \end{cases} \qquad \forall i \in user, j \in Gauge$$

where

$$\theta_j = \frac{nFlGA_j - MinFlow_j}{\sum_{\substack{k \\ WlGA_{kj}=1}} WkLi_k}$$

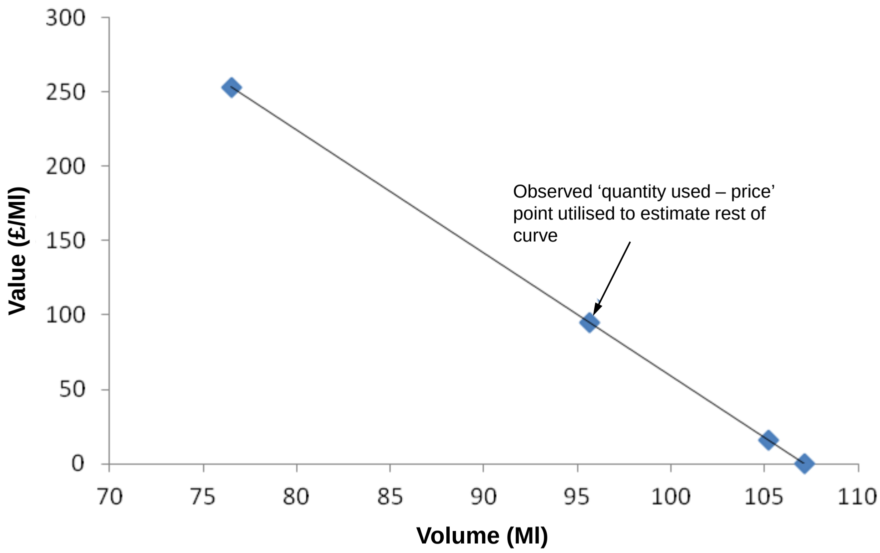
C. Water demand estimation curves

C.1. Demand curves – how economists quantify 'value'

In economics, the relationship between price and quantity of the good demanded by the consumer is described by the demand function. As the price of the good rises, the quantity the consumer will purchase will fall. The demand curve equally allows us to estimate, for a given quantity of water available, what the user's willingness-to-pay for it would be.

Estimating the demand function is not straight-forward, as in the economy other factors may not stay the same when water is more or less available. As prices change, other factors that impact the quantity of water demanded (e.g. such as incomes, technology) change as well. As a consequence, the relationship between price and quantity is not directly observable and we can only estimate it. Despite the fact that estimating demand functions is challenging, economists have been using them for many decades and standard methods of approximation are available. In our project we use demand curve because they provide a good starting point to attempt to understand and/or predict how abstractors might behave in a water market. An example of the derivation of the demand curve is shown in Figure C1.1.

Figure C1.1: Example of demand curve derivation



C.2. Method of estimating demand curves

The method used for deriving demand curves in this project was to use an observed supply - price points and extrapolate from them to build the functions. To do this, a measure of responsiveness of water quantity demanded to price was utilised ('price elasticity of demand'). Elasticity values are based on past research and vary across industries. This is discussed in more detail in a later section. The observed point uses two pieces of information:

- The volume of water used and the value of the last unit of water used (the 'marginal value');
- A separate demand function was estimated for each week, as the models use a weekly time-step.

The figures for volumes of water used were obtained from the Environment Agency dataset on actual water abstractions by licence holders in the catchment. As these values are monthly, they were divided by 4 to estimate weekly usage. A separate demand function was estimated for each week for each user, reflecting the changes in water demand throughout the year. For example, Figure C2.1 shows the demand function for Anglian Water abstraction point located near Bedford. The data is based on weekly abstractions. That is, demand functions vary across months, but not weeks, so the plot for January, for example, shows the demand function for each week in January.

Figure C2.1: Derived water demand curves

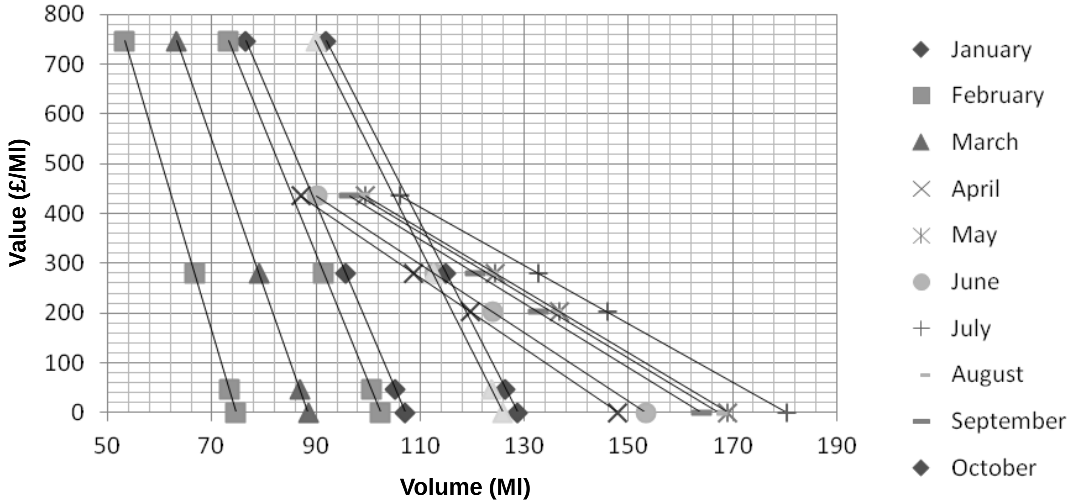
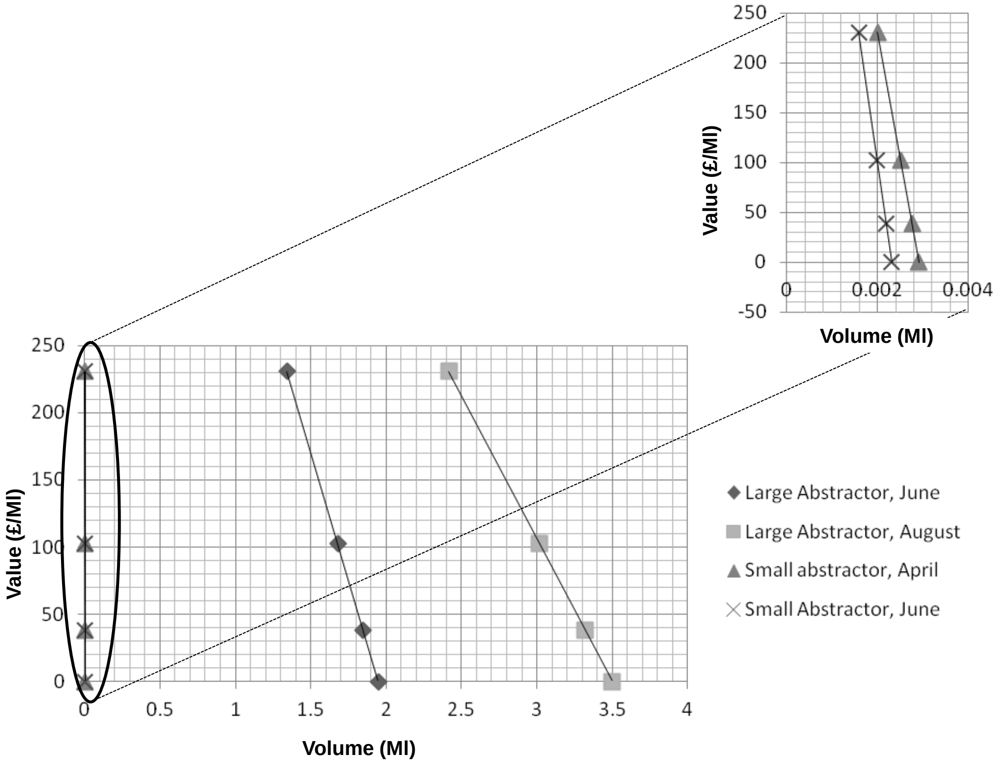


Figure C2.2 shows two demand functions (during months of low and high water use) for two agricultural users, one large and one small. Both are located just outside the town of Bedford, and their yearly licence limits are 69 Ml for the large abstractor and just over 1.2 Ml for the small one. Owing to the fact that the volumes demanded by small agricultural user are very small, the plot shows them almost coinciding with the y-axis.

Figure C2.2: Water demand functions for two agricultural abstractors



C.3. Initial water values

Observed volumetric water charges do not reflect the value of water, as the prices for water abstraction are not set by interaction of users in the market. As a general rule, current UK water abstraction charges are reflective of administrative costs, and not of the value placed on water by consumers. Therefore in our first order valuation study we chose to use values obtained from past research on the topic.

The value of irrigation water in Spain was estimated to be in the range from about £32 to £437 per Ml (converted to £/Ml from the original values) by Berbel et al. (2011)1. Literature on water trading in Australia states that prices paid for temporary water purchases by agricultural users ranged between AUD 8 to AUD 1508 13, i.e., around £5 to £972 per Ml. The report by Paccagnan (2010) quotes the marginal values suggested by Morris et al. (2003), ranging from "3p per m^3 (£30/Ml), when water is not scarce, to £2 per m^3 (£2000 per Ml), when water is not available at all". These ranges vary considerably, partly because different studies employ different methods, which in turn can provide widely varying or even contradicting results.

Frederick et al. provide a set of freshwater values which have been converted to £/Ml as follows:

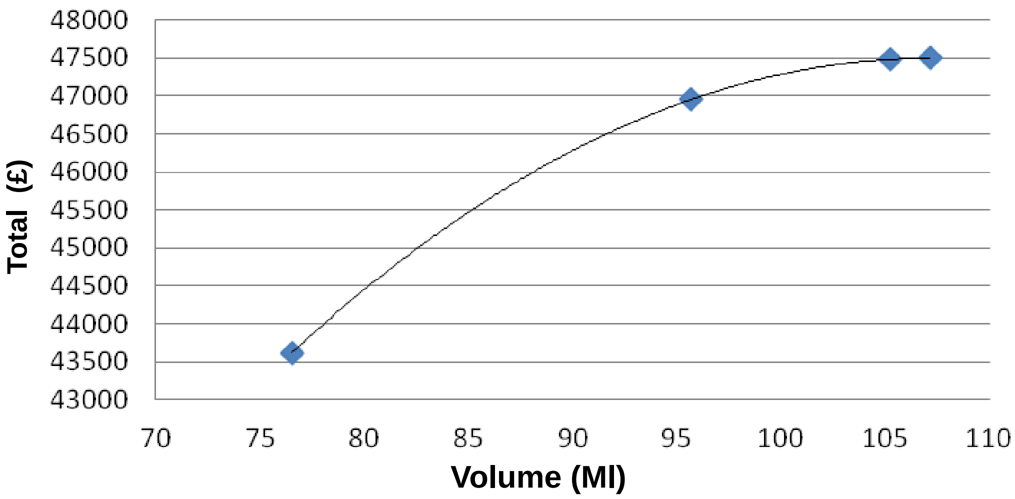
Domestic	£95 per Ml
Agriculture	£40 per Ml
Industry	£140 per Ml
Energy	£15 per Ml

This value for agricultural use satisfies the criteria described above. The value lies closer to the lower bounds of the ranges. This, however, does not present a problem for the model, as trading behaviour is driven by the water value of one abstractor relative to water value of another. We decided to use the above figures as a starting point because their estimation was consistent across industries (they originate from the same time period and the same study). Values in different studies vary considerably, as is illustrated by the ranges provided above.

C.4. Benefit functions

The demand function can be used to find the total economic benefit generated from water use by each abstractor. To build a benefit function you calculate the area under the demand curve ('integrate' the demand curve). An example of a benefit function is shown in Figure C4.1. The benefit function is increasing, as is expected, because each unit of water adds to total benefits, but flattens out, as each additional unit of water adds less to the accumulated benefits than the previous unit did. Within the model, these points are connected by straight lines, including the point of origin (0,0) connecting to point 1 above. Beyond the fourth point, the total benefit is assumed to decrease. An intuitive reason for this is that, for example, if more water is used for irrigation than the volume that can provide the maximum quantity and quality of crop, the additional water will create oversaturation which will damage the yield.

Figure C4.1: An example benefit function generated from a demand curve



The four points in the above graph represent (from left to right) the benefit obtained from consuming:

1. 20% less water than actually abstracted historically;
2. Exactly the volume of water abstracted historically;
3. 10% more water than abstracted historically:
4. The point of maximum total benefit.

C.5. Demand function estimation

Demand curves are estimated for this study using the point expansion method described in Griffin (2006). The curves are linear with the assumption that price elasticity varies between the points on the demand curve. This method estimates the lower bound marginal values away from the original point of expansion, as we generally assume that demand function is convex. That is, according to theory, this method generates the values that most likely underestimate the marginal values at points away from the original point.The point expansion method requires one point and elasticity of demand to derive the demand schedule. The volumes used are based on the actual abstraction data, the elasticity of demand values were selected from previous literature, and the marginal values are based on past literature values.To ensure consistency in estimation of demand curves across different types of abstractors, we systematically applied the linear point expansion method. This allows for cross-comparisons between different abstractors and sectors.Water Demand Price Elasticities. The short-run price elasticity of demand is generally found to be in the range from 0 to -0.5 and elasticity of demand (in absolute terms) in summer is higher than in winter. The short-run median value of elasticity in meta-analysis in Espey et al. (1997) was found to be -0.38. The short-run elasticities found in Dandy et al (1997) are consistent with the above figures: Summer SR elasticity -0.36 and Winter -0.12. These last figures are the values used.

More et al. (1994) found highly inelastic demand for water at farm level (0.1 or less in absolute terms). The meta-analysis by Scheierling et al. (2006) considered 73 price elasticity estimates, with mean -0.48 and median -0.16. The latter figure has been chosen for this study. This figure is particularly fitting because the agents are not forward-looking, and they are unable to change the choice of crop based on the price and availability of water for the growing season.The price elasticity of demand for the industry sector was taken from Renzetti (1988), -0.2486 (price elasticity for intake of water used for heavy industry).

C.6. The price elasticity of demand for energy sector tends to be higher than the sectors above: De Rooy (1974), -0.89411, Dupont, D. P., & Renzetti, S. (2001), -0.794712 (Cooling/steam). It is the second value that has been adopted. References

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D. Technical approach in setting up the common pool model and trading demonstration

D.1. Introduction

The common pool market demonstration utilised a large complex data set and custom programs. These included:

- A GIS database of the river network;
- Abstraction licence data with locations of abstractors;
- Assessment point locations and environmental flow limits;
- Systematic reduction from the complete river network to the abstract model network;
- Construction of a database with area and weekly gauge flow data, with calculation of natural inflows by catchment location and time period (mapped from the river network onto the model network);
- Sewage waste water treatment inflows, mapped from the river network to the model network;
- Development of plausible default bids;
- Development of an algorithm for scaling users' rights to the available water.
- Users were treated as either fully consumptive or fully non-consumptive. The non-consumptive users were the two power generators and the user associated with the Royal Society for Protection of Birds.

Each dataset was checked (e.g. for duplicates and bad data), matched (and sometimes aggregated) by location, and aggregated or disaggregated by time period (e.g., converting hours, days, or months into weeks), and integrated into a single hydrology database and model.

The demonstration required an optimization model to clear the market, connected to the market database and a hydrology database, and an associated auction manager's web page to set up auctions and to control the market clearing. The optimization model is the clearing engine, which the market manager uses to decide how to allocate water and how to set prices. It is based on 60 years of classical operations research and well-established economic theory. The optimisation calculates the optimal allocation from users' bids, maximising the total value of the water, i.e. the model will try to allocate water to users who bid highest (using the default bid curves as described in Appendix C for users who did not participate in the demonstrations), while satisfying the physical and environmental requirements. Following optimisation , a separate script calculates trades based on users' initial rights and final allocations.

This technical document describes the data, scripts, difficulties, and detailed assumptions of setting up the common pool model and the associated trading demonstration.

D.2. Units of measure

The market-running programs do not convert units, not even a multiplication to convert days to weeks. Data preparation scripts convert source input data to the correct units where necessary.

D.2.1. Time

Period lengths are weeks (always starting 1 January for the model year). Dates are Excel spreadsheet format (integers), e.g., 25569 is 1 January 1970. A 52 week year period starting on 1 January has been assumed.

D.2.2. Licence volumes

Licence volumes are treated in some sense as initial rights. Conversion of existing licence volumes to initial rights for trading was a critical step and is discussed below. The GIS shapefile provided by Anglian Water did not show units in the header. However, a licence spreadsheet (which seemed to have perhaps only one licence matching the shapefile) showed licence quantities in m^3/day. For data purposes, then, the licensed quantities were converted and stored as Ml/week.

D.2.3. Incremental flows

Catchment areas were given as km^2, by node in a detailed river network. The nodes are 200m apart. These incremental areas were then aggregated and stored for model input as incremental areas on the reduced "model" network, in km^2/[simplified model node]. Incremental natural flows were given as Ml/day/gauge. These data were aggregated and stored as Ml/week/gauge.

D.2.4. Sewage inflows

Sewage inflows were not considered to be "natural" flows, and the percentile minimum residual flow (MRF) calculations excluded them. This means the calculated MRFs are somewhat lower than if the "natural" flows included the sewage inflows. Sewage inflows received were assumed to be in m^3/day

D.2.5. Assessment MRFs

MRFs at each assessment point are calculated in Ml/week.

D.3. Key initial step: specify the model network and its data

Criteria for a "good" network include: topologically a tree; no parallel arcs; detailed enough to have valid allocations and pricing; to have credibility; and to have a compelling visualization. The input network should be sufficiently detailed that users not clearly on the network can be automatically connected near their actual points. Inflows can be calculated with reasonable accuracy. A shapefile reverse-engineered from the northings and eastings in the inflow data file was produced. This was used to produce a simplified network.

D.3.1. Get complete river network

Python script 01Make_network_from_area_CSV.py was used to read eastings and northings as river nodes from "Bedford_and_Upper_Ouse _Areas.csv". It then created a minimum spanning tree from those nodes. This is the "complete river network", from which calculate inflows were calculated and gauges and users added, and simplified further to the "model river network".

Input: Bedford_and_Upper_Ouse _Areas.csv

Outputs: Bedford_and_Upper_Ouse_Areas_network_edges.shp,
Bedford_and_Upper_Ouse_Areas_network_nodes.shp.

D.3.2. Delete duplicate licences

The input shapefile contained records which appeared to be duplicates.

- Duplicate records with the same licence number, but different locations, were deleted;
- Duplicate records with different licence numbers, with only the use as different, were retained.

Python script 02Delete_duplicate_surface_water_users.py reads the shapefile "Combined_surface_water_users.shp", removes duplicate licences, ensures unique eastings-northings (moving the duplicate northing by 100), and outputs "Combined_surface_water_users_unique.shp". This *does* remove some user locations (multiple locations for a single licence), which we assume to be without significant loss to the ultimate results of the study; on inspection, these seemed like duplicate records only for visualization. It was noted that at least one apparent duplicate remained, where two different licences were at the same location and had the same licence quantity.

D.3.3. Add user locations

Python script 03Find_surface_water_users_nearest_river_node.py reads the file "Combined_surface_water_users_unique.shp" shapefiles and the "Bedford_and_Upper_Ouse _Areas_network_nodes", and outputs a shapefile of arcs "Surface_water_river_assignment_edges" from each user's node to the nearest river node. (Ideally, these edges would be of length zero, indicating that the super network is sufficiently detailed to correctly place every user's abstraction point.) The user is then assigned to that river node. A river node may have more than one assigned user, but each user has exactly one assigned river node. The output shapefile "Surface_water_river_assignment_edges" contains each user's easting and northing, and the user's assigned river node's easting and northing.

D.3.4. Add special nodes for gauges

It was assumed that the flow gauges would be the assessment points. A CSV file "Gauge_northings_and_eastings.csv" was created that was imported into QGIS, and exported as a shapefile of the same name. An additional flow constraint was required at the end of the CAMS area, otherwise, users below the most downstream gauge would get all remaining water for free. Hence, another "gauge" at the downstream end of the CAMS area was added and named "Mouth", at (538798,27499).

The gauge nodes (like the user nodes) were not located exactly on the river network. A Python script 04Find_gauges_nearest_river_node.py, was created which reads "Gauge_northings_and_eastings" and "Bedford_and_Upper_Ouse_Areas_network_nodes" and outputs "Gauge_river_assignment_edges" as a shapefile. Following this it was noticed that the script placed the Ivel and Bedford Ouse 1 gauges on branches, not the main stem, the Gauge_northings_and_eastings was changed to Gauge_northings_and_eastings_Ivel_corrected, to have the easting and northing for Ivel and Bedford Ouse to be closer to the main stem the script was then re-run. The gauge at Grafham appeared to be a headwater, so it has been removed as an assessment point from the optimization model.

D.3.5. Simplify the "super network" to create the "model network"

Recursively delete non-special nodes of degrees 1 and 2. Python file 05simplify RiverNetwork.py reads Bedford_and_Upper_Ouse_Areas_network_edges, Surface_water_river_assignment_edges, and Gauge_river_assignment_edges. It then creates new shapefiles "edges" and "nodes", which were renamed Model_network_edges and Model_network_nodes. kly gauge flows, which will let us calculate nodal flows by week, rather storing the expanded data, and (2) 90%, 95%, and 99% environmental total flows at the gauges.

As "Mouth" is not a listed gauge the following was carried out in Excel,

Inputs:

- Model_node_incremental_areas.csv.
- Gauge_northings_and_eastings_Ivel_corrected_all_names.csv
- Catchments_incremental_hydrological_data_JFR.csv, converted from Catchments_incremental_hydrological_data_JFR.xls. The Mouth gauge has area of all the nodes, minus the areas for the other gauges. In the spreadsheet, the incremental area for the Mouth was calculated by summing the total area of all nodes, and subtracting the incremental areas for the other gauges. The incremental flow was calculated at the mouth calculated based on average inflow/area of the other gauges. Crude!

Output: AWnodeflows.db, with the following tables:

- Nodes [nodeid, nodeName, easting, northing, incremental_km2, cumulative_km2, nearestGaugeID, pctGauge_km2]
- Gauges [gaugeID, gaugeName, gaugeNumber, Catchment_km2, NationalGridRef, modelEasting, modelNorthing, easting, northing, flow90pct, flow95pct, flow99pct]
- GaugeNaturalFlow [id, gaugeID, firstDayOfWeek, incrementalFlowML, totalFlowML]

D.3.6. Aggregate waste water treatment inflows from the full network to the first model node downstream.

Accumulate daily waste water flows by river node to weekly flows by model node.

D.3.7. Corrections to the data

The shapefile has 156 records. Before changing the data by hand (as described below), the daily flow file had 119 columns (one Sewage Treatment Works (STW) per column). The following 66 locations in the shapefile had no data in the daily flow file. Beachampton STW, Bedford STW, Buckingham STW, Caldecote STW, Chackmore STW, Chalton STW, Chawston-Tythe Farm STW, Cotton Valley STW, Covington STW, Dean (Lower) STW, Ducksworth STW, Duloe STW, Dunstable STW, Dunton STW (Aylesbury Vale) – assumed different to Dunton STW, Filgrave STW, Flitwick STW, Foxcote STW, Gayhurst STW, Great Linford STW, Hardmead (New) STW, Hardwick STW, Hargrave 2 STW, Hexton STW, Hillesden Hamlet STW, Hillesden-Church End STW, Hitchin STW, Honeydon STW, Horton STW, Huntingdon (Godmanchester) STW, Ivinghoe Aston STW, Kempston Hardwick STW, Leckhampstead STW, Ledburn STW, Leighton Bromswold STW, Leighton Linslade STW, Letchworth STW, Little Barford STW, Marston Moretaine STW, Melchbourne STW, Middle Claydon STW, Millbrook STW, Milton Bryan STW, Newport Pagnell-London Rd STW, Newspring Wtw STW, Newton Bromswold STW, Potterspury

Lodge STW, Poundon STW, Preston Bissett STW, Pulloxhill STW, Radstone STW, Sherington STW, Souldrop STW, Stanbridgeford STW, Stoke Lyne STW, Swineshead STW (Beds), Tempsford STW, Thornborough STW, Turvey-Station Road STW, Upper Sundon STW, Uttons Drove STW, Water Stratford STW, Wavendon-Lower End STW, Weston Underwood STW, Whitfield STW, Wyton (Raf) STW, Yielden STW.

The following columns were duplicated, or nearly duplicated: Everton STW, Fritwell STW, Gamlingay STW, Little Staughton STW, North Marston STW, Sandon (New) STW, Syresham STW, Turvey-Cottage/N Blovil R STW, Twyford STW, Waresley STW, Winslow STW one of each of these records was deleted.

Ashbrook STW appeared twice in the header ("Total FLO1FR Flow (Flow To Outfall)" and "Total Flow to Works"), but the data were quite different. Similarly for Odell STW, and Stewartby STW (actually with 3 columns), Swanbourne STW, Whaddon STW, these were added them together.

Blank, or mostly or completely zero, and deleted: Easton STW (Cambs), Fringford STW, Hail Weston STW, Hemington Main Street STW, Lavendon STW, Newnham STW (HERTS), Stowe STW, Westbury STW.

Some of the data was clearly wrong. The incorrect values were changed to those of the previous day for that STW:

23-09-2011, Molesworth STW, release 2,147,390,976 ML, changed to 65 Ml.
14-12-2011, Sandon (New) STW, release 2,147,483,904 ML, changed to 43 Ml.
26-09-2011, Papworth Everard STW, release 1,399,830 ML, changed to 256 Ml.
13-10-2011, Papworth Everard STW, release 2146068992, changed to 1911 Ml.
08-08-2011, Stewartby STW, release 65324.43, changed to 534.94.

Records that may be incorrect but were left alone were: Roxton STW, Catworth-Hostel STW.

D.3.8. Using the data

It was assumed that the weekly flows would be independent of the natural hydrology, and do not depend on anything else happening in the catchment; the flows are independent of any user's take and natural inflows. The model disregards intake from the catchment for these flows; intake and release are completely independent.

From a market point of view, the abstraction of water to supply these treatment flows-to-river has nothing to do with the outflows; the abstractor must manage those takes, and the assumed outflows are treated as a contractual commitment, which are not traded in the current market. More realistically, these releases should be treated as tradable, with the initial "right" as a commitment to release. The relevant sewage treatment agency could offer to sell a greater release, or could bid to buy the right to release less. If the taking institution cannot get enough water to supply the outflows, it would be considered in default of its contract to release, unless it could buy the right to release less.

However, STW flows would be modelled better if they were explicitly linked to the associated intakes from the river. This would price urban takes much more accurately, because the user would get compensated for the return flow. So, in the demonstration, Anglian Water will see higher prices for buying water than they would really have to pay, as the model only charges them for what they take, and cannot reimburse them for the return flow.

Scripts: 09a_Find_stw_nearest_river_node.py and 09b_get_sewage_inflows.py. The first script matches each STW to its nearest river node, and creates stw_river_assignment_edges.shp. The second script works similarly to the area-aggregating script, with sets of STWs, then calculates weekly flows by model node. The output is sewage flows by model node per week.

Inputs:

- Bedford_and_Upper_Ouse_Areas_network_edges.shp.
- TEL218937_2011_JFR.csv. This is the most recent complete sewage flow data. It has been assumed that each future year will have the same weekly series of flows. The data was hand edited as described above.
- STW_BedfordOuse.shp. This shapefile is assumed to contain the location of each sewage treatment outflow point.

Output: stw_flows_for_model.csv, and a table “StwFlows” with the same data in Sqlite database AWnodeflows.db.

D.3.9. Create a script to calculate inflows for each model node and day, and to get MRFs

Python script “get_inflows_utilities.py”

D.4. Get Python trading model working

D.4.1. Set up the trading database

Script 11setup_foreverfair_AW_database.py prepares the trading database. In this script, it is possible to choose the year for natural inflows in this script. Currently, it is set for 1976. The script itself contains important about Grafham reservoir. The reservoirEasting, reservoirNorthing, reservoirCapacityML, minimumInventoryML, and weeklyLeakageML, as follows: 517250.41, 266840, 55450, 2535, 0.245.

D.4.2. Read reaches and nodes from shapefiles. Set up the optimization objective, mass balance, and assessment point constraints

This is part of the market-clearing script, SolveAW.py.

D.4.3. Add Grafham to the market model

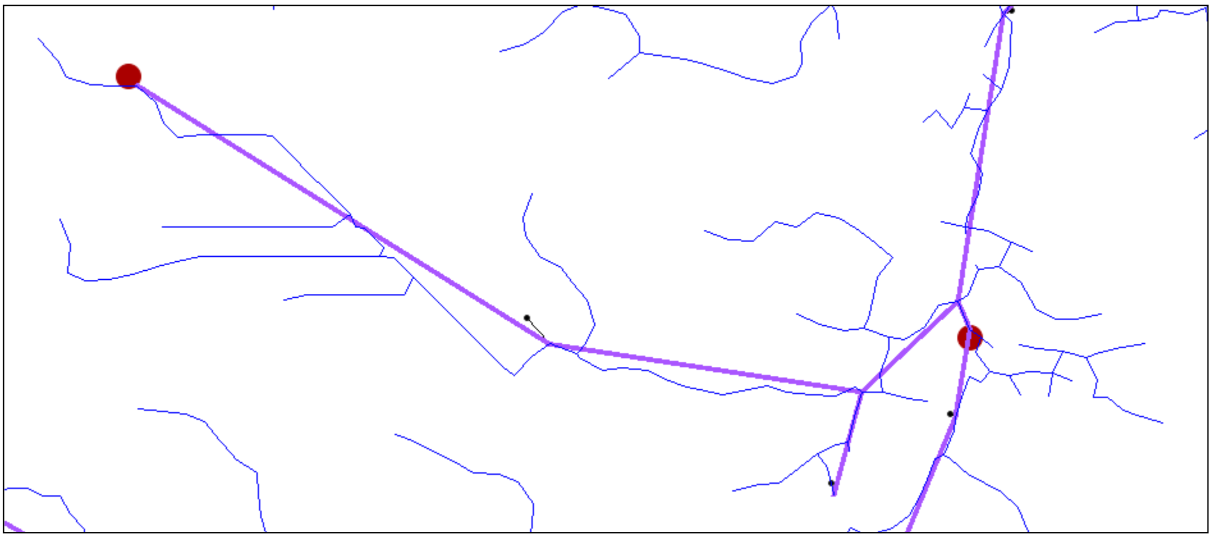
Shapefile. The river shapefile was unsatisfactory, and had to be hand-edited. Hence, many of the above steps were repeated. The Anglian Water user record at (521402,266121) was deleted, changed the shapefile to ensure that the Grafham reservoir connection to the river is upstream of the Offord gauge, and the irrelevant Grafham gauge at (512900,269600) was deleted. The Grafham Reservoir model location will be the same point in the model river network from which the user node associated with Anglian Water is connected to the river.

Because the catchment is quite flat, some arcs may actually be two-way, in that a user appears to be located on a tributary which flows into the main stem, but the tributary can actually withdraw from the river. This is likely the case for the Little Barford power station. Without topographic data, we had no obvious way to automatically identify such two-way links. (One way to check this is to see whether large users are able to abstract close to their full amount. So the checking process should be by largest users descending.)

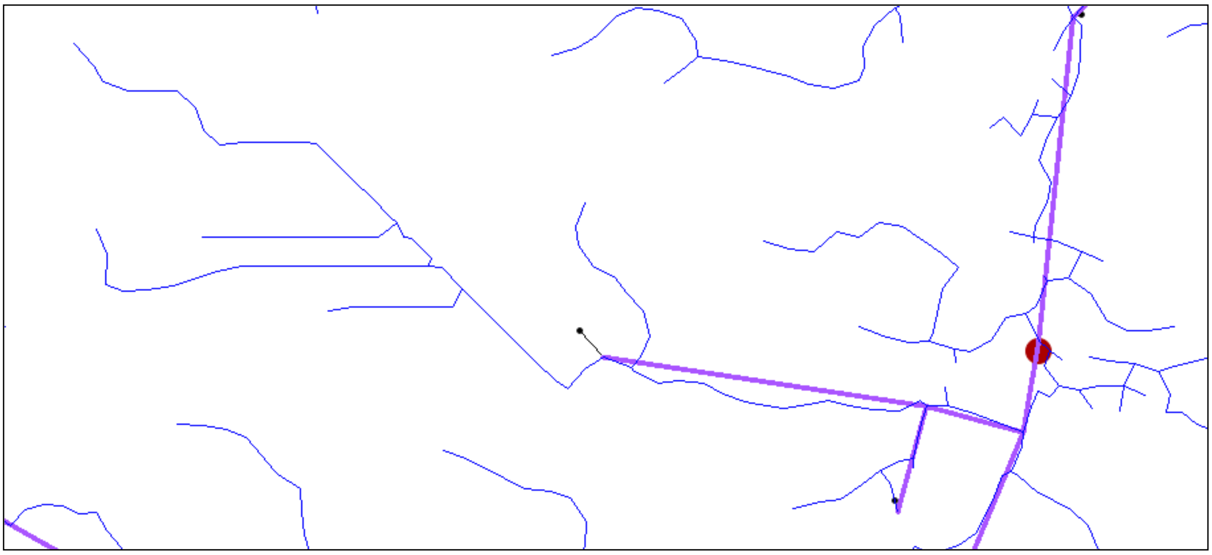
At the same time that the changes for Grafham were made, a manual change was also made for the Little Barford power station (moving from 518100,257600 to 517739.783099296, 258422.811236343, and unfortunately the decimals matter). This is a thermal power station, not a hydro-generator, so the water is abstracted consumptively. It was assumed that the power station – “this user” – takes directly from the river. The Barford node was dragged towards the river; now its shapefile easting and northing does not match the EASTING and NORTHING records in the shapefile database. A change was made for a user very near the river at 517400, 258600, simply deleting a river segment to avoid changing the user data.

The Buckden sewage treatment works is assumed to flow into the river, not the reservoir.

Before: Note that (1) inflow point to Grafham is downstream of the Offord gauge, while (2) the Anglian Water river “user” is upstream of the Offord gauge, and (3) the Grafham “gauge” at top left is useless.



After: (1) the reservoir inflow is correctly located upstream of the Offord gauge, where the Anglian Water river “user” was located, (2) the Anglian Water “user” is now taking directly from the reservoir node, and (3) the useless Grafham “gauge” is omitted.



The node xijt((471433.13,_236239.24),(472965.52,_235186.21),1) is free (positive or negative). The first node is Foxcote reservoir. The arc needs to be able to flow toward the river to allow the inflow to escape. It also needs to be able to flow toward the Foxcote "user" to allow abstraction.

The arc xijt((536963.2,273283.85),(536975.12,_273052.45),1) ≤ 0 connects the RPSB non-consumptive user to the river. The first node is the user connection. The second node connects to the mainstem. This should be ≤ 0, because the user will inject downstream.

The arc xijt((517250.41,266840.0),(520479.13,_266345.44),1) ≤ 0 feeds the Grafham reservoir. The first node is the reservoir. This should be ≤ so it flows only toward the reservoir.

The arc xijt((520479.13,266345.44),(521447.15,266083.36),1) is free (positive or negative). The first node is the midpoint "neighbour" node toward the reservoir. The second node is the river connection. This is the arc connected to the river toward Grafham.

The arc xijt((520193.75,265289.47),(521447.15,266083.36),1) is free (positive or negative). This arc is connected at one end to an abstracting user, and the other to the Grafham river connection. This should be free to allow flow in either direction, to release inflow, in case the user does not wish to take water.

Initial rights for Grafham. The made important operational assumptions about Grafham Reservoir was made Grafham Reservoir could be operated by the market manager, or by Anglian Water.

If the reservoir is operated by the market manager, the market optimization determines the reservoir intake (and releases, if any). All users from the reservoir are then "stacked" into a single user, assumed to be represented by Anglian Water. In this case, the optimization must be mult-period.

If the reservoir is operated by Anglian Water, then Anglian Water must bid for reservoir intakes, offer to sell reservoir releases, and manage the inventory level completely. Anglian Water would need its own optimization model to do this planning. All users from the reservoir then buy and sell directly from Anglian Water, not the public market. In this case, the optimization can be single-period.

Anglian Water may not have a reservoir optimization model appropriate to use in the demonstration. Developing such an optimization is a major undertaking itself. It has been assumed that the reservoir is operated by the market manager. In the shapefiles, the Anglian Water "user" was deleted as connected to the River Ouse and dropped the 459.09Ml/day limit. Instead, the Anglian Water "user" withdraws directly from the reservoir, with an initial right of 7*120,000ML/365 days = 2,301.37 Ml/week. These rights were scaled to the available inflows at the local mainstem node.

Operational rules.

1. Compensation release is ignored.
2. The minimum residual flow at Offord was calculated using the formula $Q_{min} = 136 + 0.25(Q – 136)$. This was ignored this in favour of the environmental flow limit formulae below.
3. The model ignores the weekend rule, because it requires measurement of hourly actions, and the model has weekly periods.
4. The model ignores river level requirements in AOD, as the model is flow-based, not head-based.
5. The agreement between Anglian Water and National Power regarding Little Barford power station is ignored, as this is viewed as a side arrangement, and not part of the market operations. Anglian Water and National Power would have to bid to satisfy any separate contract.
6. The model ignores Anglian Water's abstraction limit at Offord intake of 459.09ML/day. Instead, Anglian Water's initial right is 7*120,000/365 = 2,301.37 ML/week, based on its right to take from the reservoir.

Note that if we design the market so that Anglian Water manages the reservoir, then this abstraction limit could be Anglian Water's initial right.

7. The model ignores pump capacities, because this demonstration is considered an aspirational long-term proposal, and pump capacities could be changed. However, this could easily be included.
8. Drought orders are ignored for this demonstration.
9. Releases from the reservoir to the river are not allowed, to prevent release of the exotic shrimp.

D.5. Environmental flow limits

The following was implemented directly in the script SolveAW.py. Changing between the two regimes is easy, simply by commenting out the appropriate line in the script.

Define the total naturalized flow in week *w* as F_w^N (stored in the Sqlite database AWnodeflows.db).

D.5.1. Selection of assessment points

Ten gauges have been used plus the Mouth as the assessment points, rather than all the assessment points. Other assessments could be added but they are unlikely to make much difference to the result. At the margin, they would raise upstream prices. Most likely, however, only a few assessment points would be needed, perhaps only the Mouth.

However, for the very dry test year of 1976, it was noticed that some users in headwaters have so little water that they cannot take anywhere near their licensed quantity, even though the assessment point limits are satisfied. For these cases, the licence is over-allocated with respect to the locally available water, but is not over-allocated with respect to the assessment points. If the market clears with this over-allocation, the market manager will have to buy quota at these over-allocated points. Therefore, *a user's quota must be scaled for every downstream node, not just the assessment points.* More on this below.

D.5.2. Planned Water Framework Directive

Various MRFs were suggested at different times. At first, MRFs were supposedly based on the percentage deviation from naturalised flow at low flows, as defined by the 95% percentile flow (Q95) and for flows above Q95. Initially the following was implemented what seems to the current environmental limits as:

actual flow ≥ min{ F_w^N, Q95 }.

This means that when the naturalized flow would be less than Q95, no water can be abstracted. However, when the naturalized flow is above Q95, all the water above Q95 can be abstracted. Our "Modelling Assumptions" document contains the following flow limits.

Time of year	March to June		July to February	
	Flow > Q95	Flow < Q95	Flow > Q95	Flow < Q95
Percentage of naturalised flow that can be abstracted	25%	15%	30%	20%

The market model runs 52 weeks starting 1 January. Further, the model requires that the limit be set in terms of required flow, not allowable abstraction, hence it was implemented this in the following way:

> if 10 ≤ week ≤ 26, then actual flow ≥ {if F_w^N ≤ Q95, then 0.85*F_w^N, else 0.75*F_w^N}, else actual flow ≥ {if F_w^N ≤ Q95, then 0.8*F_w^N, else 0.7*F_w^N}.

This is believed to be equivalent to the above requirements, except that the week numbers do not align with the months perfectly.

Compared to the apparent current flow limit regime, this regime will allow relatively less water in high flow, and relatively more water in low flow. From a market perspective, prices under this regime will therefore be moderated compared to the previous regime, as prices will be relatively higher (from a low point) when water is abundant, and prices will be relatively lower (from a high point) when water is scarce.

On 14 September 2012, the following environmental flow ere provided:

Q30 (30 percentile naturalised flow) Up to 26% of the naturalised flow can be abstracted.
Q50 (50 percentile naturalised flow) Up to 24% of the naturalised flow can be abstracted.
Q70 (70 percentile naturalised flow) Up to 20% of the naturalised flow can be abstracted.
Q95 (75 [sic] percentile naturalised flow) Up to 15% of the naturalised flow can be abstracted.

Apparently, these limits do not depend on the calendar.

D.6. Calculating initial rights and default bids

Script 12getInitialRightsAndBids.py.

D.6.1. Key inputs

The common pool market requires a state-of-the-art licensing system, to specify users' initial rights before trading begins. The licensing system must (1) specify how users' rights adjust with the variability of inflows, and (2) define users' rights by time period, where the time period matches the auction calendar (weekly in this case). For the demonstration, users need to have the sense that their initial rights are respected, but the current licence system does not provide these two requirements.

Many users have annual licences that are a small multiple of their daily licences, e.g., 10, implying that the user is licenced to take water for only 10 days. However, the market model requires initial rights for each week. Multiplying a user's daily licence by 7 to obtain a weekly right would exceed many users' annual rights, worsening over-allocation. We could assume users' initial rights for those weeks in which they have used water in the past, based on actual extractions, but this answers only part of the initial rights question. (One user, easting-northing 536398,271902, has a daily licence of 0, but an annual licence of 40,000.)

The key inputs are:

- the daily and annual licence for each user (see the next section),
- the abstraction returns "Upper Ouse and Bedford Ouse Return data - Aug 12.xls",
- the estimate water value curves from UC London.

For the demonstration, these problems were addressed in three steps:

1. Assign non-calendared licence to specific weeks of the year. The abstraction returns were used to know when users probably wanted to take water from the surface water sources.
2. Scale the weekly rights to weekly inflows. This is a reasonably complicated graph algorithm, because the scaling depends on the location in the river network.
3. Create bids from scaled initial rights and water value curves.

Script: 12getInitialRightsAndBids.py

D.6.2. Rules of estimating initial quota

For each user *u*, for each week *w*, the average weekly abstraction was calculated $use_{u,w}$ from "Upper Ouse and Bedford Ouse Return data - Aug 12.xls".

For each user *u*, for each week *w*, the initial quota was calculated using $quota_{u,w} = annuallicense_u * use_{u,w} / \sum^{52}_{t=1} use_{u,t} /1000$. If the user *u* recorded $use_{u,w} = 0$ for all weeks *w*, the variable $quota_{u,w}$ was set as follows $quota_{u,w} = annuallicense_u/52/1000$. Note the conversion from m^3 to mega-litres.

This calculated data was saved to "Surface_water_estimated_use_and_initial_quota.csv."

D.6.3. Rules for scaling initial quota to inflows

For the 1976 case, it was noticed that some higher reaches could be short of water. It was concluded that *every* river node must be considered as an assessment point to the extent of the available water for non-assessment points, and to Environment Agency requirements for assessments points. The EA requirements will tend to dominate strongly.

A method was devised to scale user quota by week and by location in the river. Briefly, the method calculates a scaling α_i (alpha) for each river node *i*, as α_i = (total licence upstream)/(total abstractable inflow from upstream). The method then scans the whole catchment for the smallest α_i. All users upstream of this node *i* are then scaled to α_i. This is repeated until all users have been scaled. Here is a simplified version of the algorithm.

```
for t in 1 to 52:

    NodesToScale = set of all river nodes

    while NodesToScale contains nodes:

        alpha = blank list.
        for each node k in NodesToScale:
            abstractableWater = getAbstractableWater(keasting, knorthing, marketYear, t)
            if upstreamQuota[(k,t)] > 0: alpha[k] = abstractableWater/upstreamQuota[(k,t)]

        kmin = node k of the smallest alpha[k].
        for k in upstreamNodes[kmin]: NodesToScale.remove(k)

        for u in upstreamUsers[kmin]: AdjustedQuota[u] = alpha[kmin]*Quota[u][t]

    save AdjustedQuota[u] for this week w, and all users u, to foreverfair_AW.db.
```

Non-consumptive users are scaled to the remaining water in the stream, after the upstream consumptive users were scaled. Scaling consumptive and non-consumptive users together may be viewed as fairer, but we had insufficient time to implement this. For the dry year of 1976, this affects only the Bedford hydropower and Barford thermal power plant, which were both scaled to zero sometimes. Other non-consumptive users always had more inflow available than their licence. Finally, my proposed approach to scaling non-consumptive rights may not be acceptable either. In any case, the immediate goal is to have something plausible, while attempting to have revenue neutrality for the auction manager. (Note that *under*-allocating non-consumptive users, so their quota is less than the available flow, may result in potential revenue for the auction manager, who could sell the excess flow to the user.)

The script stores Quota and the output AdjustedQuota in the database foreverfair_AW.db, table initialQuota, fields [wellid, takePeriod, initialQuota, scaledQuota, nearestScalingNode]. Note that this has to be re-built for each test year. The initialQuota and scaledQuota would be better in separate tables, because initialQuota depends only on licence and historical use, while scaledQuota also depends on the inflows which vary by time period.

D.7. Notes on specific users

When the quota scaling ratios were being calculated, the following users turned up as having licensed far less than their local inflows. Of course, this makes sense for the Foxcote Reservoir, but the others needed more investigation.

6/33/03/*S/0057, 471300, 236200, ANGLIAN WATER SERVICES ... FOXCOTE RESERVOIR. **Make this a withdrawal arc, not an injection arc.** Initial rights for the Foxcote Reservoir licence were based on node 471433.13,236239.24, at the river mainstem.

Nonconsumptive user. 6/33/26/*S/0376, 537020, 273380, RSPB, EAST ANGLIA OFFICE ... Make-Up Or Top Up Water ... RIVER GREAT OUSE AT OVER. Steven Wade wrote, “RSPB use water for floodplain nature reserves so again there may be some evaporative losses but this is essentially not taking water and just slowing the flow and storing water for wading birds.” However, the “Consumption factor.xls” file shows this user as having 100% consumption. This was changed to 0% consumption**.** The user is bidding to abstract water from the river, but the water is returned. **A withdrawal arc was added, and also a virtual “outflow” reach from the user river node to the next node downstream on the mainstem.** Initial rights for the this licence were based on node 536975.12, 273052.45, at the river mainstem. The arc had to flow both ways, to have feasibility in case the user did not take water.

Nonconsumptive user. 6/33/13/*S/0061, 518400, 237800, HENLOW LAKES & RIVERSIDE LTD ... Mineral Washing. The user is bidding to abstract water from the river, but the water is returned. It was assumed that the user is taking and returning upstream of the Arlsey gauge. This is a critical market assumption; the purpose of the gauge could actually be to measure the reach in parallel to the abstraction, rather than the user’s absolute consumption. **A virtual “outflow” reach from the user river node to the next node downstream on the mainstem was added.** The downstream node is 518949.99,237949.3, at the Arlsey gauge. So the user could run the modeled reach dry.

Nonconsumptive user. 6/33/20/*S/0116, 518100 , 257600 (corrected in the shapefile to 517739.7831,258422.8112), Little Barford power station, RWE NPOWER PLC, SURFACE WATER SOURCE OF SUPPLY, Process Water. The user is bidding to abstract water from the river, but the water is returned. **A virtual “outflow” reach from the user river node to the next node downstream on the mainstem was added.** The downstream node is 517500,258550.

Nonconsumptive user. AN/033/0012/004, 505893, 249472, BEDFORD BOROUGH COUNCIL, P-ELC-240, Hydroelectric Power Generation. The user is then bidding for flow along the reach, not for abstraction. **The “abstraction” variable qwt was set as follows qwt = flow on the user’s reach downstream.**

Rights of these non-consumptive users have critical effect on others' rights and the market. A right for a non-consumptive user may be viewed as an obligation (at least an obligation not to consume).

The following two users have licences far in excess of the local inflows. However, it was decided to leave this unchanged

6/33/16/*S/0099, 501400, 236300, E W PEPPER LTD ... Spray Irrigation – Storage. Treat as normal abstraction, subject to local inflows.

6/33/19/*S/0286, 522500, 252160, M MEEKS & SON LTD ... Spray Irrigation – Storage. Treat as normal abstraction, subject to local inflows.

D.8. The website.

D.8.1. Add web page to display reservoir operations.

Anglian Water indicated that this was unneeded.

D.8.2. Write visualization script.

This is part of SolveGW.py.

D.9. Assumptions and improvements

D.9.1. Major assumptions

The model assumes perfect foresight of inflows. We ignored groundwater. The sewage treatment works flows into the river are modelled as constant, but should be modelled with a more complex flow structure, and should depend on the natural inflows. These flows are much too high for the drought year of 1976, make that year look better than it was, and probably shows an over-high payment to Anglian Water for those flows.

Consumption factors were binary – a user was either consumptive (100% abstraction) or non-consumptive (only using flow, with 0% abstraction). This also implies that return flows for consumptive users were ignored.

The environmental limits were used as listed in the Modelling Assumptions document, not the more detailed ones given later.

D.9.2. Minor

The following users must be withdrawing water from the river mainstem, not the local headwaters. However, each user's local arc is pointing toward the river: AGRESERVES LTD at 512410, 278780; CHAMBERLAIN at 518116, 242364; B O PAPWORTH & SON, 519800, 235200; UNILEVER LTD at 497100, 259800. There may be others.

Non-consumptive users were scaled to the remaining water in the stream, after the upstream consumptive users were scaled. For the dry year of 1976, this affects only the Bedford hydropower and Barford thermal power plant, which were both scaled to zero sometimes.

Very late, it was found that the user shapefile database has eastings and northings different than the shapes themselves. Two users (92 and 178) at (516300,249020) were found, the shapefile database lists them as (516300,249020) and (516300,249120), but the shapefile shapes have them colocated at (516300,249020).

This would need to be corrected. One's annual licence is 4,545 m^3/year, the other's is 386 m^3/year, so they're a bit different. Two "users" (55 and 198) at (518020,261300), two licences for the golf course were found. These two licences have different user web pages, but it cannot be guaranteed that the optimization manages them correctly.

E. Abstractor telephone questionnaire

1. Introduction
2. How many abstraction licences does your organisation hold?
3. What is the volume of each of those?
4. Are they surface water abstraction licences or ground water?
5. Are they year round or seasonal?
6. If seasonal what months do they cover?
7. What are their time periods e.g. unlimited; number of years
8. What do you use most (the greatest volume) of the water you abstract under your licence/s for?
9. How does your water demand change throughout the year?
10. For those whose demand changes considerably ask in which months or time of the year is your water demand highest?
11. In which months or time of the year is your water demand lowest?
12. To the best of your knowledge, approximately what would be the cost to you or your organisation to obtain a new abstraction licence?
13. Would you say there are any other costs associated with getting a licence e.g. time delays etc? What figure in pounds would you put on that?
14. IF they have a renewable licence then ask: How much is your renewal fee
15. How much are your annual abstraction fees to the Environment Agency.
16. Would you say you have any leeway to **reduce** your water consumption in your **peak use** times e.g. summer irrigation for farmers? E.g. through more efficient methods

    Yes/No

17. If yes, thinking about your peak water use times , how much money per cubic metre of water do you think you would have to be paid to to reduce your water consumption by:
    a. by 10%? b. 20%? c. by 50%?
18. 18 Now, Thinking about the time in the year when your need for water is at its lowest, how much would you need to be paid £/m^3 or other units to reduce your water consumption by:
    a. by 10%? b. by 20%, c. by 50%?
19. Thinking about the time of year when your need for water is at its highest, and supposing you **could** increase you abstraction above your licence limit, how much would you be willing to pay in £/m^3 or other units to be able to increase your abstraction above your current licensed limit:
    a. by 10%? b. by 20%? C. by 50%?
20. Thinking about the time of year when your need for water is at its highest, how much money in pounds) would you/your organisation lose if the amount of water available to you through your allowable abstraction volume dropped by:
    a. 10%? b. 20%? c. 50%?

F. Questionnaires used in the October 2012 workshops

Collaboratory on Sustainable Water Stewardship Working Group on Water Allocation: Research into Water Trading Potential:
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QUESTIONS TO PARTICIPANTS (1)

1. **How would you describe your knowledge of water trading? (please circle one)**

   Very little knowledge 1 2 3 4 5 Considerable knowledge

   Comments:

2. **How would you describe your experiences of water trading? (please circle one)**

   I have……….

   …..never been involved in water trading …..some indirect experience of water trading through friends, colleagues, research…..carried out/advised on informal trades…..carried out/been involved with a trade through the Environment Agency

   Comments:

3. **How would you describe your views on water trading?**

4. **What do you hope to get from today's workshop?**

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QUESTIONS TO PARTICIPANTS (COMMON POOL APPROACH)

Thinking about the COMMON POOL APPROACH …

1. How fair or unfair do you think the COMMON POOL approach is? (please circle one)

   Completely fair 1 2 3 4 5 Completely unfair

   Comments:

2. How flexible/inflexible do you think the COMMON POOL approach is? (please circle one)

   Very flexible 1 2 3 4 5 Very inflexible

   Comments

3. How efficient/inefficient do you think the BIDDING PAGE for the COMMON POOL approach is? (please circle one)

   Very efficient 1 2 3 4 5 very inefficient

   Comments:

4. How do you think the COMMON POOL approach would affect the efficiency of water use in the catchment? (please circle one)

   Make it much more efficient 1 2 3 4 5 make it inefficient

   Comments:

5. If you had access to the COMMON POOL approach, can you see yourself engaging with it? (please circle one)

   Definitely 1 2 3 4 5 very unlikely 0 not applicable

   Comments:

6. What would have to happen for you to engage with the COMMON POOL approach if it were available?

7. Overall, what do you see as the main benefits of the COMMON POOL approach?

8. Overall, what do you see as the main limitations of the COMMON POOL approach?

9. Any other comments?

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QUESTIONS TO PARTICIPANTS (IMPROVED PAIR-WISE APPROACH)

Thinking about the IMPROVED PAIR-WISE APPROACH…

1. How fair or unfair do you think the IMPROVED PAIR-WISE approach is? (please circle one)

   Completely fair 1 2 3 4 5 Completely unfair

   Comments:

2. How flexible/inflexible do you think this approach is? (please circle one)

   Very flexible 1 2 3 4 5 Very inflexible

   Comments

3. How do you think the IMPROVED PAIR-WISE approach would affect the efficiency (i.e., ability of water to go where it creates the most economic benefits for the region) of water use in the catchment? (please circle one)

   Make it much more efficient 1 2 3 4 5 Make it inefficient

   Comments:

4. From what you have heard today, do think the IMPROVED PAIR-WISE approach has the potential to make your business or organisation better off?

   Definitely 1 2 3 4 5 Very unlikely

5. If you had access to the IMPROVED PAIR-WISE approach, can you see yourself engaging with it? (please circle one)

   Definitely very unlikely 0 not applicable

   Comments:

6. What would have to happen for you to engage with the IMPROVED PAIR-WISE approach if it were available?

7. Overall, what do you see as the benefits of the IMPROVED PAIR-WISE approach

8. Overall, what do you see as the limitations of the IMPROVED PAIR-WISE approach

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