The Impact of Water Abstraction Reform

Final Report WT0964/WT0995

Produced: May 2014
The Impact of Water Abstraction Reform

Final Report WT0964/WT0995

Produced: May 2014
A report of research carried out by Risk Solutions, on behalf of the Department for Environment, Farming and Rural Affairs

Research contractor: Risk Solutions

Publishing organisation
Department for Environment, Food and Rural Affairs
Flood Risk Management Division,
Nobel House,
17 Smith Square
London SW1P 3JR

© Crown copyright (Defra); 2014

Copyright in the typographical arrangement and design rests with the Crown. This publication (excluding the logo) may be reproduced free of charge in any format or medium provided that it is reproduced accurately and not used in a misleading context. The material must be acknowledged as Crown copyright with the title and source of the publication specified. The views expressed in this document are not necessarily those of Defra. Its officers, servants or agents accept no liability whatsoever for any loss or damage arising from the interpretation or use of the information, or reliance on views contained herein.
The Impact of Water Abstraction Reform

A report for Defra, the Environment Agency, the Welsh Government and Natural Resources Wales
May 2014
Issue 3.2
Summary

Introduction
Water abstraction is the process of removing water from sources like rivers, lakes, reservoirs and aquifers. Water abstraction is regulated in England and Wales through a system of licences. Anticipated pressures from climate change and population growth mean that the current licensing system is no longer considered fit for purpose.

The Government in England has committed to working closely with stakeholders to reform the abstraction system. The Welsh Government will also consider the different options for reform in developing its Water Strategy.

Aims of the modelling
An important part of the policy development process is to test the costs, benefits and risks of alternative policy options against the current regime. Defra and the Welsh Government commissioned a team led by Risk Solutions to model the behaviour of abstractors and compare the alternative policy options. The team comprised: Risk Solutions, HR Wallingford, London Economics, Wilson Sherriff and Vivid Economics. Additional expertise was provided by Mott Macdonald, ADAS, Cranfield University, Simon Less Consulting, The Centre for Ecology and Hydrology, The British Geological Survey and Blackwell Water Consultancy. In addition AMEC worked with the Environment Agency to represent future abstraction permissions and regulatory conditions under the reform options and provided support reviewing early model outputs. URS worked with the Environment Agency to model the administrative costs of current and future reforms.

The overall goal was to explore how well the alternative policy options perform under different climate change and socio-economic scenarios and in a range of different types of catchment and to inform option design.

About this report
This report describes the modelling work carried out between February 2012 and September 2013 in support of the Consultation Impact Assessment published in November 2013, and work carried out subsequently from December 2013 to February 2014 to improve the modelling prior to planning work for the Final Impact Assessment.

Our current focus has been on ensuring that the model is adequately capturing the many hydrological, behavioural and economic processes at work, and exploring how the options are working at the abstractor level.

Options for reform
Defra, the Environment Agency, the Welsh Government and Natural Resources Wales have defined three abstraction reform options for the purpose of modelling. These are:

1. **Current System**: Continuing with the current system, following changes to licences required by the *Habitats Directive Review of Consents (RoC)*, *Water Framework Directive (WFD)* and *Restoring Sustainable Abstraction (RSA)*.

2. **Current System Plus**: This option aims to refine the current system to make it more flexible and support abstractors as they adapt to the impacts of climate change. It strengthens the link between water availability and permitted abstraction to allow more water to be abstracted when more is available and improve environmental protection, particularly at very low flows. It also makes it easier for abstractors to trade water with each other, through pre-approving temporary low risk trades.

3. **Water Shares**: The Water Shares option embeds the principle that abstractors have a share in the available water resource rather than an absolute allowance whatever the water resources available, encouraging abstractors to take a shared responsibility for water.
resources in catchments. This creates the potential to implement a more systematic approach to accounting and managing water in rivers to reflect the variability in their flows. This option would allow for pre-approval of shorter-term trading between abstractors and of a wider range of trades.

Under both Current System Plus and Water Shares the intention is to:

- Improve the link between abstraction charges and usage.
- Remove time limits from licences that currently have them and instead introduce a new transparent and risk based process to review catchment conditions. This would enable the regulator to change any abstraction permission within each catchment, with notice, to protect the environment.
- Take an evolutionary and proportionate approach to implementation. The full package of reforms would only be introduced in those catchments where there are clear economic and environmental benefits to doing so. Each option has therefore been split into basic components which will have to be in place regardless of type of catchment, and enhanced components, which will only be put in place where there are likely to be economic and/or environmental benefits.

More information about the options can be found in Chapter 2.

**Case study catchments**

Seven case study catchments were initially selected for modelling. These were:

- The Kent Stour
- The Tees
- The Cam and Ely Ouse
- The Trent and Derwent (this covers seven separate Catchment Abstraction Management Strategy (CAMS) areas)
- The Dee
- The Usk
- The Hampshire Avon.

They are shown on Figure a.

They were carefully chosen, in discussion with Defra, the Welsh Government, Environment Agency, Natural Resources Wales and abstractor representatives to cover as many different local conditions relevant to abstraction and abstraction reform as possible.

After an initial round of modelling and consultations it was decided, in discussion with the Project Steering Board, to focus on four catchments where there were significant water availability challenges and the modelling was tractable in the timescales available for the Consultation Impact Assessment. Modelling of the Tees, Dee and Trent and Derwent was therefore stopped at this stage, although work on additional catchments will be looked at to support the Final Impact Assessment. The Trent and Derwent catchment is considered particularly important because it has a significant power generation presence. The Trent and Derwent also includes sub-catchments that are more surface water dominated, which is particularly helpful for characterising catchments in Wales and significant parts of northern and southwest England.

To make best use of the time available, the decision was taken to suspend modelling of the Dee

![Figure a: Proposed case study catchments](image-url)
and focus on those sub-catchments of the Trent and Derwent that will provide representative outputs for Wales, and the Southwest and Northwest parts of England.

More information about the case study catchments can be found in Chapter 3 (Case study catchments) and Appendix 3.

**Approach to modelling**

For each case study catchment we developed a fully integrated hydrological and abstractor behaviour model. The model estimates the overall cost benefit of each reform option in each catchment from implementation in 2025 to the end of the modelling period in 2050. It also allows us to explore in detail the impact on different types of abstractors and the environment and to understand where each reform option performs well, where less well and why. It therefore supports detailed design of the options. It is important to note that we are not trying to accurately model the catchments, but to create a varied landscape that will test the options under a wide range of situations.

We also developed an aggregation model to provide an indication of national level costs and benefits based on scaling the results from the case study catchments. This provided key input to the Consultation Impact Assessment.1

Finally Vivid Economics produced a simple top down economic model to provide an additional perspective on the results.

**Why adopt this approach?**

The abstraction reforms proposed, in particular Water Shares, are complex. The system that they affect are also complex, and the level of benefits will be critically dependent on local characteristics of the catchments including the local hydrology (which determines for example who can trade with whom) and the characteristics of the abstractors (which determines who will trade with whom). Further, the determination of the level of benefit must take account of complex interactions and feedbacks between the hydrology, weather, the licensing regime and abstractor behaviour and between agents.

Agent-based modelling has emerged as a key methodology for developing understanding of the interactions between people and their environment in situations such as these drawing on techniques from social sciences and ecological modelling, and evidence from behavioural economics.

We have therefore constructed an agent-based model (the ABM) designed to estimate the performance of each policy option based on the sum of responses of different agents (abstractors) interacting together, each with their own motivations and approach to decision making. This ‘bottom-up’ approach has many advantages over other, simpler approaches. Perhaps the four most significant advantages of this approach in the current application are that it helps us to:

- Identify unanticipated behaviours that emerge from the interactions of the many different elements that make up the water abstraction system
- Simulate decision making processes that are much closer to real life, and
- Differentiate meaningfully between reform options that only differ at the level of detailed design, and
- Provide input to the design process; both the modelling process (thinking through how each option should be represented in the model and how the various actors may respond) and examination of results emerging from the modelling can help inform the design of the reforms.

This approach is introduced below and in more detail in Chapter 3.

---

The hydrological model

For each case study catchment the hydrological model is used to estimate river flows and groundwater levels in each 1 km grid cell at a daily time step. It takes account of:

- Abstractions
- Discharges
- Precipitation
- Evapo-transpiration
- Land use, and
- River flows.

Data sources include:

- Abstraction Licensing Records
- CAMS Ledgers

Information is passed, on a daily basis, from the hydrological model to the abstractor behaviour model.

More information about the hydrological modelling is given in Chapter 4 and Appendix 4.

The abstractor behaviour model

The abstractor behaviour model (ABM) estimates both Public Water Supply (PWS) and non-PWS abstractors' demand requirements, and determines their behaviour taking into account the information received from the hydrological model. It determines abstraction and return flows, and passes this information back to the hydrological model.

In the model abstractors are represented as agents. In addition to day to day operational decision making (for example, whether to irrigate crops or from which source to abstract water to serve PWS customers) the model also determines agents' longer term decision making. This may include for example a decision to stop producing a particular product or to invest in water infrastructure. At each step the model establishes the costs to agents associated with water abstraction and investment decisions.

In this way the integrated model helps us establish a comprehensive picture of how abstractors are expected to respond to the challenges and opportunities presented by increased water availability challenges and water abstraction reform. It allows a picture to be built up of the anticipated impacts (benefits, costs and risks) of both the reforms and retention of the current system. It is important to remember however that the agents in the model are model constructs, not real businesses and a number of simplifications regarding their processes and products have had to be made.
More information about the abstractor behaviour modelling and how shareholdings, allocations, environmental abstraction limits and reformed license conditions were established for each reform option and the current system are given in Chapter 5 and Appendix 5.

The aggregation model
The results for the catchments were then aggregated and scaled up to provide an indication of costs and benefits for England and separately Wales.
The aggregation model is spreadsheet based. It reads in ABM outputs and scales up the results for all catchments in England and separately Wales using an appropriate scaling method depending on the type of output. It is designed among other things to explore whether the benefits of full (enhanced) implementation in only a proportion of catchments, outweighs the broader costs associated with minimum (basic) implementation nationally. It produces outputs that can be copied straight into the Government’s Impact Assessment calculation template. It produces two main outputs:

- Yearly net costs and benefits from 2025 to 2050 for England and separately Wales
- The total number of catchments that are classified as Basic or Enhanced.
The model can also produce sectoral impacts for the four example catchments to highlight whether there are any major distributional effects in the overall cost benefit case.
More information on aggregation modelling is given in Chapter 6.

The top down model
Traditional top down economic modelling provides high-level aggregate analysis and is less useful in delivering meaningful conclusions in complex situations because it is difficult to represent the myriad interactions involved. It is also difficult to model differences between options that arise, for example, due to differences in the detail of implementation. Nevertheless, top down modelling can provide additional useful insights into the options that can be explored further using the Integrated ABM. It can also provide a sense check of the detailed modelling by giving an indication of the scale of results from the alternative method. Vivid Economics were therefore asked to construct a simple model designed to explore the potential gains available from trade and whether these are sufficient to merit the costs of setting up the markets.
The model complements the detailed catchment modelling described above, drawing together information on actual abstractions, climate and demand scenarios, and values of water in use and cost of water supply, to estimate the potential scope for value creation by trading water.
The most significant simplification made is the lack of consideration of hydrology in the model. In water resources, spatial relationships are very important, but they also bring complexity. So for this simple model, most of the richness of hydrological and spatial relationships has had to be put aside. All trades between abstractors are allowed within single catchments in the model. This will significantly overstate the trades that would naturally be allowed in practice and therefore the benefits of reform. It also treats all trades as if they were licence transfers, so is not able to distinguish between the different types of trades possible under the current system and the two reform options.
More information on the top down model is given in Chapter 6.

Emerging findings
Running the models
We do not know how the future might unfold; we have therefore used scenario analysis to explore how the options perform under a range of different possible futures. Scenario analysis involves defining a range of scenarios that scope the range of possible futures, and then carrying out model runs for each of these scenarios.
We agreed with the project board that we would use the same socio-economic and climate change scenarios adopted by the Environment Agency (EA) in their Case for Change analysis.
This identified four socio-economic scenarios and four climate change scenarios (which combine to give 16 possible scenarios). Together these cover the different types of climate and socio-economic uncertainty relevant to the four catchments we have modelled.

Figure d shows that a full set of scenario combinations for the three policy options and four modelled catchments totals 192 runs of the ABM models, which is equivalent to approximately 8 days computing time. The results are then passed through the Aggregation Model to estimate the costs and benefits at a national level.

For each climate and socio-economic scenario we carried out model runs beginning modelling in 2023 to provide a two year ‘warm-up’ period, and ending in 2050. We used the models to explore:

- Whether reform delivered benefits compared to the current system
- The extent to which we could distinguish reliably between Current System Plus and Water Shares
- How the options are working in practice, and to
- Identify areas in the modelling where further improvements would help to:
  - Improve confidence in the results, or
  - Allow more agile development and testing of options.

The findings are summarised below. More information is provided in Chapter 7.

**Does reform deliver benefits?**

The modelling carried out for the Consultation Impact Assessment suggests that in England reform could provide economic benefits compared with the current system in all scenario combinations. The benefits are relatively small; estimates ranged from about £100m up to about £500m net present value (NPV) over 25 years. In Wales, the case is more variable, with estimates ranging from net benefits of £30m to net costs of £10m.

The findings of the latest work are consistent with the Consultation Impact Assessment findings, with reform seen to deliver benefits across a wide range of climate and socio-economic scenarios in the case study catchments. However, improvements in the modelling have resulted in increased estimates of the benefit of reform at the catchment level, and for some catchments and scenario combinations the increase is significant.

**Can we distinguish between options?**

We find that performance of the options is affected by a complex series of interacting drivers, with the ‘best’ option dependant on how these play out in each catchment and scenario.
Depending on the catchment and scenario combination different factors become more or less important.

Detailed examination of the catchment level results allowed us to identify three aspects of the current modelling with the potential to affect assessment of the comparative performance of the options. These are:

- The modelling of environmental protection and groundwater, and interactions with PWS investment decision making
- Characterisation of some economically significant agents where non-water related economic decision processes may be masking some differences between the options
- Policy options that constrain access to water at very low flows may affect the calculation of PWS deployable output and hence their investment decisions; this is not reflected in the current modelling.

Further exploration of these factors is recommended prior to the Final Impact Assessment to increase confidence that the model is reliably distinguishing between the options.

**How do the reforms work in practice?**

Benefits of enhanced reform accrue from better access to high river flows and earlier abstraction trading providing increased profits and more efficient investment profiles in water management infrastructure while delivering similar levels of water security. We see the reforms enabling agents to access more water than under the Current System.

Water companies are important players with significant benefits often coming from their being able to defer investments, or advance them to release water for other users who are willing to pay.

It is hard to generalise the results, because we see different impacts and behaviours in each catchment and sector, however some broad patterns can be seen. For example, agents with regular steady demand for water (generally industrial agents) generally perform equally well under all the policy options, particularly in the early years. However, in the latter part of the modelling period, when environmental protection measures begin to come into force, agents can benefit from reform, because the take back of water is often smaller.

We see agents being able to increase access to water rights by trading with those who no longer need those rights. We also see agents that are highly dependent on within-year rainfall (for example arable farmers) being better able to access water when they need it with reservoir building increasing to support this. This is particularly the case under Current System Plus, but is more varied under Water Shares for the reason discussed below.

Trading volumes vary between catchment and scenario. The PWS and agricultural agents are the most active. Agriculture to agriculture trades are most common, with some trading between other sectors.

We are able to identify elements of each reform option that are particularly beneficial or which lead to unintended outcomes. The model can therefore be used to help optimise the design of the reforms, and has delivered significant insight already. For example the work has exposed:

- Constraints under Water Shares on ‘high volume over short period’ abstractors
- The fact that trading results in licensed water abstraction moving over time to the bottom of the catchment under Current System Plus trading because once a downstream trade has occurred it is not possible in the current design to reverse it
- Increased abstraction from groundwater sources, which are regulated differently.

The options are being developed to address identified issues, including potentially definition of a hybrid option that will build on the strengths of both Current System Plus and Water Shares.

**Interpreting the results**

It is important to remember when examining the models and results of the modelling that while the aim is to provide a representation that is sufficiently varied and plausible to provide a robust
test of the comparative performance of the options, we are not attempting to reproduce reality or forecast the future.

We have noted above three limitations of the current model that may be affecting the comparison of the options. The modelling has also helped us to identify a number of other factors that may have a significant impact. For example, in some catchments and scenarios secondary markets and water release (also called ‘put and take’) trading may provide agents with additional flexibility to manage water challenges, and these may be particularly important in the Water Shares option.

The wide consultation already carried out (and which remains on-going) in support of the reform programme has helped us anticipate many of the impacts of the reforms and capture these in the model. However, in reality there will of course be some unanticipated effects, both positive and negative, which cannot be anticipated and modelled in advance.

With the help of peer reviewers and stakeholders, we have identified a number of other areas where the model could be improved. These have been identified as recommendations below.

**Recommendations**

In addition to carrying out further exploration of the three areas of modelling identified above we recommend that:

- Put and take (water release) trading is implemented in the model
- The way policy set-up and transition are handled in the modelling is streamlined to support the design and testing of hybrid options.
- The Trent and Derwent catchment is modelled, and that outputs from this model are presented at a CAMS catchment level. This will provide two key benefits. Firstly it will permit inclusion of benefits to the power sector, and secondly it will increase the size of the evidence base, which in turn will improve the aggregation process. In particular, the Trent and Derwent includes sub-catchments that are:
  - More surface water dominated (particularly helpful for characterising many Welsh catchments and significant parts of northern and southwest England)
  - More highly managed than the other English case study catchments (helpful for both English and Welsh catchment characterisation), and
  - A corridor catchment (helpful for providing some insight into other similar systems such as the Thames and Severn).

  However, the Trent and Derwent catchment is very large and we will need to ensure that we can modify the model so that it will run in manageable timescales.

- The performance of reform options in drought conditions and their potential to improve the resilience of catchments to drought is explored. This will involve modelling drought regulations and carrying out sensitivity runs using drought scenarios.

Finally, as noted above, the Integrated ABM generates a large amount of data about the reforms that could be processed to provide a very rich picture of how the options are performing and to generate narratives to generate the result. We recommend that ways of efficiently processing this data are developed and that adequate time is given to its analysis and reporting to inform the Final Impact Assessment.

Options for further work have been discussed and a priority agreed with the project board. Our recommendations are given in full in Chapter 8. We will continue to expose this work to the project board, peer review group and stakeholders and every effort will be made to understand and take account of consultation responses and feedback to shape the final phase of modelling work.
Further information

The report is supported by a number of companion reports:

<table>
<thead>
<tr>
<th>Companion reports</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR Wallingford: The Impact of Abstraction Reform: Hydrological modelling¹</td>
<td>Issued</td>
</tr>
<tr>
<td>London Economics/Risk Solutions: The Impact of Abstraction Reform: Non-PWS agent behaviour¹</td>
<td>Issued</td>
</tr>
<tr>
<td>HR Wallingford: The Impact of Abstraction Reform: Public water supply operations¹</td>
<td>Issued</td>
</tr>
<tr>
<td>Vivid Economics: The Impact of Abstraction Reform: A simple top down water abstraction economic model for England and Wales¹</td>
<td>Issued</td>
</tr>
<tr>
<td>Environment Agency / Natural Resources Wales: Assessing the Regulatory Cost of Abstraction Reform - Supporting Evidence on Component Costs, September 2013²</td>
<td>Issued</td>
</tr>
<tr>
<td>AMEC: Support to Abstraction Reform Programme, Hydrological Aspects of Regulatory Inputs to Trial Catchment Modelling, AMEC Environment &amp; Infrastructure UK Limited, September 2013³</td>
<td>Issued</td>
</tr>
</tbody>
</table>

The reports can be accessed at:
2. available on request to abstraction_reform@defra.gsi.gov.uk
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td></td>
<td>Why reform is needed</td>
</tr>
<tr>
<td></td>
<td>The objectives of reform</td>
</tr>
<tr>
<td></td>
<td>Aims of the modelling</td>
</tr>
<tr>
<td></td>
<td>About this report</td>
</tr>
<tr>
<td></td>
<td>Acknowledgements</td>
</tr>
<tr>
<td>2</td>
<td>Description of the options</td>
</tr>
<tr>
<td></td>
<td>Options for reform</td>
</tr>
<tr>
<td></td>
<td>Current System</td>
</tr>
<tr>
<td></td>
<td>Current System Plus</td>
</tr>
<tr>
<td></td>
<td>Water Shares</td>
</tr>
<tr>
<td></td>
<td>Moving to any new system</td>
</tr>
<tr>
<td>3</td>
<td>Overview of the modelling approach</td>
</tr>
<tr>
<td></td>
<td>Case study modelling</td>
</tr>
<tr>
<td></td>
<td>Case study catchments</td>
</tr>
<tr>
<td></td>
<td>The integrated hydrological – abstractor behaviour model</td>
</tr>
<tr>
<td></td>
<td>Developing the model</td>
</tr>
<tr>
<td></td>
<td>Model testing, validation and sensitivity analysis</td>
</tr>
<tr>
<td></td>
<td>Aggregation</td>
</tr>
<tr>
<td></td>
<td>The aggregation model</td>
</tr>
<tr>
<td></td>
<td>Validating the aggregation model</td>
</tr>
<tr>
<td></td>
<td>Key assumptions and simplifications</td>
</tr>
<tr>
<td></td>
<td>Hydrological modelling</td>
</tr>
<tr>
<td></td>
<td>Behavioural modelling and decision making</td>
</tr>
<tr>
<td></td>
<td>Modelling the options</td>
</tr>
<tr>
<td></td>
<td>Modelling transition</td>
</tr>
<tr>
<td></td>
<td>Aggregation modelling</td>
</tr>
<tr>
<td></td>
<td>Top down modelling</td>
</tr>
<tr>
<td></td>
<td>Interpreting results</td>
</tr>
<tr>
<td></td>
<td>Why adopt this approach?</td>
</tr>
<tr>
<td>4</td>
<td>The hydrological model</td>
</tr>
<tr>
<td></td>
<td>Requirements of the hydrological model</td>
</tr>
<tr>
<td></td>
<td>Implementation of the modelling framework</td>
</tr>
<tr>
<td>5</td>
<td>Behavioural modelling</td>
</tr>
<tr>
<td></td>
<td>Agent-based modelling</td>
</tr>
</tbody>
</table>
The Impact of Water Abstraction Reform

Model implementation 26
Modelling non-PWS behaviours 27
Modelling PWS behaviours 29
  Short term decision making 29
  Long term decision making 30
Modelling policy options 30
Setting up the model 32
  Establishing reformed licence conditions and environmental abstraction limits 32
  Establishing future scenarios 34

6 Aggregation and the top down model 38
The Aggregation Model 38
  Model overview 38
  Model outputs 40
The top down model 41
  Model overview 42
  Limitations of the model 42
  Model outputs 42

7 Findings 44
  Aggregated results generated for the Consultation Impact Assessment 44
    Headline results 45
    Sources of cost and benefit 47
    Benefits to the Environment 49
    Variation in results by scenario combination 50
    Variation of results by catchment 51
    Sensitivity analysis 52
  Model development after the Impact Assessment 58
    Case study findings 59
    Sensitivity analyses 84
  Understanding the options 91
    Constraints and responses 91
    Exploring the options 95
  The top down model 95

8 Conclusions and recommendations 97
  Conclusions 97
    The Consultation Impact Assessment 97
    Work following the Consultation Impact Assessment 98
    Overall 99
Appendix 1: Project oversight

The Project Board
The Abstraction Reform Advisory Group (ARAG)
Internal project experts
Peer reviewers
  Peer Review Meeting – 12 November 2012
  Peer Review Meeting – 13 March 2013
  The peer review and experts meeting – 21 May 2013
  Peer Review Meeting – 03 September 2013
  Peer Review Meeting – 03 February 2013

Appendix 2: Engagement

Phase I engagement
Phase II engagement
  Catchment based engagement
  PWS engagement
Phase III engagement
  Continuing engagement

Appendix 3: Case study catchments

Kent Stour catchment
Cam and Ely Ouse catchment
Usk catchment
Hampshire Avon catchment

Appendix 4: Hydrological modelling

Background to the hydrological model
Objectives of the hydrological modelling
Introduction to the CatchMOD hydrological model
Use of a gridded hydrological model
Input data for the hydrological models
Combined hydrological and ABM model and its effect on the overall modelling approach
Calibration of the hydrological models
Soil moisture module
Catchment storage module
Bibliography

Appendix 5: Abstractor behavioural modelling

Introduction
The Impact of Water Abstraction Reform

| Choices available to abstractors                     | 134 |
| Modelling abstractor decision making                | 137 |
| PWS operational decision making                     | 138 |
| PWS investment decision making                      | 139 |
| Consumptiveness                                     | 144 |
| Shareholdings and allocations                       | 144 |
| Setting environmental abstraction limits and reformed licence conditions | 145 |
| Implementation of trading                           | 150 |

**Glossary**

| Catchment Abstraction Management Strategy (CAMS) terms | 153 |
| Water resources management plan, infrastructure and operational terms | 154 |
| Terms relating to reform                                | 157 |
| General terms / current system                          | 157 |
| Current System Plus (Specific terms)                    | 158 |
| Water Shares (Specific Terms)                           | 159 |
| Modelling and data sources                              | 160 |
| Other acronyms and definitions                          | 162 |
# Table of figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Case study catchments</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>Overview of the CatchMOD model structure as implemented within the semi-distributed modelling framework</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Interaction between the hydrological model and ABM</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>PWS short term (operational) behaviours and responses</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td>PWS Investment planning behaviours and responses</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Definition of the socio-economic scenarios</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>Trends in total water demand - 2008 to 2050 (England &amp; Wales)</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>Climate change scenarios: changes in flow at relatively low flows</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>Scenario combinations selected for initial model runs</td>
<td>37</td>
</tr>
<tr>
<td>10</td>
<td>Catchment categorisation flowchart</td>
<td>39</td>
</tr>
<tr>
<td>11</td>
<td>The Dee and its neighbouring catchments</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>Scenario Combinations</td>
<td>44</td>
</tr>
<tr>
<td>13</td>
<td>Reform Benefits for England</td>
<td>45</td>
</tr>
<tr>
<td>14</td>
<td>Reform Benefits for Wales</td>
<td>46</td>
</tr>
<tr>
<td>15</td>
<td>Illustrative Impact of increased growth rates on reform benefits for England</td>
<td>54</td>
</tr>
<tr>
<td>16</td>
<td>Illustrative Impact of increased growth rates on reform benefits for Wales</td>
<td>54</td>
</tr>
<tr>
<td>17</td>
<td>Impact of increased economic rationality on reform benefits for England</td>
<td>55</td>
</tr>
<tr>
<td>18</td>
<td>Impact of increased economic rationality on reform benefits for Wales</td>
<td>56</td>
</tr>
<tr>
<td>19</td>
<td>Impact of 20% variation in adaptation costs on reform benefits in England and Wales</td>
<td>57</td>
</tr>
<tr>
<td>20</td>
<td>Impact of 20% variation in production gross margin on reform benefits in England and Wales</td>
<td>57</td>
</tr>
<tr>
<td>21</td>
<td>Net benefit of each reform option compared to the current system presented by socio-economic (SE) and climate change (CC) scenario</td>
<td>60</td>
</tr>
<tr>
<td>22</td>
<td>Net benefit of each reform option compared to the current system presented by increasing net benefit</td>
<td>60</td>
</tr>
<tr>
<td>23</td>
<td>Policy comparison – comparison of net benefits of Current System Plus and Water Shares</td>
<td>61</td>
</tr>
<tr>
<td>24</td>
<td>Stour overview</td>
<td>62</td>
</tr>
<tr>
<td>25</td>
<td>Comparison with previous analysis</td>
<td>63</td>
</tr>
<tr>
<td>26</td>
<td>Average annual benefit by sector</td>
<td>64</td>
</tr>
<tr>
<td>27</td>
<td>Example of investment prompted by environmental protection measures</td>
<td>65</td>
</tr>
<tr>
<td>28</td>
<td>The Hampshire Avon overview</td>
<td>66</td>
</tr>
<tr>
<td>29</td>
<td>Average annual benefit by sector</td>
<td>67</td>
</tr>
<tr>
<td>30</td>
<td>Licence reductions due to take back under the three policies</td>
<td>68</td>
</tr>
<tr>
<td>31</td>
<td>Example of PWS investment</td>
<td>68</td>
</tr>
<tr>
<td>32</td>
<td>The Cam and Ely Ouse overview</td>
<td>70</td>
</tr>
<tr>
<td>33</td>
<td>Comparison with previous analysis</td>
<td>71</td>
</tr>
<tr>
<td>34</td>
<td>Average annual benefit by sector</td>
<td>72</td>
</tr>
<tr>
<td>35</td>
<td>Average annual benefit by sector</td>
<td>72</td>
</tr>
<tr>
<td>36</td>
<td>Value of trading 2025 - 2050 in the Cam and Ely Ouse, by type of trade</td>
<td>75</td>
</tr>
<tr>
<td>37</td>
<td>Cumulative annual volume of permanent transfer trades</td>
<td>77</td>
</tr>
<tr>
<td>38</td>
<td>Summary of the value of allocation trades (undiscounted)</td>
<td>80</td>
</tr>
</tbody>
</table>
Figure 39: The value of allocation trades and summer rainfall
Figure 40: Volume weighted average trade price and summer rainfall
Figure 41: Summary of sensitivities carried out
Figure 42: Overview of sensitivity runs – policy comparison
Figure 43: The Stour sensitivity tests
Figure 44: The Hampshire Avon sensitivity tests
Figure 45: The Cam and Ely Ouse sensitivity tests
Figure 46: Example of how Daily Limit can constrain abstraction
Figure 47: Example of how Periodic Licensed Consumption can constrain abstraction (Current System Plus)
Figure 48: Example of how Periodic Licensed Consumption can constrain abstraction (Water Shares)
Figure 49: Example of how short term Flow Based Limits (HOFs - Current System Plus and 14-day Allocation – Water Shares) can constrain abstraction
Figure 50: Example of how water share group are distributed
Figure 51: Peer review prioritisation framework
Figure 52: Non-PWS Abstracting Sectors
Figure 53: Representation of the CatchMOD model components
Figure 54: Overview of the CatchMOD gridded model
Figure 55: Schematisation of the gridded hydrological model for a typical catchment
Figure 56: Development stages of CatchMOD hydrological models
Figure 57: Typical drying curve indicating how the parameters Dc and K are defined
Figure 58: Interaction between the hydrological model and ABM
Figure 59: Underlying modelling processes within an abstractor agent
Figure 60: Example of supply-demand balance projections in ML/day under the four socio-economic scenarios
Figure 61: Example of data accompanying each water resource management option
Figure 62: Relationship between catchments and water resource zones
Figure 63: Example of how water share group are distributed
Figure 64: Setting environmental abstraction limits and reformed licence conditions (source AMEC)
Figure 65: Significant breaches as defined in the modelling
Figure 66: Implementation of Soft HOFs
1 INTRODUCTION

1.1 Water abstraction is the process of removing water from sources like rivers, reservoirs, lakes and aquifers. Water abstraction is regulated in England and Wales through a system of licences. Anticipated pressures from climate change and population growth mean that the current licensing system is no longer considered fit for purpose.

1.2 The Government in England has committed to working closely with stakeholders to reform the abstraction system to promote economic growth while protecting the environment in a way that is fair, least cost and adaptable. The Welsh Government will consider the different options for reform in developing its Water Strategy.

1.3 An important part of the policy development process is to test the costs, benefits and risks of alternative policy options against the current regime.

1.4 Defra and the Welsh Government commissioned a team led by Risk Solutions to model the behaviour of abstractors and compare the alternative policy options. This report describes the modelling work carried out in support of the Consultation Impact Assessment published in November 2013, and work carried out subsequently to improve the modelling prior to planning work for the Final Impact Assessment.

Why reform is needed

1.5 England and Wales already face challenges in water availability. Many catchments have no spare water that can be allocated for further abstraction due to a need to protect the environment. Managing available water resources is likely to become more of a challenge in the future with an increasingly varied climate and increased demand for water from a growing population. The Environment Agency’s Case for Change shows that there are significant risks of less water being available in the future than today, and that this is unlikely to be limited to the south and east of England. As the severity of pressures on water resources may vary across England and Wales, as well as changing over time, the approach for managing them will need to be adaptive and flexible.

1.6 The current system for managing abstraction of water from rivers and aquifers was introduced in the 1960s. Most abstractors were given a licence to take a fixed volume of water, regardless of availability. The current system does not help abstractors to trade water effectively, nor does it provide an incentive for abstractors to manage water efficiently. Much of the water that is licensed is not actually used, but the regulator cannot make it available to others who may need it. The current process to change most licences that are causing damage to the environment is expensive and time consuming.

1.7 These weaknesses in the current system mean it could start to constrain economic growth and reduce the resilience of water supply; and that it does not protect the environment adequately.

The objectives of reform

1.8 The detailed objectives of reform build on the UK Government’s Water White Paper vision. If the Welsh Government takes the decision to move from the existing system to a reformed one, it is the general intention that principles in relation to this specific policy for Wales will be in the main aligned with UK Government policy in England. The objectives are to:

Promote economic growth

- Water availability is linked to water flows, taking into account discharges, to maximise water available to support economic growth
- Charges are made for actual water use to promote efficient use of water;
Trade is facilitated to maximise the economic value from available water, allow new entrants access to water and incentivise investment in infrastructure to deliver resilience to underpin economic growth in the face of future uncertainty.

The system for setting water availability over the short and long-term is transparent and provides reasonable certainty for abstractor business planning.

While protecting the environment:
- Water ecosystems are protected in line with legal requirements through linking water availability to water flows and reviewing water availability regulation over the longer term, taking into account discharges.
- Initial abstraction permissions on reform do not create risks of environmental deterioration.

1.9 Two broad options for reforming the system to achieve these aims have been defined. They are described in Chapter 2 of this report.

Aims of the modelling

1.10 An important part of the policy development process is to test the costs, benefits and risks of alternative reform options compared with continuing with the current regime. Modelling to explore this and support the Consultation Impact Assessment was carried out between February 2012 and September 2013 by a consortium comprising Risk Solutions, HR Wallingford, London Economics, Wilson Sherriff and Vivid Economics. Additional expertise was provided by Mott Macdonald, ADAS, Cranfield University, Simon Less Consulting, The Centre for Ecology and Hydrology, The British Geological Survey and Blackwell Water Consultancy. In addition AMEC worked with the Environment Agency to represent future abstraction permissions and regulatory conditions under the reform options and provided support reviewing early model outputs.

1.11 Following completion of the Consultation Impact Assessment, Defra, in consultation with the Welsh Government, commissioned a short programme of work (from the end of December 2013 to February 2014) to address some of the most significant outstanding issues, improve understanding of the results, and plan for additional work to inform the Final Impact Assessment.

1.12 The overall goal of the modelling is to examine how well the alternative policy options perform under different climate change and socio-economic scenarios and in a range of different types of catchment between 2025 and 2050 in terms of the objectives of reform. Our current focus has been on confirming the model is adequately capturing the many hydrological, behavioural and economic processes at work, and exploring the way the options are working at the abstractor level to support ongoing option development.

1.13 Both the modelling process (thinking through how each option should be represented in the model and how the various actors may respond) and examination of results emerging from the modelling, has informed the design of the reforms.

1.14 The work also forms a critical part of the evidence base for the consultation-stage and final policy Impact Assessments. To support this, information on impacts at national (Wales and England) levels is needed. This requires us to scale or aggregate results from the individual sample catchments to the national level. In addition a top down, economic model has been developed to provide further perspective on the modelling outputs.

About this report

1.15 This report describes the approach and presents the findings of the work. It is structured as follows:
- Section 2 describes the options as represented in the modelling.
- Section 3 provides an overview of the modelling approach.
- Section 4 describes the approach to the hydrological modelling.
• Section 5 describes the approach to the behavioural modelling
• Section 6 describes the aggregation and the top down modelling
• Section 7 sets out the findings of the work, and
• Section 8 presents our conclusions and recommendations

1.16 More detailed technical information is provided in the appendices to this report and the companion reports:
• HR Wallingford: The Impact of Abstraction Reform: Hydrological modelling
• London Economics/Risk Solutions: The Impact of Abstraction Reform: Non-PWS agent behaviour
• HR Wallingford: The Impact of Abstraction Reform: Public water supply operations
• Vivid Economics: The Impact of Abstraction Reform: A simple top down water abstraction economic model for England and Wales
• Risk Solutions: Abstraction licensing reform, Catchment reports
• Environment Agency and AMEC: Abstraction licensing reform: Preparing inputs for modelling.

1.17 A glossary of terms and abbreviations is provided at the end of the report. Terms identified in the glossary are highlighted by italics in the report.

**Acknowledgements**

1.18 We are very grateful for all the input, advice and enthusiasm provided by our project steering board (Defra, EA, Natural Resources Wales and the Welsh Government) and in particular:
• The Abstractor Reform Advisory Group (a list of members is provided in Appendix 1)
• Our Peer Review Group (a list of members is provided in Appendix 1), and
• All the abstractors and experts who have engaged with the project through workshops and interviews (see Appendix 2).
2 DESCRIPTION OF THE OPTIONS

2.1 This chapter introduces the three policy options examined through the modelling for the Consultation Impact Assessment. Some assumptions and simplifications were required to represent these in the models. These are described in Chapter 5 and Appendix 5. Thinking on the options continues to evolve as the consultation and impact assessment work continues.

Options for reform

2.2 The three policy options defined by Defra, EA, the Welsh Government and Natural Resources Wales for the purpose of modelling are:

- **Current System:** Continuing with the current system (CS), following changes to licences required to meet the requirements of the Habitats Directive Review of Consents (RoC), Water Framework Directive (WFD) and Restoring Sustainable Abstraction (RSA). The current system uses daily and annual abstraction limits and Hands Off Flows (HOFs) to control abstraction, maintain environmental protection and protect the rights of downstream abstractors. Licence trading is possible but uncommon and not dynamic enough to meet short term changes in demand. Charges are set to recover management costs and are not designed to react to water availability.

- **Current System Plus:** The Current System Plus (CSP) option aims to refine the current system to make it more flexible and support abstractors as they adapt to the impacts of climate change. The Current System Plus option retains annual and daily volumetric abstraction controls as well as HOF conditions where these are effective in controlling flow impacts. It aims to refine these tools to improve the link between water availability and abstraction in the short and long term and makes it easier for abstractors to trade or share water. In line with the other reform option, the more sophisticated aspects of this would only be used in ‘enhanced’ catchments where water was more scarce.

- **Water Shares:** The Water Shares (WS) option embeds the principle that abstractors have a share in the available water resource rather than an absolute allowance whatever the water resources available. This creates the potential to implement a more systematic approach to accounting and managing water in rivers to reflect the variability in their flows to:
  - make it possible to more closely and systematically link abstraction to river flows;
  - make shorter-term trading easier as amounts of water can be accounted for over short periods; and
  - make pre-approval of a wider range of types of trades possible due to the better accounting of water.

This system includes many of the changes proposed in Current System Plus, for example, moving from seasonal to availability-based conditions, separating and simplifying abstraction permission conditions, introducing usage charging more widely and introducing a more consistent way of changing abstraction conditions. It differs in the way that it links abstraction to availability for surface water by using a share based allocation system.

---

3 The No Go Below Flow limit (which by its design sometimes falls below the EFI) is currently used in all three policies considered including Current System. This could be considered to be part of the reform process itself (representing a move away from attempting to meet all WFD requirements and accepting that we are not prepared to pay to fix some environmental damage). However, Defra consider that this is inline with WFD requirements as EFIs are only an indicator and achieving good status is subject to tests such as disproportionate cost.
2.3 Both the Current System Plus and Water Shares options for river flow based reform are underpinned by a common proposed system of smarter groundwater regulation. This is designed to link annual abstraction limits to long term average recharge as well as promoting shorter term trading to optimise the development of storage where this is environmentally acceptable.

2.4 The thinking that underpinned these options is described in more detail below. All of the options apply to all abstractors wishing to take more than 20m$^3$ per day.

**Current System**

**Linking Abstraction to water availability**

2.5 As water has become scarcer, licences have been issued with progressively more restrictive conditions such as HOFs. These are specified river flows or levels at which abstraction must stop or reduce. Around a quarter of licences, generally those issued more recently, include conditions which crudely link the amount of water that can be taken to water availability.

2.6 Some licences are restricted to winter or summer use only. Winter use licences are generally to give access to high flows to fill reservoirs generally available in winter, while summer licences generally provide access to low flows for irrigation.

**Trading water**

2.7 Abstraction trading is possible but not straightforward or quick. Each individual trade is subject to 3 month approval procedures by the regulator and abstractors have to find willing trading partners independently. Short term trades are generally not feasible under standard procedures due to the slowness of the system. Trading is currently rare.

**Making licence changes**

2.8 Licences are generally changed if they are unsustainable. Demonstrating that a licence is unsustainable (removing more water than the environment is able to cope with) requires investigation. If required, permanent licences can be amended voluntarily under section 51 of the Water Resources Act (1991) or compulsorily under section 52, with compensation paid in some cases for resulting losses. Compensation is funded by the Environmental Improvement Unit Charge (EIUC), a tax on abstractors. Licence changes cannot be made until the full compensation amount has been collected. To keep the burden on abstractors down, this has to be collected over a number of years, and therefore licence changes can take years to fund.

2.9 New licences and licence variations have been time limited since 2001. These typically require renewal after 12 years. At the end of the time limit there is a presumption that the licence will be renewed unless the abstraction is damaging the environment, the abstractor no longer has a reasonable need for the water or is not using the water efficiently. Licences granted before 2001 are unlikely to be time limited and therefore not subject to the renewal process.

**Administrative approach**

2.10 The administration of this system is based on paper licences. Abstractors are informed of changes to their licences or HOFs by phone call, text or letter.

2.11 In the current system, abstractors are charged for the annual volume of their licence, with the exception of spray irrigators who can opt to use a two part tariff that includes a volumetric component. Generally the fixed price of abstraction is low (significantly below the value of the water to the abstractor) and varies according to the season and consumptiveness.

**Application to different catchments**

2.12 Under this option, the detailed implementation of the current system may vary according to local requirements and the different characteristics of catchments but there is no systematic approach to variation.
Current System Plus

Linking abstraction to water availability

2.13 Allowed abstraction would be linked to water availability more closely by:

- Replacing seasonal conditions with flow based conditions allowing, for instance, access to high flows at all times of the year;
- Allowing surface water abstractors to take additional water at the highest flows;
- Enhancing HOF conditions that apply to surface water abstractors so that abstraction controls are more gradually imposed;
- Introducing a regulatory minimum level at very low flows so that all abstraction is gradually restricted as flow levels approach this level with no abstraction being allowed when flows are lower than this level;
- Allowing licensed abstraction from groundwater to respond to long term changes in groundwater recharge.

Trading water

2.14 Low risk water trades would be pre-approved so some trades would be processed almost immediately. Due to the limitations of the current water accounting system, the majority of low risk trades that could be pre-approved would be temporary trades involving abstractors trading with other abstractors down stream of them. Pre-approved short term trading would also facilitate abstraction shifts towards groundwater sources well placed to develop storage and minimise environmental risks. The system would inform all abstractors which trades were pre-approved to facilitate trading.

Abstraction permission changes

2.15 All permissions to abstract would have the same status rather than some being permanent and others time-limited. None would be time limited but the regulator would be able to change any regulation settings if published environmental conditions are breached due to current abstraction regulation settings. Abstractors would be given notice of any such changes. Where changes are made and abstractors are given appropriate notice, abstractors would not be compensated for changes to the conditions that determine how much they can abstract. Improving the link between water availability and abstraction should reduce the likelihood of breaching environmental conditions. The regulator would maintain the right to intervene at any time should abstraction cause serious environmental damage. For modelling purposes, we have assumed that reviews take 6 years to decide on required action from being triggered and 6 years notice is given to abstractors before changes are implemented, effectively a 12 year period from identification of a risk of change being needed to implementation.

Administrative approach

2.16 Regulatory tools are split into three main elements. These are:

- Site-specific permits
- Catchment abstraction rules
- Water Account

2.17 Site specific permits are a pre-requisite for abstraction and include local conditions that apply to abstraction, for example, the requirement to have a certain type of fish screen on an abstraction point. They also detail the maximum daily abstraction limit possible from that site. These permits ensure that local sensitivities are not overlooked and allow conditions to be tailored to local requirements.

2.18 Catchment abstraction rules documents include conditions specific to the catchment, such as trading rules, standard HOF conditions and review conditions. Detailing the rules in one
place allows them to be applied transparently and consistently. It also makes trading easier and clarifies environmental requirements.

2.19 The **water account** details how much each abstractor can abstract over a set period, for example, over one year. Separating the periodic abstraction constraint from local conditions and catchment conditions enables water to be traded quicker and more simply.

2.20 Charging would be based on a combination of the size of the abstraction permission and actual use, and charges would more accurately reflect both how much water is returned to the environment (consumptiveness) and how reliable an abstraction permission is.

**Application to different catchments**

2.21 Where there are competing demands for water between abstractors and water ecosystems are sensitive, there will be a greater need to facilitate trading and regulate flows to protect the environment, both of which requires a more sophisticated and costly approach to abstraction regulation. This cannot be justified where there is no water availability challenge. To reflect this, we have split the reform option into universal components which will have to be in place regardless of type of catchment, and enhanced components, which will only be put in place where there are likely to be economic and/or environmental benefits. Hence some catchments will only have basic components whereas others will have enhanced components.

2.22 The main extra components in enhanced catchments are:

- Abstractors have access to additional high flow water;
- HOFS and the regulatory minimum level controls on abstraction are gradually implemented rather than being crude on/off mechanisms in basic catchments; and
- Pre-approval rules are developed to facilitate trading.

2.23 The first two of these components are implemented in all enhanced catchments, but pre-approval rules are only developed in catchments where there is a demand for trading.

2.24 In order to allow these enhanced components to function, abstractors in these catchments are required to have smart meters compatible with Environment Agency / Natural Resources Wales telemetry systems, which would be installed.

2.25 Over time, environmental conditions or levels of demand for trading may change, and decisions can be made to introduce enhanced components to catchments. For modelling purposes, catchments have been split into three groups; those only requiring the basic (universal) components over 25 years, those requiring all the enhanced components for the full 25 years and those which introduce enhanced components after 12 years. This classification is driven by levels of water availability under different climate change scenarios and estimated benefits from trading compared to the costs of introducing enhanced components. It is explained in Chapter 6.

**Water Shares**

**Linking abstraction to water availability**

2.26 This option links abstraction to availability for surface water by using a share based allocation system. The approach for groundwater is the same as for Current System Plus.

2.27 A share is a right to a percentage of the water available in the catchment. The actual volume of water is defined by an allocation in a given period, which sets out what that percentage allows you to abstract during that period. An abstractor may own a 10% share, which is 10% of the water available in that catchment. That 10% could provide 10,000m$^3$ in a wet period, but the allocation may be shrunk to 8,000m$^3$ or 6,000m$^3$ during a dry period where flows have dropped.

2.28 Allocations define how much water an abstractor can use during a fixed period of time and are uninterruptible. For the purposes of modelling the options, we have trialled fortnightly allocations. However we are aware that this may not be the right duration and that the appropriate duration may vary in different catchments.
2.29 Shares would be grouped by reliability. For example, more reliable shares allow abstraction at both lower and higher flows and less reliable shares allow abstraction only at higher flows. These groups of shares may allow abstractors to tailor their portfolio of shares so they can abstract at different flows as required.

2.30 Shares would be initially allocated based on previous water usage. The exact details of this process are to be finalised, but will comply with the transition principles set out in the ‘Policy Objective’ section.

2.31 By varying allocations, abstractors can take more when more is available and less when less is available. In this system, because the volume of water that can be abstracted is linked to the volume available shares would not be modified. Instead, fortnightly allocations will allow for responsive reductions or increases in abstraction to meet flows and environmental conditions.

**Trading Water**

2.32 Under this option it will be possible to pre-approve trades up stream as well as downstream due to the better water accounting. It will also be possible to facilitate short-term trading during the period of allocation. So a wider range of trades will be possible to complete with low transaction costs than with the current system or Current System Plus. Because the long term right to a proportion of water is separated from the short term right to abstract a specific volume of water, abstractors can make short term trades by trading in allocations, or by transferring water through ‘put and take’ trading (putting water into a river from a reservoir or other storage mechanism to be taken out further downstream) without impacting their long term entitlements. There will then be a market in both short-term allocations and in long-term shares.

**Making changes to abstraction permissions**

2.33 This will happen through a review system in a very similar way to Current System Plus although required changes would be to rules for setting allocations rather than licences. As there is better linkage between flows and abstraction in this option, changes through this system should be less required than under Current System Plus.

**Administrative approach**

2.34 Under Water Shares, regulatory tools are split into the same three main elements as for Current System Plus. These are:
- Site-specific permits
- Catchment abstraction rules
- Water Accounts

2.35 Water accounts would include periodic allocations and shares. Catchment rules would set out how allocations are determined.

2.36 Charging would be based on a combination of the size of the shareholding and actual use, and charges would more accurately reflect both how much water is returned to the environment (consumptiveness) and how reliable an abstraction shareholding is in a similar way to Current System Plus.

**Application to different catchments**

2.37 As with Current System Plus, Water Shares can be implemented in a more or less sophisticated way depending on demand for trading and the environmental sensitivity of catchments. There are a wide range of potential designs in terms of, for instance, the periods for allocation and the pre-approval of different types of trades. For the purposes of modelling, we have assumed two versions as with Current System Plus, basic and enhanced. In the enhanced version:
- Allocations are more closely linked to flows; and
- Pre-approved trading rules are developed.
2.38 The first of these components are implemented in all enhanced catchments, but pre-approval rules are only developed in catchments where there is a demand for trading.

2.39 As with Current System Plus, in order to allow these enhanced components to function, abstractors in these catchments will need to have smart meters compatible with Environment Agency / Natural Resources Wales telemetry systems which would be installed.

2.40 Over time, environmental conditions or levels of demand for trading may change and as with Current System Plus, decisions can be made to introduce enhanced components to catchments and the same approach to classification of catchments has been taken as for Current System Plus.

**Moving to any new system**

2.41 A number of different approaches to changing licences to make them compatible with a reformed system have been considered. The volume, price and reliability of water allocated to abstractors in a new system would take account of current licences and the actual volumes of water used, but volumes would vary according to overall water availability. A key objective is to make sure licences are changed in a way that ensures reform itself does not inadvertently lead to environmental deterioration.

Environment Agency statistics show that, on average, between 2002 and 2011 only 45% of the annual total of water licensed for abstractions in England and Wales was actually abstracted. This means that in some catchments, if all this unused water was actually abstracted, there could be significant deterioration of the environment. Reform itself increases this risk as easier trading could lead to abstractors selling their unused volumes to others who would then actually abstract them. In catchments that are already fully licensed, even if all the water is not used, no further licences can be given to new abstractors, or existing abstractors who need more water.

2.42 This is why under reform it is proposed to reduce unused volumes of water as licences are moved into a new system. A number of broad options are under consideration for calculating volumes to transition into the new system, including those that apply universally to all abstractors and those that could be tailored to catchments.

2.43 For modelling purposes, in the catchments enhanced to facilitate trading abstractors have received an initial amount based on recent average use, assessed over the last 6 years, plus 20 per cent of their licensed amount capped by licence volume. More detail about the assumptions we have made about transition for modelling purposes are described in Chapter 5, Appendix 5 and the companion report: Environment Agency / AMEC: Abstraction licensing reform, Establishing reformed licence conditions and environmental abstraction limits.

2.44 In the next phase of modelling, we will be revising these assumptions based on the consultation options and response and the findings emerging from the modelling.
3 OVERVIEW OF THE MODELLING APPROACH

3.1 We have used detailed agent-based economic modelling of a range of case study catchments, introduced below, to explore the costs, benefits and risks of the different reform options when compared with retaining the current system.

3.2 For each catchment we developed a fully integrated hydrological and abstractor behaviour model. The model estimates the overall cost benefit of each reform option from implementation in 2025 to the end of the modelling period in 2050. It also allows us to explore in detail the impact on different types of abstractors and the environment and to understand where each reform option performs well, where less well and why. It therefore supports detailed design of the options.

3.3 The results for the catchments have then been aggregated and scaled up to provide an indication of costs and benefits for England and separately Wales.

3.4 This chapter provides an overview of the approach. Further details can be found in the following chapters, appendices and supporting documents referenced throughout the section.

Case study modelling

Case study catchments

3.5 Seven case study catchments were initially selected. These were:

- The Kent Stour
- The Tees
- The Cam and Ely Ouse
- The Dee
- The Usk
- The Hampshire Avon.
- The Trent and Derwent (this covers seven separate Catchment Abstraction Management Strategy (CAMS) areas)

3.6 They are shown in Figure 1. Descriptions of the modelled catchments are provided in Appendix 3.

3.7 They were carefully chosen, in discussion with Defra, the Welsh Government, Environment Agency, Natural Resources Wales, ARAG and abstractor representatives.

3.8 The aim was to cover as many different local conditions relevant to abstraction and abstraction reform as possible, while trying to ensure that the modelling is not too complex. So, for example the River Thames catchment draining to Teddington in London covers an area of some 10,000 km² and has a population of around 13 million. This was a potential candidate for a large, complex catchment but is heavily dominated by public water supply in terms of volume of water abstracted. It was felt that the Trent and Derwent would make a more interesting large, complex catchment case study owing to the fact that there are a wider range of industries and a higher number of agriculture abstractions.

After an initial round of modelling and consultations it was decided, in discussion with the Project Steering Board, to focus on four catchments where there were significant water availability challenges and the modelling was tractable in the timescales available for the Consultation Impact Assessment. Modelling of the Tees, Dee and Trent and Derwent was therefore stopped at this stage, although work on the Trent and Derwent will continue to support the Final Impact Assessment. The Trent and Derwent catchment is considered important because it is the only catchment that has a significant power generation presence. The Trent and Derwent also includes sub-catchments that are more surface water dominated, which is particularly helpful for characterising catchments in Wales and significant parts of northern and southwest England. To make best use of the time available, the decision was taken to suspend modelling of the Dee and focus on those sub-catchments of the Trent and
Derwent that will provide representative outputs for Wales, and the Southwest and Northwest parts of England.

3.9 Reform, the decision was taken to suspend modelling of the Dee for the present to make best use of the limited time available for further modelling.

3.10 It is important to note that we are not trying to accurately model the catchments or precisely predict people’s behaviour, but to create a varied landscape that will test the options under a wide range of situations.

**Figure 1: Case study catchments**
The integrated hydrological – abstractor behaviour model

3.11 For each case study catchment the hydrological model is used to estimate naturalised behaviour of the surface and ground water systems and the impact of abstractions and discharges on these over time. Further details of the hydrological modelling are provided in Chapter 4 and Appendix 4. Information on river flows and groundwater levels is then passed, on a daily basis, from the hydrological model to the abstractor behaviour model.

3.12 The abstractor behaviour model (ABM) estimates both Public Water Supply (PWS) and non-PWS abstractors’ demand requirements, and determines their behaviour taking into account the information received from the hydrological model. It determines abstraction and return flows, and passes this information back to the hydrological model.

3.13 In the model abstractors are represented as agents. In addition to day to day operational decision making (for example, whether to irrigate crops or from which source to abstract water to serve PWS customers) the model also determines agents’ longer term decision making. This may include for example a decision to stop producing a particular product or to invest in water. At each step the model establishes the costs to agents associated with water abstraction and investment decisions.

3.14 In this way the integrated model helps us establish a comprehensive picture of how abstractors are expected to respond to the challenges and opportunities presented by increased water availability challenges and water abstraction reform. It allows a picture to be built up of the anticipated impacts (benefits, costs and risks) of both the reforms and retention of the current system.

3.15 Further details of the agent-based behavioural modelling are provided in Chapter 5 and Appendix 5.

Model outputs

3.16 The ABM model generates detailed outputs at the individual agent level as a time history, including:

- Target production levels and actual achieved production levels for each of the agent’s products (there are 38 main product types modelled in total)
- Income, costs and profits from production
- Volume of water traded, number of trades, type of trade, and the income and costs from trading
- Licensed volumes and period allocations
- Actual water use from each of its available abstraction sources, from stores and from the public water supply
- Level of water available in stores
- Investments made (farmers building new storage, PWS implementing options from its WRMP, etc.)

3.17 These outputs are also aggregated at the product level, sector level and catchment level so that for example we can see the level of trading between sectors, the economic value created as different products are produced over time, and the investments made.

3.18 In addition, the model generates environmental outputs, including:

- Number of significant breaches of environmental limits
- Number of water bodies in breach at any moment in time
- Licensed volume taken back by the Environment Agency or Natural Resources Wales in order to recover from the breaches
- Volume of water required for other environmental purposes such as stream support and level management.
Developing the model

Modelling the hydrology
3.19 We have based our hydrological modelling on the existing CatchMOD model, which is used widely by the Environment Agency and by a number of water companies for water resources modelling. Each catchment model splits the catchment up into a rectangular mesh or ‘grid’. The size of the grid used in the hydrological model is flexible but for these catchments we have used a 1km by 1km grid. Each abstraction or discharge point represented in the ABM is located within the relevant grid cell. River flows and groundwater levels in each cell are passed to the ABM on a daily basis.

3.20 The existing CatchMOD approach to groundwater has been improved to enable estimation of the spatial distribution of groundwater abstractions on river flows to be accommodated using information already held within EA and Natural Resources Wales’ Water Resources GIS (WRGIS) and CAMSLedgers. It is recognised however that this is very much an approximation (see below).

Modelling abstractor behaviours
3.21 Information on who abstracts water, and how much, is available from a number of sources. The EA and Natural Resources Wales hold information about all live abstraction licences held in England and Wales. This includes maximum annual and maximum daily abstraction limits. This database provides an indication of the purpose or purposes for which the water is abstracted and the location of the abstraction point or points associated with the licence. Details of actual abstractions (volumes, location and discharges) are recorded in the CAMSLedgers also kept by the EA and Natural Resources Wales.

3.22 While these data sources provide information on the actual levels of licensed abstractions throughout the year, they do not tell us anything about how abstractors use water, nor how they might respond to the reforms and the challenges of decreasing water availability. Nor can it tell us about abstractors who are currently exempt from the licensing requirements.

3.23 Engagement with real abstractors, and with abstractor representatives, was therefore crucial, helping us understand the challenges abstractors face, what drives decision making around water in their industry, and how they might respond to new constraints and opportunities. At the same time we were conscious that the way we react to change when it is a potential future option, and what we do when presented with actual change, can differ markedly. So we supplemented information gathered from workshops and one to one consultations, with information from experts, from the behavioural literature and about responses to similar changes in the UK and overseas. Information about product prices and production costs and supply and demand were required to establish the context within which decisions about water are made. These were sourced from data sources such as business surveys, market reports and manuals, as well as the consultations.

3.24 This information helped us structure the ABM and parameterise it to provide a reasonable representation of how agents might behave in real life given changes in water availability, price and other economic and behavioural drivers.

3.25 The full list of consultations carried out is provided in Appendix 2 and further information on data sources is provided in the chapters and appendices dealing with the different aspects of the modelling.

Modelling the options
3.26 We have modelled the policy options as constraints and rules within which the abstractor agents are allowed to operate. Where behaviours are not proscribed by the rules, they can occur in the modelling. In this way the model is able to explore the potential for unpredicted emergent behaviour. Further, where possible, we have designed the underlying policy options in generic terms, with the specific policies (for both the current system and the reform options)
being determined by data inputs. This means that it is easier to change key aspects of the options and see how this affects the results.

3.27 More specific detail is provided in Chapter 5 and Appendix 5.

3.28 The process of determining how to model the options has been iterative with model development and options development proceeding in parallel. The process has prompted a more structured and systematic approach to thinking about how various aspects of the options would play out in real life, than might otherwise have been possible.

Modelling the future

3.29 We wish to model the costs, benefits and risks of the policy options from 2025 to 2050. However, we cannot know how the future will unfold. In these situations we use scenario analysis to explore how the options would perform under a range of possible futures. This involves defining a range of possible future scenarios that we believe will scope the full range of likely futures, and then carrying out model runs for each of these scenarios. Key sources of future uncertainty are climate and socio-economic change.

3.30 We agreed, in discussion with the project board to use the same four climate and four socio-economic scenarios that were used in the EA Case for Change analysis. These were:

- Four climate change scenarios selected from a national assessment of seasonal changes in river flows and groundwater levels for the 2050s. These are designated:
  - Scenario A - minimal change in flows
  - Scenarios C, G and J, greater changes in flows at different locations.
- Four socio-economic scenarios referred to as:
  - Sustainable behaviour
  - Local resilience
  - Innovation, and
  - Uncontrolled demand

3.31 These scenarios are described in more detail in Chapter 5.

Model testing, validation and sensitivity analysis

3.32 Validation of models of this type is very difficult. Apart from in some very limited areas, we cannot test its outputs against real world outcomes. We have adopted, as far as we can, the approach recommended by Nick Taylor of Reading University. This establishes the following principles for validating complex models:

1. **Valid models should make technical sense** – subject matter experts should be satisfied that the conceptual framework is supported by, and model outputs can be explained in terms of, the current state of knowledge. (This is not to say that unexpected results automatically invalidate a model. It may be possible to interpret current knowledge in different ways and an unexpected model result may lead to novel interpretations of current knowledge.)

2. **Valid models should be able to reproduce recorded reality** – however the fact that a model reproduces a recorded reality does not necessarily prove validity. A model may contain internal errors within the conceptual framework which compensate, cancelling out the errors in a particular situation. This makes the checking of the conceptual framework of the model mentioned above essential.

3. **Valid models should be fit for the use they are designed for** – Decision makers and subject matter experts should jointly assess what information is critical in the decision to be taken. The utility of the model then depends on how well it can provide that

---

4 Taylor, N., 2003: Review of the use of models in informing disease control policy development and adjustment. VEERU report for Defra, School of Agriculture, Policy and Development, University of Reading
information. If components of a model have little influence on the outputs of the model which are critical to the decision then the model is still useful and therefore 'valid' if these components are not developed to a high degree of detail. Sensitivity analysis is the process by which the influence of model components on the final outcomes (in terms of information provided for decision making) should be judged. Taylor considers this criterion the most important of the three.

3.33 We have applied this approach as described below. It is important to note that this process is ongoing. Delays in obtaining data and the complexity of the modelling required have meant that we have been unable to apply a number of steps of the validation process as we would have liked to. We therefore continue to subject the models to sensitivity testing and internal and external scrutiny to ensure that they are providing robust information for decision makers.

**Technical sense**

3.34 The technical sense has been assured as follows:

- The model structure, inputs and intermediate outputs, (both from the hydrological model and ABM) have been, and continue to be, exposed for sense checking at regular intervals to academic expert peer reviewers, ARAG members, experts from other stakeholder organisations and from Defra, EA, the Welsh Government and Natural resources Wales, and actual abstractors. Membership of the various groups providing input and oversight of the project is given in Appendix 1.

- The hydrological models have been developed using conceptual models that are widely used in practice by the Environment Agency, consultants and water companies. The approach has been peer reviewed and where weaknesses have been identified the team worked with peer reviewers to improve the models.

- The behavioural model models behaviours under circumstances that it will be hard to test directly in a meaningful manner with abstractors. We are therefore drawing on the behavioural economics literature where that can provide useful insights.

**Testing against experience**

3.35 In this project, we are exploring possible futures, in which much behaviour and interaction could be considerably different from any recorded reality observed so far. However, some tests are possible. For example, the combined hydrological model and agent-based model has been calibrated and checked against actual flow statistics, as recorded in the CAMSledger and a summary of actual flows over a long time period (18 to 30 years). This has provided a check that average abstractions and discharges are correctly modelled. The process is reported in the hydrological modelling companion report.

3.36 The most challenging aspect to test against actual experience is the agent-based modelling because it aims to describe future behaviour in situations with which abstractors are not familiar. Stakeholders may not find these situations plausible (let alone the actual model), which makes testing quite difficult. We have however shown that the agent-based rules developed can produce plausible simulations of current behaviour and sensible outputs, for example:

- We can see farming agents abstracting and irrigating more as soil moisture levels reduce
- The prices agents are willing to pay for water are sensible, i.e. they are comparable with the prices paid for PWS supply and higher margin agents are willing to pay higher prices
- Agents choose to use less reliable water first when it is available in order to retain higher reliability water for times of shortage
- Agents place higher value on water that is more reliable
- Agents move towards those products that generate greater profits as product prices and water costs change
• Water moves towards those sectors that value water more highly and water uses that add the most economic value
• PWS agents make use of low water prices to delay investment activities
• PWS agents make use of high water prices to help fund investment activities.

3.37 We have also tested emerging results from one of the more complex catchments (the Cam and Ely Ouse) with representatives from the catchment and they confirm that the patterns of behaviour look plausible.

Fitness for purpose

3.38 In order to ensure that the model is fit for purpose the model structure and outputs have been developed in consultation with the project board, Peer Reviewers and ARAG, and with the team developing the options. This has helped ensure that differences between the three policy options are adequately captured in the models as far as this is possible

3.39 We have carried out sensitivity analyses to help ensure that simplifications and assumptions are understood and that the modelling remains fit for purpose. The main simplifications are discussed at the end of this chapter.

Aggregation

The aggregation model

3.40 The Integrated ABM models in detail the impact of the three policy options in a selection of catchments. It assumes that each option is implemented on day 1 of the reforms in each catchment. The Consultation Impact Assessment requires information on costs, benefits and risks at a national (England and Wales) level. Aggregation, therefore, presents us with two challenges:
• While some elements of reform would be implemented over the whole country (England or Wales) on day 1, many substantive elements will not. These will only be implemented, as described in Chapter 2 above, when there are clear benefits from doing so. About half of the catchments in England and Wales are expected to meet the conditions for full implementation of any reform, and many of these will not do so on day 1.
• We needed to develop a meaningful way of scaling from a few catchments to the whole country.

3.41 We have therefore developed a spreadsheet-based aggregation model, which reads in ABM outputs and scales up the results for all catchments in England and separately Wales using an appropriate scaling method depending on the type of output. It is designed to explore whether the benefits of full (enhanced) implementation in only a proportion of catchments, outweighs the broader costs associated with minimum (basic) implementation nationally. It produces outputs that can be copied straight into the Government’s Impact Assessment calculation template.

3.42 The aggregation model produces two main outputs:
• Yearly net costs and benefits from 2025 to 2050 for England and separately for Wales, calculated as the sum of the costs and benefits from each of the 116 catchments depending on whether each is categorised as a Basic or an Enhanced catchment
• The total number of catchments that are classified as Basic or Enhanced

3.43 The model can also produce sectoral totals to highlight whether there are any major distributional effects in the overall cost benefit case

3.44 The approach is described in Chapter 6.
Validating the aggregation model

3.45 The scaling proposed for the aggregation modelling is very much a simplification and validating the model will be very difficult. To provide a basis for comparison, a simple top down economic model has been produced by Vivid Economics.

3.46 This model addresses three questions. These are:

- How would a system that optimises the allocation of water use through trading affect the distribution of water in the future, compared to a scenario in which there is no trading?
- What is the scale of economic benefit of allowing trading?
- How sensitive are the benefits of trading to climate scenarios, specifically patterns of low rainfall?

3.47 The top down model cannot take into account the hydrology in a catchment, which affects for example who can trade with whom, and cannot differentiate between the two different reform options (Current System Plus and Water Shares. Because it assumes that all abstractors in a catchment can potentially trade with all others, it will over-estimate the benefits from trading. However, the thinking that has gone into the design of the model has helped inform thinking around aggregation (and vice versa). Inputs to this model, such as how abstractors value water, are intermediate outputs from the Integrated ABM, and this therefore provides another interesting point of comparison.

Key assumptions and simplifications

3.48 Abstraction reform is complex and the modelling described here presents unique challenges. It involves integration of hydrological models (complicated systems in their own right) with a bespoke abstractor behaviour model (ABM).

3.49 Catchments are generally large areas (from 1000 to over 8000km²), with a large number of abstractors. This means the models are necessarily large with implications for run time, and the data sets required to parameterise them.

3.50 The ABM has been designed to capture the behaviour of a wide range of different types of abstractor, with different requirements for water and different capacities to respond effectively to changing water availability and the abstraction reforms.

3.51 We cannot characterise the catchment and abstractors exactly as they are in real life. It is necessary to simplify.

3.52 Key areas where simplifying assumptions have been made are described below. Where we believe the simplifications may have a significant impact on the results (the relative performance of the different options) we have carried out sensitivity tests. These are described in Chapter 7.

3.53 This process of developing the model is ongoing. Following completion of the Consultation Impact Assessment, Defra, in consultation with Welsh Government, commissioned a short programme of work (from the end of December 2013 to February 2014) to address some of the most significant outstanding issues, improve understanding of the results, and plan for additional work to inform the Final Impact Assessment. We have highlighted below areas where we have developed the modelling further. These developments are described in Chapter 7.

Hydrological modelling

3.54 The representation of groundwater in the models has had to be significantly simplified. Groundwater is considered as a lumped model for each groundwater response area (see Chapter 4). A lumped model is one that does not consider any spatial variability across the area being modelled. The simplified approach to groundwater modelling in the hydrological models means that:
3.55 These simplifications may result in an underestimate of the role which groundwater storage could play in supporting supply during low flow periods but were not expected to affect the comparative assessment of abstraction reform options. Further analysis revealed a concern that the simplifications in groundwater modelling could be contributing to the appearance that environmental protection measures have little impact. This was therefore highlighted as an area where further investigation was required for the Final Impact Assessment.

3.56 Inter-catchment transfers of water by the PWS are modelled, where these connections exist already or where they are listed as possible future options in Water Resource Management Plans, but with a number of simplifications. In particular transfer rates are limited by the capacity of the infrastructure but we assume that water will always be available when required. In reality, regional droughts affecting neighbouring catchments may result in unavailability of some PWS transfer options.

**Behavioural modelling and decision making**

**Characterising agents**

3.57 It was of course not possible to model every agent in each catchment precisely. We could not fully represent the complexity of their production processes or accurately model the economics of their operations. Instead we made a number of simplifying assumptions. For example, we identified a series of generic products or services in each sector and assumed production was confined to these. Further we had to impute the levels of current production of these products from estimates of the amount of water required per unit of production and the amount of water currently abstracted by each agent. We also had to impute the location and nature of agricultural businesses that may become abstractors in the future. While these are major simplifications it has provided us with a rich mixture of different type of abstractor, delivering different products or services with different requirements for water and different levels of price sensitivity, thereby providing us with a suitable test bed for the options. We found that results in some catchments and scenarios can be sensitive to decisions made by a small number of economically significant agents relating to changes in production that are not directly related to water. This was therefore identified as an important area for additional investigation.

**Non-Public Water Supply agent decisions**

3.58 We assume that non-Public Water Supply (non-PWS) agents must accept the market price for their output (i.e. they are price takers). That is, there is no dependency between the amount of output an agent produces and the unit price of their output (so they can increase or decrease production without affecting the price). This means, for example, that if an individual agent experiences an increase in input costs that is specific to them they cannot pass this on to their customers through an increase in prices. Note however, that if there are general increases in input costs that are experienced by all non-PWS agents in a particular sector, then this will cause prices in those final product markets to rise.

**PWS long term (investment) decision making**

3.59 Over the modelling period to 2050, our PWS agents take decisions about how to invest in water resource management schemes in a way that is intended to broadly follow the approach that water companies in England and Wales are currently required to take in their Water Resource Management Plans (WRMPs). At a workshop with the water industry in January
2013 there was broad acceptance that this was a sensible approach given that there was no way of knowing now how companies might be required to take these decisions in future.

3.60 The main difference between our modelled approach and the approach the companies actually undertake is that the companies are required to undertake a Strategic Environmental Assessment (SEA) of options chosen for potential implementation. We do not model this process. We note however that we use company options from the feasible options list and in many cases these have already been screened for environmental impacts, though we recognise that this is not the same as a full SEA.

3.61 Also PWS investment strategies are typically focused around Water Resource Zones (WRZs), the regions within which PWS companies manage their water resources. While we model PWS decisions at the WRZ level, we need to incorporate these outcomes into our catchment level models as the latter define the principal regions in which trading of water abstraction rights can occur. WRZs generally do not correspond with catchments. We have therefore had to scale PWS abstractor responses within the WRZs to represent the overall impact in the associated catchments.

3.62 One aspect of PWS investment decision making that is not currently included in the modelling is the tendency for large scale investment options (such as desalination) not to be implemented on the timescales suggested by water company plans, but to be pushed back at each new planning cycle as additional lower cost options are identified.

3.63 We find that significant benefits accrue from PWS companies being able to delay large scale investments under the reform in some catchments and scenarios, but as the remaining options tend to become large and more expensive the actual benefits realised can be sensitive to small changes in sequencing and timing. The impact of the emergence of smaller (and lower cost) options is an important area to explore in the next phase of work.

3.64 It will also be important to consider the treatment of deployable output. Policy options that constrain access to water at very low flows when not in drought conditions may affect the calculation of PWS deployable outputs and hence their investment decisions. This will be investigated as part of the next stage of policy development and assessment.

Modelling the options

Modelling trading

3.65 The trading mechanism needs to work in policy scenarios that involve a number of trading units in the catchment. A trading unit is a geographic region (based on a river reach or aquifer) within which low risk trading may be allowed, depending on pre-approval rules applied to determine the environmental acceptability of individual trades. Buyers and sellers have different restrictions placed upon them as to which trading units they can operate in. Thus there are in effect a number of sub-markets that all interact with each other.

3.66 For the Consultation Impact Assessment we focused for the ABM on developing a trading mechanism that ensures that the highest bidders get first choice in the markets, and choose to buy from the trading unit that offers the lowest price for the water they need. Overall this approach will attempt to maximise the value of trades. The mechanism has not been tested using economic experiments or other methods.

3.67 We have assumed that the trading mechanism does not introduce any barriers to trading, other than a value for transaction costs, and in modelling the outcome of trading we have assumed that there is no collusion in the market, or any anti-competitive practices.

3.68 We have not implemented all the trading mechanisms that would be available under the options. Mechanisms excluded for the Consultation Impact Assessment included:

- Water release (also called put and take) trading. This is the trading of physical releases of water from one agent to another further downstream (or within a level managed area)
- Trades that would not meet pre-approved trade criteria (since assessing the circumstances of more complex trades is beyond the scope of the model)
• Surface water to ground water trades.

3.69 Because of this, and because of an inherent bias against the trading of shares that we have identified in the complex interactions between agents and their assessment of water reliability, we believe that the modelling carried out for the Consultation Impact Assessment model was under-reporting the levels of trading that might be expected, particularly under Water Shares. This was therefore identified as a key element to tackle in the on-going work. The current model includes an improved representation of trading, however water release trading and secondary markets are not modelled.

Evolving environmental limits

3.70 For the purposes of modelling for the Consultation IA we assumed that to prevent environmental deterioration the quantity of water reserved for the environment in 2025 is maintained for the entire modelling period to 2050. This is a simplification of a more complex process. In reality environmental standards could need to be adjusted as water ecosystems adapt to a changing climate. This was identified as a priority to address for the Final Impact Assessment.

Modelling transition

3.71 Some simple assumptions have had to be made to model the transition from historic (1992 to 2010) to projected climate scenarios (2025-50). This, alongside other issues (such as groundwater impacts, other transition assumptions, evolving environmental limits, and the modelling of the environmental protection measures), is probably resulting in a more severe transitional change in water scarcity than would in reality occur, or would be apparent within each climate projection.

Aggregation modelling

3.72 We recognise that the scaling to national level can provide only a broad brush estimate of costs and benefits because only a small number of detailed catchment models are available as a basis for scaling and catchments have very different abstracter profiles and hydrological properties.

3.73 The basic assumption at the heart of the aggregation modelling is that the benefit of reform in each catchment across England and Wales can be estimated from the benefits calculated for each case study catchment on the basis of the amount of water abstracted and the mix of sectors present in each sector. In reality a large number of other factors will affect the level of benefits.

3.74 It is difficult to test the validity of this assumption but it is perhaps less likely to be valid in Wales and the northwest and southwest of England where the hydrological profile of the catchments can be very different to the profile in other parts of England.

3.75 Another challenge for scaling in the aggregation is the dependence of some catchment outcomes on a few PWS decisions. The inclusion of the Trent and Derwent and consideration of alternative approaches to aggregation will be important for the Final Impact Assessment.

Top down modelling

3.76 The top down model is designed to be very simple. The most significant simplification is the lack of consideration of hydrology in the model. In water resources, spatial relationships are very important, but they also bring complexity. So for this simple model, most of the richness of hydrological and spatial relationships has had to be put aside. All trades between abstractors are allowed within single catchments in the model. This will significantly overstate the trades that would naturally be allowed in practice and therefore the benefits of reform. It also treats all trades as if they were licence transfers, so is not able to distinguish between the different types of trades possible under the Current System and the two reform options.
Interpreting results

3.77 Simplification has been necessary as described above. However it is important to remember the aims of this work. We are not trying to accurately reproduce catchment and abstractors' behaviour, but to understand how different potential abstraction reforms will operate in practice and the impacts they might have, to inform the design of the new system. This means that, for example, detailed modelling of all aspects of the hydrogeology is not necessary, provided the main features of the system that will drive abstraction behaviours are captured.

3.78 The fundamental challenge has therefore been to ensure that the principal drivers are identified and represented appropriately within the model and that the impact of the remaining assumptions and uncertainties are explored either through uncertainty and sensitivity analysis, or when interpreting the results.

Why adopt this approach?

3.79 While the abstraction reforms proposed are not complex, the system that they affect is, and the level of benefits will be critically dependent on local characteristics of the catchments including the local hydrology (which determines for example who can trade with whom) and the characteristics of the abstractors (which determines who will trade with whom). Further, the determination of the level of benefit must take account of complex interactions and feedbacks between the hydrology, weather, the licensing regime and abstractor behaviour and between agents.

3.80 Traditional top down economic modelling struggles to deliver meaningful conclusions in these situations because it is difficult to represent the complex interactions. It is also difficult to model differences between options that arise, for example, due to differences in the detail of implementation.

3.81 Agent-based modelling has emerged as a key methodology for developing understanding of the interactions between people and their environment in situations such as these. Drawing on techniques from social sciences and ecological modelling, agent-based modelling allows the investigation of several key issues including: the effects of policy on decision-making, the impact of heterogeneity for example of agents, and feedbacks between agents such as learning, imitation and communication; and feedbacks between environmental change and agent actions. Further, agent-based modelling is a bottom up approach that allows more specific local arrangements, rules and complexities to be incorporated (such as local hydrology, real licence conditions and production/process specific requirements).

3.82 The ABM is an agent-based model designed to estimate the performance of each policy option based on the sum of responses of different agents (abstractors) interacting together, each with their own motivations and approach to decision making. This ‘bottom-up’ approach has many advantages over other, simpler approaches. Perhaps the four most significant advantages of this approach in the current application are that it helps us to:

- Identify unanticipated behaviours that emerge from the interactions of the many different elements that make up the water abstraction system
- Simulate decision making processes that are much closer to real life
- Differentiate meaningfully between reform options that only differ at the level of detailed design, and provide input to the design
- Explore findings from a range of different perspectives.

Identifying emergent behaviours

3.83 By simulating the simultaneous operations and interactions of multiple agents with the different policy options within changing climate and socio-economic conditions, the ABM is able to

---

5 Conference IALE, Changing European Landscapes, September 2013
model complex systems behaviours that may emerge when many individual elements of a system interact together following relatively simple rules. This emergent system behaviour may lead to unanticipated impacts (both good and bad).

**Simulating real-life decision making processes**

3.8.4 In the ABM non-Public Water Sector agents are not represented as purely profit maximising, in the same way as they might be in a traditional economic model. Agents do not take decisions (such as determining their output level) in order to generate the maximum theoretically feasible level of profit. Although agents do take expected profit into account in their decisions, many agents act in a variety of ‘sub-optimal’ ways identified from the behavioural economics literature and through our consultations. For example:

- Agents use ‘rules of thumb’ to specify the range of production levels and the investment options that they will consider
- They exhibit delays in their decision making (compared to optimum timing of decisions), for example in the timing of their investment decisions.
- Some agents imitate their peers rather than calculating their own optimum strategies
- *Satisficing behaviour* (this is where people target satisfactory profits rather than maximum profits) is reflected in the behaviour of some agents
- Agents’ decision making may change depending on their recent experience.

**Modelling the options**

3.8.5 The construction of the ABM has involved an ongoing dialogue between the team designing the options and the modellers. This has served two purposes:

1. It has helped ensure that the key differences in the options are captured in the model – the mechanistic modelling of interactions at individual abstractor and time step level makes this possible, and
2. It has imposed a level of discipline, and depth of quality, in thinking about how the options will work in practice at the individual abstractor level, that it would be hard to replicate in any other way.

**Exploring findings from a range of perspectives**

3.8.6 Different stakeholders will have different interests and will raise different questions about reform. Many of these can be explored within the model and illustrated using narratives derived from the model – this is a great benefit of this type of approach.
4 THE HYDROLOGICAL MODEL

4.1 This chapter introduces the hydrological modelling. A detailed description of the hydrological modelling approach is provided in Appendix 4 and in the companion report: The Impact of Abstraction Reform: Hydrological modelling.

Requirements of the hydrological model

4.2 The hydrological model provides estimates of river flows and groundwater levels based on climatic input variables (i.e. precipitation, and potential evapotranspiration (PE)) at each time-step. These are ‘passed’ to the abstractor behaviour model (ABM). The ABM then calculates the abstractions and returns made by abstractors (taking into account their licence conditions\(^6\)), and additional factors such as:

- River regulation
- Impounding storage, and
- Transfers (both into and out of the catchment).

4.3 The total impact of these abstractions and returns are then fed back to the hydrological model so that it can calculate the hydrological position for the next time-step. The ABM can also feed back other factors that affect the hydrology. For example the types of crops grown can have a significant influence on the conversion of potential to actual evapotranspiration, and different socio-economic and climate change scenarios will favour different land uses.

Implementation of the modelling framework

4.4 We have used a semi-distributed (‘gridded’) hydrological modelling framework based on the existing CatchMOD model\(^7\), which is used widely by the Environment Agency in their Southern, Thames and North-West Regions, some catchments in Anglian Region and by a number of water companies for water resources modelling. The CatchMOD modelling structure (presented in Figure 2) forms the basis of the hydrological models used for this project.

Model overview

4.5 Key features of the modelling framework include:

- **Spatial resolution**: The hydrological models split each catchment up into a rectangular mesh or ‘grid’. The size of the grid used in the hydrological model is flexible. For all of the case study catchments a 1 km by 1 km grid has been used.
- **Temporal resolution**: The model operates at a daily time step, which is appropriate for linking with the ABM and sufficiently detailed for characterising catchment scale impact to meet the needs of this project. The integrated hydrological and ABM models have been run over a 25 year timeframe from 2025 to 2050, with a daily time step.
- The modelling framework is **computationally efficient**.
- The model can be **fully integrated with the ABM**.

---

\(^6\) Licence limitations include daily and annual limits, Hands Off Flow (HOF) conditions, conjunctive arrangements (whereby a total cumulative limit may apply across multiple abstraction points)

Figure 2: Overview of the CatchMOD model structure as implemented within the semi-distributed modelling framework

**Representation of surface water elements**

4.6 The river topology and the location of agents are ‘snapped’ to a 1km grid for all case studies, with abstractions and discharges aggregated to each 1km cell by the ABM before being applied to the hydrological model.

4.7 Reservoirs are explicitly modelled as a mass balance within the ABM (rather than in the hydrological model) and their operation is simulated based on information provided by the water companies such as control curves and details of compensation releases. Abstractions and discharge are passed to the hydrological model via associated intakes and outflow points which are ‘snapped’ to the 1km grid of the hydrological model.

4.8 Internal Drainage Board areas have been delineated based on information provided by the Environment Agency. The ABM models each IDB area explicitly and incorporates an IDB Agent which seeks to maintain a target water level via off-take points within the hydrological model that connect to the river system.

**Representation of groundwater**

4.9 CatchMOD uses a simplified approach to modelling groundwater. The underlying model structure uses a single ‘flow pathway’ for each groundwater response area. Groundwater zones can be calibrated to release water slowly, to mimic the response of an aquifer, or with a limited delay, to mimic the response of a flashy zone⁸,⁹.

4.10 While CatchMOD has been shown to work effectively in a number of areas across England and Wales, groundwater effects are important in some of our case study catchments and we have therefore discussed with experts at EA, BGS and AMEC how best to approach groundwater modelling in this project. Based on these discussions we refined the existing

---

⁸ See the CatchMOD User Manual, Environment Agency, 2005
⁹ Note that surface runoff is also routed through the upper and lower storage modules but with very low routing coefficients so that runoff reaches the catchment outlet quickly.
CatchMOD approach to groundwater to enable an approximation of the spatial distribution of groundwater abstractions on river flows to be accommodated using information already held within EA and Natural Resources Wales’ Water Resources GIS and CAMSLedgers.

4.11 *Groundwater recharge* is the hydrological process where water moves downward from surface water to groundwater. *Base flow* is the portion of stream flow that comes from groundwater seepage into a river.

4.12 Recharge to groundwater, and base flow to rivers, have been represented by lumped models at a WFD surface water body and CAMS Assessment Point sub-catchment level. Because a lumped groundwater model has been used, the spatial variability of groundwater abstractions across each area being modelled has been taken into account using the assumptions that are recorded in the CAMSLedgers. It has not, however, been possible to represent abstraction-centred groundwater level drawdown and the associated local development of groundwater storage which in reality tends to reduce the impacts of pumping on river flows during dry periods.

4.13 We recognise that this approach remains a gross simplification of the actual hydrogeological processes present including the localised variations in geology and the relative proximity of rivers to abstractions. However, it is not practicable to consider the use of detailed three-dimensional groundwater models (e.g. MODFLOW) for this project to provide a ‘step-change’ in accuracy and utility because such models are significant projects in their own right requiring detailed conceptualisations, data collation and interpretation and computational resources. More information can be found in Appendix 4.

4.14 These simplifications may result in an underestimate of the role which groundwater storage may play in supporting supply during low flow periods and could be contributing to the appearance that environmental protection measures have little impact. This is discussed further in Chapter 7.

**Calibrating the model**

4.15 *Calibration* is the process of adjusting model parameters so that they can produce river flows in the catchment consistent with those observed in real life. For this application the models have been calibrated to provide the best fit at a number of different points across each catchment and at low river flows. This is to ensure that the model can provide credible results across the whole catchment and when levels in the rivers are low, the situation we are most interested in. Most catchments were calibrated using ‘naturalised flows’ provided by the Environment Agency. These are an estimate of the flows that would occur naturally without human influences of abstraction, discharges or impoundment.

4.16 *Recent Actual flow duration curves* were also compared with CAMSLedger flow duration curves (which themselves are checked against gauged flows). This was carried out in a series of calibration runs of the integrated model in which ABM functionality was switched off and abstractions and discharges fixed at recent actual rates. Findings from these runs were then used to identify any issues (such as simplifications associated with representing the river network and surface water abstractions at a 1km resolution), and to improve hydrological model set-up and calibration.
5 BEHAVIOURAL MODELLING

5.1 This chapter introduces the approach we are adopting for the abstractor behaviour modelling. A detailed description of the behavioural modelling approach is provided in Appendix 5 and the companion reports: Abstraction licensing reform, Non-Public Water Supply agent behaviour and The Impact of Abstraction Reform: Public water supply operations.

5.2 The chapter provides an introduction to the:
- Agent-based modelling approach adopted
- Modelling of non-public water supply behaviours
- Modelling of public water supply decision making, and
- Modelling of the policy options.

5.3 It also describes the steps required to establish the reformed licence conditions and environmental abstraction limits that would be applied under reform. Finally it describes how we tackled the uncertainty around future conditions relating to both how the climate and the socio-economic environment might develop.

Agent-based modelling

5.4 The modelling of abstractor behaviour has been carried out using an agent-based modelling approach. An agent-based model is a type of computational model that is used to simulate the actions and interactions of autonomous agents in order to assess their effects on overall system behaviour. They can be used to explore the simultaneous operations and interactions of multiple agents (including both PWS and non-PWS agents), in an attempt to recreate and predict the appearance of complex phenomena. The process is one of emergence from the lower (micro) level of systems to a higher (macro) level. As such, a key notion is that simple behavioural rules generate complex behaviour.

5.5 Agents can be individuals, organisations, groups, or a combination of all three. Individual agents are typically characterised as rational, presumed to be acting in what they perceive as their own interests, such as reproduction, economic benefit, or social status using heuristics or simple decision-making rules. By limiting the rules and data which agents use to make decisions, and allowing agents to be influenced by the behaviours of other agents, models can simulate behaviour that is not fully rational, in a traditional economic sense, which has led to increased interest in their applicability to economic modelling.

5.6 Agent-based models are generally composed of:
1. Numerous agents specified at various scales (or granularity)
2. Decision-making strategies or heuristics
3. Learning rules or adaptive processes
4. An interaction topology.

Model implementation

5.7 We have constructed an agent-based model to simulate the behaviour of abstractors (agents) operating in the context of a catchment area (topology) while being subject to some licensing regime (rules). Choices about adaptations (decision making heuristics), responses to pricing signals (heuristics, learning processes), and interactions with other abstractors are

---


incorporated into agents’ abstraction behaviour. The individuality of each agent is determined by its water needs, location, relationships with other abstractors, and the localised water availability challenges it is subjected to. In this way, the modelling framework can explore how individual abstractor behaviour is likely to combine to produce overall abstraction behaviour, with its consequential impact on environmental flows. These rules have been established through detailed consultations and literature review. Our approach to modelling behaviours is introduced below and described in more detail in Appendix 5 and the companion report London Economics/Risk Solutions: The Impact of Abstraction Reform: Non-PWS agent behaviour.

5.8 The agent-based model has been developed using a Rapid Application Development (RAD) environment called Delphi\textsuperscript{12}. The model calculates the water abstractions and returns in the next time period for each hydrological model cell based on abstractors’ water requirements, adaptation behaviour and responses to reform options. Agents located in one cell may make abstractions and returns to other cells depending on their particular circumstances. In particular it considers how abstractors might react to price signals to make adaptations, and how they might interact with each other as individual abstractors make choices about cooperation, investment and market opportunities. A picture of this process at work is shown in Figure 3.

5.9 Given that some sectors are dependent on water of a particular quality as well as quantity, we have also considered the basic quality of water (i.e. the presence or absence of particular features) to capture the broad issues associated with treatment for use (or discharge) and inter catchment transfers.

Modelling non-PWS behaviours

5.10 From our consultation work we identified three distinct levels of non-PWS abstractor behaviour:

- **Tactical responses**: Short term (daily/weekly/monthly) choices about when to abstract or release water from currently available water sources, and how to match changes in

\textsuperscript{12} http://www.embarcadero.com/products/delphi
demand or water availability for example abstracting to fill reservoirs in periods of high flows, trading unused water allocation with another abstractor.

- **Seasonal responses**: Medium term (monthly/yearly) choices about particular production (or service provision) behaviours to match anticipated water availability or to guarantee supplies in order to meet current demands for example varying crops or growing seasons to match water availability, acquiring water allocation rights.

- **Investment cycle responses**: Long term (yearly/investment cycle period) choices about capital expenditure, production levels, location, land usage, acquiring long term water access rights etc.; for example investing in irrigation equipment to allow transition away from rain-fed crops, buying long term water entitlement rights.

5.11 These three types of response have been separated within the model (in order, for example, to prevent choices about long investments being considered every day). However, we recognise that they are not independent and that longer term responses draw upon ongoing shorter term experience.

5.12 The choices each abstractor can make are defined in terms of:

- Production process/service provision choices – how water is used within the business or organisation
- Water source choices – where abstractors obtain the water they need
- Abstraction permission requirement choices – decision making about acquiring (or releasing) rights to (or temporary allocations of) water, and
- Adaptation choices – long term decisions to invest to reduce long term business costs, secure access to more water, change production processes to reduce water demand, replace aging assets with more water efficient options, or allow production growth.

5.13 A range of factors drive choices including demand for products or services, water quality requirement and various economic and risk factors. The starting point is to suppose that agents make decisions with the aim of increasing their profit. A benefit of agent-based modelling is that this approach can be augmented using lessons from behavioural economics; the influence of, for example, time constraints and social interactions on decision making can be taken into account. In the ABM we have included a number of behaviours, derived mainly from a survey of the literature by Armstrong and Huck (2010)\(^\text{13}\), informed by our consultations:

- Agents use rules of thumb for decisions such as what range of production levels they will consider (e.g. within a certain range around their current level), which investment options to consider (e.g. a random selection of a certain number of options), and when to assess these investment options (e.g. after a given number of periods, or when their price expectations change by a certain degree).

- Some agents may be influenced by the decisions of other agents, such as those in the same sector.

- Some agents only consider production levels that are close to their current level and some agents choose the most profitable investment option from a subset of potential options, rather than considering all options.

- Some agents have a propensity to believe that observed price trends (upwards or downwards) will continue for many periods (which will impact on the profitability of strategies and projects).

\(^{13}\) Armstrong and Huck (2010), "Behavioural Economics as Applied to Firms: A Primer", survey the literature on behavioural and experimental economics as applied to firm behaviour.
Modelling PWS behaviours

5.14 The behaviour of PWS abstractors within a catchment is one of the key factors determining general water availability for other users. PWS abstractors are therefore included as agents within the catchment model. These PWS agents make both short term and long term decisions.

Short term decision making

5.15 PWS demands are driven by changes in population, by changes in domestic consumption per person and also by changes in industry demand.

5.16 In the short to medium term water companies generally have to make use of sources of water they already have, and any potential trades with other companies from their existing sources. Short term decisions are likely to be centred on maintaining stored supplies, drawing upon natural flows and stored supplies to meet PWS demand, broader management of flows in rivers on controlled river sections (such as in the Dee catchment), and the handling of treated effluent discharge (from their own customers, other PWS companies and other trade effluent). This is illustrated in Figure 4.

5.17 The rules underpinning these decisions have been determined by reviewing existing operating plans and direct engagement with the specific water companies to determine:

- Key aspects of their operation within the catchments we are modelling
- Operating rules/tactical decision making processes that are currently used for managing normal operations, in particular the actual abstraction profiles for different hydrological and demand conditions
- Special considerations relating to drought
- What operating rules and decision making processes might be anticipated in the face of the specific climate change and socio/economic scenarios that we are considering
- The nature and level of current inter-WRZ transfers that already occur
- Likely operating rules for currently identified new infrastructure options.

5.18 Further details of PWS short term operations are provided in the companion report: Abstraction licensing reform: Public water supply operations.

![Figure 4: PWS short term (operational) behaviours and responses](image-url)
**Long term decision making**

5.19 Long term PWS decision making and investment strategies are focused on meeting predictions of future water supply and demand. Some of the long term PWS water resource management options could be significantly affected by the behaviour of non-PWS abstractors as they compete for supplies and potentially make additional demands on the PWS. The overall approach is shown in Figure 5.

**Figure 5: PWS Investment planning behaviours and responses**

5.20 In taking investment decisions, PWS agents are trying to ensure that they can fully meet any projected dry year deficits in the supply-demand balance at least cost, taking into account environmental and social costs. The supply-demand balance is the difference between the projected excess of supply over demand (‘actual headroom’), and ‘target headroom’ - an additional buffer of supply over demand to reflect risks. They take these water resource management decisions every five years, in order to reflect the actual WRMP process. They select a programme of water resource management options in order to meet any projected supply-demand deficits at least cost. The process is described in more detail in Appendix 5.

5.21 Water resource management options include, but are not limited to: increasing the capacity of water treatment works; increasing water storage capacity; importing water from water resource zones elsewhere in the company’s area; importing water from other companies; desalination; additional leakage control; additional roll out of water meters; changes in water meter price structures; and provision of water efficiency information and support to customers.

**Modelling policy options**

5.22 The detailed design of the options has been continuing in parallel to the model development, and has been informed by the design process. In broad terms two different approaches are being considered (Current System Plus and Water Shares) in addition to retaining the current system. In practice the design of any final reform option may use elements of both these new approaches, however for modelling and impact assessment purposes we have defined two distinct options that implement, as far as is possible within the constraints of the model, the features of the two options are described in Chapter 2. Both these options consist of two types of reform (basic and enhanced).
5.23 Basic reform is aimed at making the whole system more fair and transparent, making administration more efficient, and laying the foundation for further reform in catchments where circumstances warrant this. These reforms include:

- Basing allocations generally on water consumed rather than water abstracted\(^\text{14}\)
- Improving estimates of consumption to support more accurate charging
- The separation of long-term access to water from permits to abstract that set local conditions for abstraction but do not allow abstraction per se
- Reviews – having criteria based on catchment water ecosystems status that can trigger catchment abstraction level reviews that apply consistently to all abstractors

5.24 Enhanced reforms are of two types

1. Reforms to improve the responsiveness of allocations to available water where there are significant levels of risks of environmental damage. Reforms include:
   - Spatial variation – introducing more sophisticated controls on abstraction (such as enhanced HOF requirements) that respond more dynamically to changes in water availability.
   - Variable short-term allocations – allowing more sophisticated variations in actual allocations on a weekly or fortnightly basis which respond to variable water availability to protect the environment where risks of environmental damage are significant.

2. Reforms to facilitate trading of entitlements or allocations of water (where this will provide benefits) to give abstractors greater flexibility in how they manage the risks associated with water availability challenges. Reforms include:
   - Flexibility – establishing rules to manage the potential for trading between water share groups
   - Risk assessment of trades – developing simpler ways to classify the risk associated with different types of trade to reduce transaction costs and time for low risk trades (e.g. those downstream within the same water share group)
   - Trading mechanisms and market rules – having clear mechanisms in place to manage and monitor the transfer of entitlements and allocations between abstractors

5.25 We have modelled these aspects of the policy options as constraints and rules within which the abstractor agents are allowed to operate. In this way the model will be able to explore the potential for unpredicted emergent behaviour into areas that are not sufficiently prescribed.

5.26 Details of how the three policy options have been modelled are provided in Appendix 5.

5.27 As described in Chapter 2, not all elements of any reform, will be introduced everywhere on day 1. Enhanced reforms will only be introduced where it is judged (based on clear criteria) that circumstances warrant it and where the benefits will outweigh the costs. This is referred to as proportionate implementation. For the purposes of the catchment modelling we have assumed that the enhanced reforms will be introduced from day one in each of our case study catchments. This is a necessary simplification to make the modelling tractable. The aggregation process then considers the effect of proportionate implementation as explained in Chapter 6.

\(^{14}\) Note: Understanding where an agent abstracts from and discharges to remains important - even for an individual whose overall consumptiveness is low. An abstractor who discharges out of a catchment will effectively be highly consumptive regardless of the discharge volumes they make.
Setting up the model

5.28 Before beginning to run the models we had to establish a starting position for the model. We had to consider two issues:

- How might licences have changed in the period up to Day 1 of the modelling period? This includes both:
  - the impacts of the current water framework direction (WFD) review processes, and
  - the transition process to move existing licences into any new system
- How might socio-economic and climate conditions change in the period up to Day 1 and how might these continue to change through the modelling period.

Establishing reformed licence conditions and environmental abstraction limits

5.29 The Environment Agency and Natural Resources Wales are currently investigating potential changes to licences in order to meet environmental standards as part of the RSA programme and WFD. Given that the start of the model runs is 2025, we needed to take account of potential changes in patterns of abstraction between now and 2025. To account for this, AMEC estimated a range of changes to licences that might be necessary before 2025. It was also necessary to consider changes that would be required to licences to transition them into any new licensing regime.

5.30 The Environment Agency worked with AMEC and Risk Solutions to establish a method for estimating how licences might change pre-transition and at transition. This was a highly iterative process designed to define individual licence conditions and operating rules compatible with the assumptions made in the hydrological models and ABM.

5.31 It was carried out in two stages

1. The first step was to estimate a range of changes to licences that might be necessary prior to the start of the modelling period in 2025 to support environmental flow standards required by the Water Framework Directive. These estimates were based on a simple set of principles developed specifically for the purposes of the modelling.
2. The second step was to establish what licences might look like under reform. A simple set of rules was developed to transition current licences (which may be seasonal and/or subject to HOF conditions etc.) to the reformed system (Current System Plus or Water Shares). This process was applied to both surface water and groundwater licences.

5.32 Basic changes relevant to both reform options included:

- Adjusting each annual abstraction limit so that is based on recent water use plus some proportion of the existing licence, but capped by current licensed volume so that no abstractors increase their access to water under reform.
- Assigning daily abstraction limits to each licence based on either the existing figure in the Environment Agency Water Resources GIS or twice the transitioned annual licence quantity divided by 365, whichever is greater. This was to avoid the day to day operation of abstractors in the model being constrained.
- Removing monthly (seasonal) restrictions on licences. In the case of summer licences annual quantities have been maintained, but the daily pumping limits adjusted to allow current summer abstraction rates to still be achieved. In the case of winter licences a HOF constraint has been added to protect against over-abstraction at low flows.
- An historic climate time series was used with abstractions and discharges fixed at recent actual rates (accounting for assumed WFD and RSA changes) in order to establish the flow thresholds and associated licence constraints and shares used to set up the reform scenarios.
Establishing for each licence the quantity of water required to be reserved for the environment (the no go below flow limit). This no-deterioration flow threshold is assumed to apply to both reform options, and also to the modelling of the current system.

Establishing a regulatory minimum limit for each surface water licence at which point abstraction must stop.

Calculating the additional abstraction which might be taken from each groundwater source in short term trades, taking into account risks to other abstractors, wetlands, river flows and saline intrusion.

Assigning an estimate of the consumptiveness of each licence based on the consumptiveness of abstractors as detailed in the CAMS/Water Resources GIS datasets.

Assigning licences to units suitable for trading.

Surface water regulation changes made for Current System Plus included:

- Establishing flow levels at which abstractors must reduce abstraction (referred to as soft HOFs).
- Defining high flow trigger levels at which abstractors can safely take extra water (referred to as bonus water) and levels at which abstraction must cease for all relevant surface water abstractors.
- Defining critical points in each catchment which the model will look at to determine whether river levels are hitting triggers.

Surface water regulation changes made for Water Shares included:

- Defining how much water is available for abstraction in each sub-unit of a catchment.
- Defining up to 5 groups of water shares with differing levels of reliability.
- Allocating shares to abstractors, taking into account the reliability of their previous licence and based on consumptive abstraction rates.

The changes were based on a set of simple principles applied equally to all abstractors in catchments, rather than pre-judging the outcomes of local investigations and attributing the licence changes to just one or a few licences. A detailed cost benefit assessment of the assumptions has not been carried out. While this may not represent a precise projection of individual abstractions, we believe that it provides a reasonable view of patterns of abstraction in catchments in 2025 suitable for the comparison of reform options.

The principles were implemented with care to generate a consistent set of licence changes that made sense within the model environment. The results at an individual licence level however must not be assumed to be representative of what will happen in practice.

By completing the above analysis we established a 2025 projection of baseline patterns of abstraction. It also estimated the quantity of water required to be reserved for the environment to comply with the Water Framework Directive. Given that a key requirement of the Water Framework Directive is to prevent deterioration of the status of the environment, this helped set the environmental threshold that should be maintained for the entire modelling period (2025-2050) for all three reform options, which was also assumed to be common and fixed through all four of the climate projection scenarios.

More details of this process are provided in Appendix 5.

Sensitivity around environmental requirements

The quantity of water reserved for the environment in the catchment models (the no go below flow limit) is based on a key requirement of the Water Framework Directive to prevent deterioration of the ecological status of the environment. The Environmental Flow Indicator (EFI) is the threshold currently set as a proportion of natural flow to indicate where flows are sufficient to support the environment. Where flow simulated at the start of reform (after WFD reductions) is above the EFI, this sets the limit on available water for more abstraction in...
modelling the reform period. Where current flows would be below the EFI, they are prevented from further deterioration through a process of periodic review and licence adjustments.

5.40 For the purposes of modelling it is assumed that to prevent deterioration, the quantity of water reserved for the environment in 2025 (set in the context of the historical climate) is maintained for the entire modelling period to 2050. This is a simplification of a more complex process. In reality the EFI could be adjusted as specific evidence on the ecological needs of catchments evolves. But more significantly, it could be adjusted in future to support habitats adaptation to the impacts of a changing climate and maintain access to water for abstraction. While adjustments to the EFI would change the quantity of water for the environment (reducing this in a drier climate), it wouldn’t deteriorate the balance of the needs of the environment compared to abstraction.

5.41 It has not been possible to model precisely the future possible evolution of environmental thresholds without also modelling the complex relationship between local ecological requirements and hydrology. As a result, the quantity of water reserved for the environment in the catchment models is likely to overestimate environmental requirements within the dryer climate change future scenarios. We have explored the sensitivity of the results to this assumption and are exploring the feasibility of more detailed modelling of evolving environmental limits.

**Establishing future scenarios**

5.42 We do not know how the future might unfold; we have therefore used *scenario analysis* to explore how the options perform under a range of different possible futures. Scenario analysis involves defining a range of possible future scenarios that scope the range of possible futures, and then carrying out model runs for each of these scenarios. Key sources of future uncertainty include climate change, socio-economic change, and the power generation sector response. For the draft Impact Assessment, we agreed with the project board to use the same socio-economic and climate change scenarios adopted by the EA in the Case for Change analysis. This identified four socio-economic scenarios and four climate change scenarios (which combine to give 16 possible scenarios) that cover the different types of climate and socio-economic uncertainty relevant in the four catchments we have modelled. These are described below.

**The socio-economic scenarios**

5.43 The socio-economic scenarios explore how the demand for water may vary depending on future societal attitudes and behaviours around consumption and how international governance systems evolve. This is shown in Figure 6.

---

**Figure 6: Definition of the socio-economic scenarios**
5.44 At one end of the attitudes and behaviours axis, consumption patterns are constrained. At the opposite end, individuals exist in an intensified ‘desire’ economy in which there is greater consumption of goods and experiences.

5.45 The second axis refers to international governance systems. At one end, governance systems and decision making focus on longer term sustainability concerns, such as climate change and resource depletion. At the opposite end, governance is based on rules concerning competitiveness and open markets, to maximise economic growth.

5.46 The four scenarios represent for different alternative futures:

**Innovation:** This is a world where society expects Government and scientists to solve the problems of climate change and resource shortfalls so they can carry on living their lives as they wish. Although sustainable development is at the core of the scenario, this is delivered through means other than a shift in societal values. Total demand under this scenario falls by about five per cent.

**Uncontrolled demand:** This scenario represents what could happen to demand where neither society nor Government takes action to control the demand for water (or many other goods). With the focus on cutting costs, water and energy efficiency measures are often forgotten or are at least given a lower priority. The result is a very large increase in demand (about 35%).

**Sustainable behaviour:** This is a world in which Individuals pride themselves in being as efficient as possible and being seen as ‘green’ is a positive attribute. This drives demand down in most sectors. But as it is primarily achieved through good will, the savings could be seen as more vulnerable than those achieved under some other scenarios. Total demand under this scenario falls by about 10 per cent.

**Local resilience:** This scenario is driven by a need to implement efficiency measures in order to get by. The level of efficiency savings that can be achieved are controlled by the limited technology available. Under this scenario the Government does not have the capital or the political will to invest in strong regulation and hence the drive to find improvements is limited. In addition to this, because people’s drive to use less (of everything) is controlled by the need to survive rather than a desire to protect the environment, the savings they are prepared to achieve are limited. Total demand under this scenario rises by about 10 per cent.

5.47 Figure 7 shows trends in total water demand - 2008 to 2050 (England & Wales) under each of the scenarios alongside current demand.
Climate change scenarios

5.48 Each of the climate change scenarios (referenced by the letters A to K), is based on a different combination of meteorological and hydrological conditions. The change in flows varies between the scenarios, both quantitatively and spatially. The EA Case for Change analysis selected four of the eleven Future Flows climate change scenarios to reflect a range of the predicted outcomes, from minimal change in flows (Scenario A) to greater changes in flows at different locations (Scenarios C, G and J) as shown in Figure 8:

- Under Scenario A the biggest impact can be seen in Powys, southern Wales and Essex.
- Under Scenarios C and G Wales, northern and south west England see the biggest reduction in flows, under C limited areas (parts of Anglian) see an increase in flows.
- Under Scenario J central parts of England and Wales, and south east and south west England see the biggest reduction in flows.

Figure 8: Climate change scenarios: changes in flow at relatively low flows

Approach to applying scenarios

5.49 For the draft Impact Assessment, we wanted to obtain a good understanding of the behaviour of options under the 16 possible scenarios. We also wished to run a range of sensitivity and uncertainty analyses, to explore the impact of some of the key assumptions and simplifications. For example, what impact did the behavioural assumptions embedded in the ABM have on the results?

5.50 A balance had to be struck between the range of different scenarios and sensitivity analyses that are explored for completeness sake, and the time it takes to carry out the analysis. We therefore used a staged approach in which we selected an initial combination of 4 scenarios from the 16 possible (shown in Figure 9) as the basis for initial analysis. We then selected two of these J-SB and G-UD and began exploring how outputs are affected by a change in one of

---

the underlying sensitivity analysis dimensions focused on those dimensions that we found to be most important to resolving the differences in the policy options being considered. These are reported in Chapter 7. At the same time we continued exploring the range of results obtained for the other 12 scenario combinations.

Figure 9: Scenario combinations selected for initial model runs
6 AGGREGATION AND THE TOP DOWN MODEL

6.1 In this chapter we introduce the approach taken to aggregation and the simple top down model developed to complement the detailed bottom up modelling.

The Aggregation Model

6.2 The aggregation process uses water abstraction information to scale up the financial costs and benefits derived for the example catchments studied with the ABM model, to all catchments in England (and separately to all catchments in Wales). This is then combined with data on catchment administration costs (using the model developed by URS for the EA and Natural Resources Wales) to provide an overall estimate of the costs and benefits of the options in England and in Wales.

6.3 The aggregation includes financial costs and benefits only. While the financial costs of curtailing licences to address environmental impacts are included in the aggregation, no attempt has been made to monetise the benefits to the environment that result. This is because we are assuming that the environmental objectives are consistent across the options, so the environmental benefits should not be significantly different. There are only economic costs of maintaining constant environmental standards, and the costs might be lower in some policy options compared to others.

6.4 The benefits of basic reform included in the aggregation derive from reduced annual operating costs once the basic reforms (e.g. move to electronic licences) have been implemented.

6.5 Benefits to the non-PWS and PWS sectors from enhanced reform depend on the nature of the enhanced reforms implemented. Where the trading is expected to be cost beneficial enhancements will include implementation of trading. Benefits will then derive, under both Current System Plus and Water Shares, from more optimal use of water across the catchment resulting in agents making more product (or more valuable products).

6.6 Considering the catchment as a whole, the income and expenditure on traded water sums to zero (neglecting the transaction costs for operating the system that is accounted for in the catchment administration costs). The economic value created in the catchment is thus the profit earned on any extra non-PWS production e.g. profit with Water Shares minus profit with the current system. Trading income must however be separately calculated to provide disaggregation of the results by sector. There may also be additional benefits derived from more efficient investment in assets related to water use, for example if enhanced reform allows agents to forgo or delay capital investments.

6.7 Regulated PWS agents have a target demand that they must satisfy at lowest cost. The main benefit of enhanced reform that they see is a change in their investment profile e.g. requiring less capital expenditure overall, or delaying capital expenditure from one year to another.

6.8 For the current system the costs and benefits also include compensation payments due to curtailment of licences and the EIUC charges made to meet these, although considering the catchment as a whole these sum to zero.

6.9 An overview of the model is provided below.

Model overview

6.10 The aggregation model firstly allocates catchments to categories that determine whether, and at what point in the modelling period, enhanced reforms will be introduced under proportionate implementation and the nature of these reforms. This determines the point at which the costs and benefits of enhanced reforms will be taken into account in the overall cost benefit calculation. This will differ for each combination of climate change and socio-economic scenario and is determined based on an assessment of both:
• Whether the catchment will be *fully allocated* at day one, or will become fully allocated during the modelling period
• The potential gains from trading, and
• The environmental sensitivity of the catchment.

6.11 Data to support this process was supplied by the EA based on WRGIS and the most recent Case for Change assessment. The categorisation process is summarised in Figure 10.

![Figure 10: Catchment categorisation flowchart](image)

6.12 The benefit under enhanced reform is then estimated for each catchment by calculating a weighted average benefit per m$^3$ of water abstracted for each sector in the catchment and multiplying this by the amount of water abstracted annually by that sector.

6.13 The weighted averages are catchment specific and the weightings are calculated to match the sectoral split in the catchment as closely as possible.

The weighted averaging process is best illustrated using an example, see Box 1:

**Box 1: Calculating the weighted averages**

Suppose we have studied, using the integrated ABM model, three catchments, and that the benefit per m$^3$ of water to the agriculture sector was £1 in Catchment 1, £2 in Catchment 2 and £3 in Catchment 3.

We could take a straight average of these three numbers ( £2 per m$^3$) and assume that this benefit per m$^3$ of agricultural water abstracted applied to all the other catchments. However, the level of benefit will depend not only on the amount of water abstracted per year, but also a number of other factors. The most significant of these is expected to be the mix of different sectors in the catchment. For example, in the ABM model we observe trading occurring between agricultural agents; therefore we would expect a catchment with a high proportion of agricultural abstractors to have higher benefits from trading.

The weightings are calculated by matching the total sectoral split across the catchment, giving greater weight to the results from modelled catchments that have a similar split of agents to the catchment under consideration.
So for example, if Catchment 1 is dominated by agriculture but Catchment 2 is dominated by PWS, a catchment in the aggregation model that is also dominated by PWS would have a higher Catchment 2 weighting percentage and a lower Catchment 1 weighting percentage. Hydrological differences, for example whether water sources are predominantly surface or ground water, are not taken into account.

6.14 Because none of the current modelled catchments have a significant proportion of thermal power generation, we cannot model these in this way. Until we have results for the Trent and Derwent we assume that these catchments are neutral to the reform option and claim no net benefits from reform.

6.15 The catchments are allocated to country (England or Wales) by reference to stated responsibility rather than geographical location.

6.16 So, for example, the Dee catchment and its neighbouring catchments are as shown below (taken from the Dee CAMS documentation on the Environment Agency web site).

Figure 11: The Dee and its neighbouring catchments

6.17 In the aggregation model the Dee, Clwyd, Conwy, and Merionnyth catchments are allocated to Wales and the Upper Severn and Lower Mersey catchments are allocated to England.

Model outputs

6.18 The aggregation model produces two main outputs:

- Yearly net costs and benefits from 2025 to 2050 for England and separately for Wales, calculated as the sum of the costs and benefits from each of the 116 catchments depending on whether each is categorised as a Basic or an Enhanced catchment
- The total number of catchments that are classified as Basic or Enhanced
6.19 The model can also produce sectoral totals for the four example catchments to highlight whether there are any major distributional effects in the overall cost benefit case.

6.20 The profile of costs and benefits is produced in a format that can be used in the BIS Impact Assessment calculator directly. It shows the change in costs and benefits arising from implementing the reform options compared to the baseline (the current system). The main categories are as follows:

- Change in investment costs (referred to as change in adaptation costs in the Impact Assessment) to business is the change in capital investment (and associated operating costs) incurred in the catchments as agents seek to balance supply and demand as the climate changes over time, expressed as an annualised difference in the NPV of the two investment profiles. The model extends the NPV calculation for a further 10 years beyond the end of the simulation run to take account of any ‘end effects’ – for example capital investment occurring in 2049 under one policy option and 2051 under another. This category includes investments by the regulated water companies (the PWS) and investments made by other abstractors such as for the construction of new water storage reservoirs on farms.
- Profit from additional production incurred from Year 0 through to Year 24.
- Net trading income (can be positive or negative for individual sectors but sums to zero overall at catchment level and national level)
- Transition costs that fall to the Environment Agency and Natural Resources Wales as a result of moving the existing abstraction licences into a new system. These are assumed to occur in Year 0, which represents 2025. These are the costs
- Administrative costs of reform to the regulator and to business, both during the transition period and once the reforms are operational (note that the costs to the regulator could also be recharged to business). These are incurred from Year 0 through to Year 24.
- Brokerage costs to fund the third party operators necessary to facilitate the execution of trades, calculated as a fixed percentage of the value of every trade that occurs.

6.21 These benefits and costs are entered automatically into the Impact Assessment template to determine the overall costs and benefits of reform for the currently selected scenario combination (choice of reform option, climate change scenario and socio-economic scenario).

6.22 The aggregation model then cycles through all possible scenario combinations and summarises which scenario combination produces the highest net benefit and which the lowest compared to the current system.

6.23 Potential costs and benefits that have not been quantified were discussed qualitatively in the Impact Assessment.

The top down model

6.24 Vivid Economics have developed a simple top down water abstraction economic model for England and Wales.

6.25 The top down model complements the programme of detailed catchment models described above through a simpler analysis, drawing together information on actual abstractions, climate and demand scenarios for 2050, and values of water in use and cost of water supply, to estimate the potential scope for value creation by trading water. The appropriate interpretation of the simple catchment-level analysis is an illustration of the pattern of benefit between users, between demand shuffling and expansion of supply, and geographically.

6.26 The model is introduced below. A full description of the model and model results can be found in the companion report: A simple top down water abstraction economic model for England and Wales by Vivid Economics.
**Model overview**

6.27 The model explores the effect of trading using a simple, top-down approach.

6.28 The model allows the reallocation of water between users where the unit value of water is higher for one user than another by at least the amount of a transaction cost of trading. Each abstractor begins with an initial use volume and use value. It is then assumed that, as licenced abstraction volumes are reduced, each abstractor will want to increase abstraction up to the original volume if possible, and be willing to pay for additional water at the abstractor’s use value. It is further assumed that if the abstractor is offered more than its use value, it is willing to sell its allocation. The initial cuts in water volumes are an input. They have been derived from the Case for Change assessment for 2050 and have been provided by EA. They are imposed equi-proportionately across all types of abstractors.

**Limitations of the model**

6.29 The simplicity of the modelling makes it quick to implement and amenable to sensitivity analysis. However, a number of qualifications to the results must be made. Most fundamentally, it is not a hydrological model that represents the physical processes in the catchments. Instead, the model examines CAMS regions, which can be aggregated to river basin district (RBD) level and an England/Wales breakdown. All trades between abstractors are allowed within single catchments in the model – in reality they would be restricted to much smaller areas due to hydrological constraints. The model cannot differentiate between different options for implementing trading (e.g. between Water Shares, Current System Plus and Current System) because it is only modelling permanent licence transfers that are possible under all three reform options.

6.30 The assumption of constant unit values and fixed amounts of water demand by sector and use is also a great simplification. It implies that within each catchment, user and use category, demand is perfectly elastic below the initial licensed volume and zero above it. In other words, it describes demand as a step function.

6.31 As far as possible inputs to the model has been designed to be consistent with data used in the ABM and aggregation models. For example, the model uses the same demand data derived from the WRGIS dataset and the Case for Change data supplied by the EA as is used in the aggregation model. PWS supply options are derived from information collected for the modelled catchments.

**Model outputs**

6.32 The outputs from the model for each catchment are listed in Table 1. Most can be reported by individual catchment or rolled up to RBD and country level. Other output metrics can be produced if desired. In addition, the buyers and sellers can be identified at any level of aggregation.

6.33 The model is set up to compare a trading policy option with no trading for the standard set of climate change and socio-economic scenarios.
# Table 1: Model output metrics

<table>
<thead>
<tr>
<th>Model output</th>
<th>Unit</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gains from trade</td>
<td>£</td>
<td>For comparison between scenarios; by catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Administrative costs of trading</td>
<td>£</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Value of traded water to seller</td>
<td>£</td>
<td>By catchment only</td>
</tr>
<tr>
<td>Proportion of value of traded water which is from supply</td>
<td>%</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Volume of water traded</td>
<td>m³</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Average unit value gained per m³ traded</td>
<td>£/m³</td>
<td>By catchment only</td>
</tr>
<tr>
<td>Highest accepted bid of seller</td>
<td>£/m³</td>
<td>By catchment only</td>
</tr>
<tr>
<td>Total water consumption</td>
<td>m³</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Supply</td>
<td>m³</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Shortfall</td>
<td>m³</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
<tr>
<td>Value of water in use before</td>
<td>£</td>
<td>By catchment and rolled up to RBD and to country level</td>
</tr>
</tbody>
</table>

**Note:** These outputs can be produced for each combination of demand and climate scenarios (25 results).

**Source:** Vivid Economics
7 FINDINGS

7.1 This chapter presents the results generated in support of the Consultation Impact Assessment and work carried out subsequently. Unless otherwise stated, costs and benefits are discounted over a 25 year period to the base year of 2025 using a discount rate of 3.5%.

Results generated for the Consultation Impact Assessment

7.2 Aggregated results for the four catchments Stour, Hampshire Avon, Cam and Ely Ouse and Usk were generated for the period 2025-2050. To do this we begin modelling in 2023 providing a two year ‘warm-up’ period. The warm-up period allows the hydrological and economic modelling to settle down from initial (and sometimes arbitrary) starting conditions. The results were aggregated using the aggregation model and unit cost data derived from the URS model.

7.3 For the Consultation Impact Assessment we used the models to carry out an initial comparative analysis of Current System Plus and Water Shares compared with the current system, to test the robustness of the model and the conclusions, and to identify areas where the modelling could be refined.

7.4 Figure 12 shows that a full set of scenario combinations totals 192 runs of the ABM models, which is equivalent to approximately 8 days computing time. The results are then passed through the Aggregation Model to estimate the costs and benefits at a national level.

7.5 At this stage the models were stable, generating repeatable results and capturing most of the major mechanisms of the current system and reform options. However simplifications have been necessary at each of the major stages of modelling: hydrology, agent characterisation, decision making and in the implementation of the options themselves. Model testing and sensitivity analysis is an ongoing process. We therefore focused work for the Consultation Impact Assessment on the following:

- What the results can tell us with a good degree of confidence about how the reform options compare with the current system, and
- How the modelling could be improved to increase its flexibility and the robustness of the findings.
7.6 The development of the model has been overseen by a panel of expert external peer reviewers and has drawn on extensive interactions with stakeholders. Nevertheless, it is important to understand that at this stage, the modelling was most useful in understanding the mechanisms by which policy options may play out in the catchments. This has been used to inform ongoing design work. Analysis will continue to be firmed up as policy development of the options continues.

**Headline results**

7.7 The findings emerging from the initial model runs performed for the Consultation Impact Assessment work were as follows:

1. The reform options deliver net benefits under a wide range of scenarios and assumptions compared with the current system in England (see Figure 13). The calculated NPV benefits are quite small varying between £90 million and £450 million over 25 years.

![Figure 13: Reform Benefits for England](image)

*Key to Figures and tables: The letter before the hyphen is the climate change scenario: A involves less significant change in climate (and hence flows); C, G or J involve greater changes in climate at different locations. The letters after the hyphen are socio-economic scenarios: Innovation (I); Uncontrolled demand (UD); Sustainable Behaviour (SB); Local Resilience (LR) (See Chapter 5 for more on the scenarios).*

2. The case is more variable in Wales, with estimates ranging from net benefits of £30m to net costs of £10m. (see Figure 14).
3. In England the administrative cost of operating the basic reformed water abstraction licensing system is lower than it is under the current system. This is primarily due to
   - the introduction of electronic licences, and
   - a reduction in the number of investigations required to manage local environmental damage.

The costs of implementing Enhanced reforms to allow trading are higher than Basic reform and will only be introduced where the benefits of trading are expected to outweigh the costs. The numbers of catchments falling into the Basic or Enhanced category depends on both the reform option and the scenario combination under consideration. For example under Scenario C-SB about 20% of catchments fall into the Enhanced category at the beginning of the modelling period and this rises to around 30% by 2050. Under Scenario G-UD a much smaller number of catchments fall into the enhanced category with the number rising to between 15% by 2050.

4. For 22 catchments in England and one catchment in Wales, it was not possible to calculate benefits for inclusion in the aggregated results because the catchment could not be adequately represented as a linear combination of the four modelled catchments (for example if it had a high concentration of power generation). However administrative costs or savings were included.

5. In general, when the financial benefits of reform are high for a particular sector of the economy in the catchment models, these become the dominant contributors to the overall NPV figures estimated by the Aggregation Model. When the financial benefits are marginal, it is the administrative cost savings that become more significant.

6. In Wales a much higher percentage of catchments are classified as Basic, reflecting higher water availability and therefore less need for trading\(^{16}\). In addition, administrative cost savings are lower because there are relatively few investigations required in Wales under the current system. So the case for reform in Wales depends on whether the benefits in a particular scenario outweigh the increase in administrative costs.

\(^{16}\) Under most scenario combinations, none of the Welsh catchments have a cost benefit case for becoming Enhanced (Trading) catchments from 2025. Thus, trading benefits do not start until 2037.
7. The modelling demonstrates that reform can provide benefits in a number of ways, and (depending on the catchment and scenario combination) different factors become more or less important:

- The removal of seasonal restrictions (summer/winter licences) and the provision of ‘bonus water’ at times of high flows:
  - allows agents access to more water
  - provides additional flexibility for agents to manage their annual water allocations through water scarce periods
  - enables agents to make better use of existing reservoirs, and makes building new reservoirs more attractive;

- The reduction of barriers to trade (in particular enabling some trades to be pre-approved) makes it easier for agents with spare water to trade it with those who have a need. We see evidence in the model that this:
  - increases the total volume of water that is being used for economic benefit
  - allows water to move to those who can generate more economic benefit from it
  - enables some PWS companies to buy abstraction rights and thus delay high cost infrastructure projects
  - enables other PWS companies to sell abstraction rights and replace these with earlier implementation of low cost infrastructure projects;

- Periodic allocation of water (under Water Shares):
  - explicitly clarifies how much water can be abstracted in the next period and allows agents in the model to identify how much water they need or have spare, which enables them to trade from a position of knowledge
  - increases short term trading, which maximizes the water being used for economic benefit, and helps agents to manage short-term high demand/low supply situations better and hence achieve higher levels of overall production.

Sources of cost and benefit

7.8 Table 2 shows a breakdown of costs and benefits for two scenario combinations C-SB and G-UD. These span the range of results observed in this set of model runs.
### Table 2: Aggregated costs and benefits for England and Wales compared to the current system for two scenario combinations

<table>
<thead>
<tr>
<th></th>
<th>ENGLAND C-SB</th>
<th>WALES C-SB</th>
<th>ENGLAND G-UD</th>
<th>WALES G-UD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current System Plus</td>
<td>Water Shares</td>
<td>Current System Plus</td>
<td>Water Shares</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition costs to Government</td>
<td>18</td>
<td>20</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td><strong>TOTAL COSTS</strong></td>
<td>18</td>
<td>20</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td><strong>Benefits/ Cost Savings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in production gross margin: business</td>
<td>7</td>
<td>22</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Administration cost savings: Government</td>
<td>81</td>
<td>72</td>
<td>80</td>
<td>71</td>
</tr>
<tr>
<td>Administration cost savings: business</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Adaptation cost savings for business</td>
<td>358</td>
<td>358</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td><strong>TOTAL BENEFITS</strong></td>
<td>483</td>
<td>488</td>
<td>141</td>
<td>138</td>
</tr>
<tr>
<td><strong>NET PRESENT VALUE</strong></td>
<td>465</td>
<td>468</td>
<td>116</td>
<td>98</td>
</tr>
</tbody>
</table>

**Note:** due to rounding the combined figures do not always total precisely.
Administration costs to Government

7.9 For England, the annual operating costs under both Current System Plus and Water Shares are expected to be lower than the baseline operating costs. These reductions are mainly driven by replacing a complex and expensive mechanism for identifying and investigating potentially harmful individual abstractions, with a simpler mechanism of catchment reviews. Furthermore the reform options tend to reduce the need to change abstraction constraints in a catchment as they tend to reduce risks to the environment.

7.10 In Wales however, the operating costs under Current System Plus and Water Shares are higher than the current system resulting in an average annual administrative cost. Wales’ costs are higher as there are fewer licences in Wales that could be subject to the complex and expensive mechanisms of the current system, hence there is less money to be potentially saved by switching to a reformed system.

Administration costs to business

7.11 The modelling suggests that annual operating costs under both Current System Plus and Water Shares are expected to be lower than the current system operating costs, so again the net effect of reform is a cost saving rather than a cost increase.

Change in adaptation costs to business

7.12 The main driver of this cost category is the change in investment profile made by the regulated water companies. Under some circumstances the more efficient use of water in the catchment under Current System Plus or Water Shares when compared to the baseline can result in a water company being able to make less future investment, or delay the investment from one year to another, while still balancing supply and demand. This generates an NPV benefit for the water company that should ultimately feed through into lower prices for customers. We have not attempted to estimate this second round effect here.

7.13 In other cases water companies are able to engage in the abstraction market, for example by selling abstraction permissions to agricultural and industrial abstractors and replacing the water for their regulated customers by bringing forward investment options.

7.14 This category also includes investments made by other abstractors such as for the construction of new water storage reservoirs on farms, but these have a much smaller impact that changes to water company investment profiles.

Change in production gross margin for business

7.15 These benefits are driven by increased access to high river flows and abstraction trading. Trading allows the purchasing business to generate additional profits above the cost of the trade. It is important to note the trading benefits reflect actual increases in profit to businesses and exclude transfers (i.e. sales values of rights from buyers to sellers).

The significance of these benefits to the overall national NPV figures varies depending on the scenario and catchment.

Benefits to the Environment

7.16 No attempt has been made to monetise the benefits to the environment. All the options are designed to achieve the same environmental outcomes set in legislation. However the options could differ in how quickly and effectively they achieve these outcomes.

7.17 Initial analysis of results suggest that in all catchment case studies the reform options perform better in preventing risks to the environment. This is due to the better links between allowed abstraction and flows and the more efficient process of changing catchment abstraction regulation reducing delays to protecting the environment.

7.18 However there are significant challenges in modelling the processes for changes in licences and the measurement of environmental risk is quite simplistic given that this is not an ecological model. The indicators of environmental risk also do not take into account the
potential for flow requirements to meet environmental objectives to change as the climate changes and ecosystems adapt.

7.19 The catchment case studies show increasing risks to the environment as the climate changes under all options. This is partly an effect of time lags in the modelled approach to constraining abstraction as the climate changes so responses never catch-up with the following climate changes. In actual practice, assessments could be made of future risks and the implications of climate change would be factored into constraints in abstraction to meet environmental objectives. Further work is needed to improve modelling and assessment of environmental risks under different options prior to the Final Impact Assessment.

Variation in results by scenario combination

7.20 Figure 13 and Figure 14 show that results vary across the different scenario combinations with the variation generally being greater across climate change scenarios that socio-economic scenarios.

7.21 Looking at the two scenario combinations illustrated on Table 2:

Climate change scenario C: Socio-economic scenario SB

7.22 The Sustainable Behaviour socio-economic scenario sees demand for the public water supply remain fairly constant. The C climate change scenario is unusual in being relatively wetter in the eastern side of the country, compared to other scenarios; nevertheless the Cam and Ely Ouse and Stour catchments are both predicted to be short of water by 2025. The Usk catchment is also expected to be short of water by 2050. The Hampshire Avon however is expected to have water available throughout the modelling period.

7.23 Less than 35% of the catchments for which benefits could be estimated are categorised as Enhanced (Trading) in 2025. By 2050 this has risen to around 40% of catchments. Less than 10% are categorised as Enhanced (Environmental) by 2050 (see Table *).

7.24 Most of the Net Benefits arise from adaptation cost savings to business and this comes largely from the water companies being able to defer capital expenditure under the reform options. Some reservoir building is observed and generally low levels of trading. The exception is in the Cam and Ely Ouse where there is significant permanent licence trading activity under Current System Plus compared to the current system, with the agriculture sector the biggest buyer of abstraction permissions. Under Water Shares there are also a number of significant permanent share transfer trades occurring but there is also significant activity in the short term multi-lateral allocation market, with most trades from agriculture to agriculture.

7.25 Overall the benefits from changes in production gross margin are small. Increases in administration costs in Wales also contribute to the reduction in net benefits in this scenario.

Climate change scenario G: Socio-economic scenario UD

7.26 The Uncontrolled Demand socio-economic scenario has the highest demand growth for the public water supply, and the G climate change scenario is relatively dry. While both Hampshire Avon and Usk are predicted to have water available in 2025 all the modelled catchments will be short of water by 2050.

7.27 In England around 30% of the catchments for which benefits could be estimated are categorised as Enhanced (Trading) in 2025. By 2050 this has risen to around 46% of catchments. Less than 10% are categorised as Enhanced (Environmental) by 2050.

7.28 Most of the Net Benefits arise from savings in administration costs, with modest adaptation cost savings arising mainly, as for the Best Case (Scenario C & Sustainable Behaviour), from the Public Water Supply deferring capital expenditure.

7.29 As in C-SB, the most significant levels of trading are seen in Cam and Ely Ouse.

7.30 In Wales, all catchments are categorised as Basic in 2025. By 2050, 37% of catchments for which benefits can be estimated are categorised as Enhanced (Environment) under both reform options and just 16% as Enhanced (Trading). The small additional benefits arising from
positive changes in production gross margin for business, administration and adaptation cost savings for businesses under Enhanced (Trading) reform are very similar to the additional costs to Government of administering the reforms in Wales.

**Variation of results by catchment**

**The Stour**

7.31 Under C-SB the Stour catchment is predicted to be short of water by 2025 although public water supply demand growth between 2025 and 2050 is relatively flat. Current System Plus reform is cost beneficial so the catchment is classified as Enhanced from 2025. The average annual net benefit (undiscounted, and excluding transition costs) is estimated to be £1.5 million. Around 90% of the net benefit (£1.3 million) is due to a reduction in the equivalent annual investment required by water companies, with 6% due to an increase in production and 4% due to administrative cost savings. Trading activity is not very significant. The catchment is also classified as Enhanced from 2025 under Water Shares. The average annual net benefit is very similar, around £1.5 million, with 90% of the net benefit again due to a reduction in water company investment. The increase in production contributes 7% of the net benefit and administrative costs savings contribute 3%. Most trading activity in the short term multi-lateral allocation market is from agriculture to agriculture or from agriculture to horticulture. There is a small increase in the number of agricultural and horticultural reservoirs being built.

7.32 Under G-UD the Stour catchment is again predicted to be short of water by 2025 and in this case the demand for the public water supply continues to grow strongly between 2025 and 2050. The PWS demand growth results in more significant trading activity between water companies under both Current System Plus and Water Shares, resulting in more permanent abstraction permission transfers and an increase in capital investment under both policy options compared to the current system. However, the gain in production profits from non-PWS trading are not sufficient to make reform cost beneficial overall, so the Stour catchment remains classified as Basic by the aggregation model under both Water Shares and Current System Plus.

**Hampshire Avon**

7.33 Under C-SB the Hampshire Avon catchment is predicted to have water available in 2025 and in 2050. It is therefore classified as Basic, and the average annual net benefits of around £90k arise purely from administrative cost savings.

7.34 Under G-UD the catchment is predicted to have water available in 2025 but be short of water by 2050. Demand for the public water supply continues to grow strongly between 2025 and 2050. Current System Plus reform is almost cost neutral. The water companies are able to defer capital expenditure, resulting in an equivalent annual saving of around £0.4 million, but this is offset by loss of profit on production, especially in the agricultural sector. There is also greater investment in reservoir capacity. There is significant trading activity under Current System Plus compared to the current system (permanent licence transfers), with the agriculture sector the biggest buyer of abstraction permissions by value. Water Shares reform is cost beneficial so the catchment is classified as Enhanced from 2037. The average annual net benefit (not discounted, and excluding transition costs) is estimated to be £0.2 million, most of the benefit arises from water companies deferring capital expenditure.

**Cam and Ely Ouse**

7.35 Under C-SB the Cam and Ely Ouse catchment is predicted to be short of water by 2025. However, the ABM model predicts a net cost to the catchment if Current System Plus reform were to be implemented from 2025 of around £0.3 million (annual average, not discounted, excluding transition costs). As in the Stour example, the water companies are able to defer capital expenditure resulting in an equivalent annual saving of around £0.5 million, but this is offset by loss of profit on production, especially in the agricultural sector. There is also greater investment in reservoir capacity. There is significant trading activity under Current System Plus compared to the current system (permanent licence transfers), with the agriculture sector the biggest buyer of abstraction permissions by value. Because Current System Plus reform results in a net cost in this case, in the Aggregation model the Cam and Ely Ouse catchment
would fail the cost:benefit test and would remain as a Basic catchment. The situation is similar under Water Shares, with a net cost to the catchment if reform were to be implemented from 2025 of around £0.4 million annual average. There is a saving in the equivalent annual investment required by the water companies of around £0.2 million but this is offset by a loss of profit on agricultural production. As with Current System Plus, there are a number of significant permanent share transfer trades occurring but there is also significant activity in the short term multi-lateral allocation market, with most trades from agriculture to agriculture.

7.36 Under G-UD the Cam and Ely Ouse catchment is again predicted to be short of water by 2025 and demand for the public water supply continues to grow strongly between 2025 and 2050. Current System Plus reform is cost beneficial so the catchment is classified as Enhanced from 2025. The average annual net benefit (not discounted, and excluding transition costs) is estimated to be £0.2 million. Water companies are able to defer capital expenditure which results in an equivalent annual saving of around £0.4 million, which is offset by a reduction in production profit of £0.2 million. There is a greater investment in agricultural reservoir capacity compared to the current system, and quite a high level of trading activity with water companies trading for permanent licence transfers with other water companies and with the agricultural sector. Water Shares reform is also cost beneficial, so the catchment is classified as Enhanced from 2025. The average annual net benefit is very similar to Current System Plus (around £0.2 million), but the permanent transfer of shares from agriculture and industry to the water companies is greater so the net effect is an equivalent annual saving of £0.9 million by the water companies offset by a reduction in production profit of £0.7 million. There is a considerable volume of short term allocation trading, with most trades from agriculture to agriculture.

7.37 Under C-SB the Usk catchment: has water available in 2025 but is predicted to be short of water by 2050. Current System Plus reform is cost beneficial so the catchment is classified as Enhanced from 2037. The average annual net benefit (undiscounted, and excluding transition costs) is estimated to be £1.6 million, and all of the benefit is because the water companies are able to defer capital expenditure, resulting in an equivalent annual saving of around £1.6 million. There is very little net impact on the other sectors in the catchment, although administrative costs increase by around £40k. There is very little trading observed. The average annual net benefit with Water Shares reform is estimated to be £1.9 million. The saving in equivalent annual water company investment is £2.1 million, but profit on production is reduced by £0.1 million. There is a small amount of activity in the short term multi-lateral allocation market, with most trades from agriculture to agriculture.

7.38 Under G-SB the Usk catchment: has water available in 2025 but is predicted to be short of water by 2050. Demand for the public water supply continues to grow strongly between 2025 and 2050. The Usk is one of only 3 catchments in Wales classified as Enhanced from 2037 under this scenario, which explains why reform can be cost beneficial in the Usk but marginal for Wales as a whole. For Current System Plus, the average annual net benefit (not discounted, and excluding transition costs) is estimated to be £0.7 million. Around 95% of the net benefit is due to a reduction in the equivalent annual investment required by water companies, with 5% due to an increase in production profit. Water Shares reform is also cost beneficial, with almost 100% of the net benefit due to water company savings, but the average annual net benefit is reduced to £0.6 million because of the higher administration costs. There is a very low level of trading in permanent share transfers but some short term allocation trading, mostly from agriculture to agriculture.

Sensitivity analysis

7.39 The discussion above demonstrates how the overall NPV of the options depends crucially on how a number of different factors play out and that this can vary between different scenario combinations and catchments. It is therefore important to understand how the overall findings
may change with changes in the assumptions that have been made. For the Consultation Impact Assessment we therefore carried out a series of sensitivity tests.

7.40 The results of a number of sensitivity tests carried out to-date are described below.

**Economic Growth Rates**

7.41 The absolute level of the benefit is sensitive to assumptions made about the maximum levels of growth that agents can achieve. Growth is a function in the model of decisions made by agents (which in turn are influenced by a wide range of factors including estimates of product prices under each of the socio-economic scenarios). However, constraints on growth such as physical or funding constraints are not explicitly included in the model. To account for this the model assumes that no individual agent can grow more than 3% a year (year on year, not accounting for inflation). Most of the agents grow at a rate below this, and many face negative growth, hence the 3% growth does not get applied very often. While 3% may be appropriate at sector level, it doesn’t reflect the ability for individual agents to grow more rapidly than this. Also agent growth at higher rates may act as a surrogate for new agents entering the market. For these reasons we investigated the sensitivity of increasing the maximum rate to 10% per year.

7.42 Figure 15 and Figure 16 show the illustrative results of this analysis for England and Wales, respectively, shown as new levels of overall absolute Net Present Value. While there is generally a small increase in the overall benefit of reform in England under Current System Plus there are some scenarios where the benefit is reduced slightly (Scenarios are represented on the horizontal axis; the notation indicates climate scenario followed (after a hyphen) by socio-economic scenario). This is usually caused by growing agents making decisions about water which then result in changes in PWS investment sequencing. These changes tend to involve moving large value investments forwards or backwards by one or two years, and introduce a certain amount of noise to the NPV calculations. However the additional flexibility of the system under Water Shares is observed to produce significant extra benefits in all scenarios considered so far, with average 25-year NPVs benefits under Water Shares almost doubling. Overall Water Shares becomes the more attractive policy in almost all the scenarios.

7.43 While there is a similar story in Wales, the case for reform still remains marginal with some scenarios continuing to show disbenefits, albeit reduced somewhat compared to the initial analysis\(^{17}\).

---

\(^{17}\) With so many catchments classified as basic in Wales (e.g. low water scarcity) there are fewer opportunities for benefits to accrue from the improved economics and therefore costs still outweigh benefits in many scenarios.
7.44 It is difficult to decide what an appropriate ‘base case’ value should be for this parameter and will continue to be the subject of sensitivity analysis.

**Agent Behaviours**

7.45 Agents are modelled as making decisions in order to achieve profitability, but the level to which they act with complete economic rationality can be varied.

7.46 Thus while agents do take expected profit into account when they make decisions about production levels and future investment and adaptation options, agents can be modelled as acting in a number of sub-optimal ways, such as:
1. Only considering a sub-set of production levels and the investment options
2. Accepting satisfactory profits, and being reluctant to change until overall profitability is threatened
3. Imitating peers rather than calculating their own optimum strategies
4. Making decision based on their most recent experience rather than with a longer term perspective, and
5. Being unwilling to sell unused water even if there was economic advantage to do so.

In the initial model runs it was assumed that agents are fully rational in their willingness to engage in trading and would:
- sell unused water, and
- be prepared to reduce production if the selling the water was more economically advantageous.

However, assumptions in areas 1-4 were adopted, that will generally lead to many agents not trying to economically optimise their decision making. Instead, most agents will only consider changing behaviour if they are starting to be loss making; otherwise they continue doing what they are currently doing, but are influenced to consider change if other (more innovative) agents are being successful with a different product or strategy.

This sensitivity test explored the impact of assuming that the majority of agents are more autonomous and economically rational, and are prepared to more regularly consider the most profitable product selection and production volumes. In reality, agents are likely to learn over time - it should be noted that the modelling assumptions do not fully factor for this. If they are followers, the choices are biased toward the choices others have made. The behavioural patterns do not change, but the choices made by innovative agents do change over time, and so actual agent behaviour does vary over time.

An increase in the level of economic rationality assumed has limited effects on the NPVs under Current System Plus in England. However, there is significant increased economic benefit under Water Shares, and this reform option becomes the more attractive option in the majority of scenarios considered so far (see Figure 17). There is a similar effect in Wales, although the case for reform still remains marginal (Figure 18).

**Figure 17: Impact of increased economic rationality on reform benefits for England**
The Impact of Water Abstraction Reform

Figure 18: Impact of increased economic rationality on reform benefits for Wales

Aggregation scaling

7.51 Aggregated results for England and Wales are compiled by scaling up the costs and benefits observed in the four modelled catchments. The final outputs are sensitive to a number of assumptions in the scaling process.

7.52 In particular:
1. Annual average costs and benefits from the four catchment models are combined (using a weighted average approach) to generate figures that are considered representative of each of the 116 real catchments.
2. Each catchment is assumed to have the most beneficial policy applied to it correctly and in a timely fashion by the Environment Agency and Natural Resources Wales

7.53 The sensitivity of the aggregation results to variations in the annual average costs and benefits has been explored by varying the two components with the largest uncertainty:
- Annual adaptation costs\(^{18}\)
- Production gross margin\(^{19}\)

7.54 Figure 19 shows the effect of varying the calculated adaptation costs by ±20%. Figure 8 shows the impact of varying calculated production gross margin by ±20%. The central bars on the charts show the 25-year NPV benefit for the base case scenario. The purple boxes show the range over which these NPVs vary in response to the applied sensitivity test. Overall results are much more affected by variations in adaptation costs than gross margin, and these are generally only material in the representative high case scenario (C-Sustainable Behaviour or C-SB). This reflects the fact that when there are significant benefits arising from reform one

---

\(^{18}\) The most significant adaptation costs are associated with PWS investment options. These are drawn from published Water Resource Management Plans, but a number of simplifications and assumptions have had to be made when considering how and when options might be selected. Further, in some instances we have had to extrapolate beyond existing WRMPs to estimate demand and supply curves and likely future options.

\(^{19}\) Each agent is modelled as manufacturing/growing one or more products. Production costs are modelled as varying with production volumes. Income is derived from selling the product for the current market price. Production gross margin is the aggregated profits from all agents, which are influenced by changes in water costs, market prices and each agent’s ability to access water under the various policies. Gross Margin is defined as sales minus cost of sales. This includes fixed and variable costs of production but excludes other costs such as financing costs.
of the largest contributions comes from being able to delay capital investment projects through improved water availability and resource management.

Figure 19: Impact of 20% variation in adaptation costs on reform benefits in England and Wales

Figure 20: Impact of 20% variation in production gross margin on reform benefits in England and Wales

Aggregation sensitivity

7.55 One further limitation of the aggregation model methodology is that it assumes the regulator has perfect knowledge of whether reform will be cost beneficial in a catchment, just before the decision is taken on whether to implement Basic or Enhanced reform. In reality the wrong decision could sometimes be taken, so a catchment may see net benefits that are smaller than predicted or even net costs.

7.56 In order to test the sensitivity of this assumption the aggregation model was re-run, but allowing catchments to be classified as Enhanced even if this would result in net costs of up to and including £200k per year on average, this being the typical size of losses that are currently excluded with ‘perfect’ decision making. The results are summarised in Table 7 below for England (the sensitivity test makes very little difference for Wales).

<table>
<thead>
<tr>
<th>Scenario and policy option</th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPV</td>
</tr>
<tr>
<td>C-Sustainable Behaviour - Current System Plus</td>
<td>438</td>
</tr>
<tr>
<td>C-Sustainable Behaviour - Water Shares</td>
<td>446</td>
</tr>
<tr>
<td>G-Unconstrained Demand - Current System Plus</td>
<td>85</td>
</tr>
<tr>
<td>G-Unconstrained Demand - Water Shares</td>
<td>73</td>
</tr>
</tbody>
</table>

Table 3: Sensitivity test results for imperfect decision making on catchment reform
7.57 Table 3 shows that the G-Unconstrained Demand scenario is quite sensitive to the assumption of perfect decision making. This is because this scenario has more catchments classified as Basic with assumed perfect knowledge of the cost-benefit case, so there is more potential for incorrectly implementing Enhanced reform to result in lower net benefits.

Model development after the Impact Assessment

7.58 The analysis carried out in support of the Consultation Impact Assessment, and the continuing process of peer review and consultation, identified a number of areas for further work. We therefore carried out some additional model development work between December 2013 and January 2014 to address some of the more important areas and further explore the potential of the modelling. We addressed the following:

Trading

7.59 We believed that the model was under-reporting the levels of trading that might be expected, particularly under Water Shares, due to an inherent bias against the trading of shares that we have identified in the complex interactions between agents and their assessment of water reliability. We had included some simple measures to compensate for this bias in the modelling for the Consultation Impact Assessment, but believed a more sophisticated approach was required to provide confidence in the ability of the model to distinguish between the two reform options.

7.60 We also identified a number of areas where agents’ analysis could be improved to support decision making. In particular, the reform policies being considered make fundamental changes to the way that water is made available to abstractors. The thinking processes that agents need to adopt in order to reason about their situations are different under each option. We found a number of areas where their analysis, especially under Water Shares, was likely to result in the benefits of the policy being under-estimated. Areas improved included:

- Analysis and assessment routines concerned with agents estimation of:
  - the reliability of water in share groups they do not yet own
  - the volumes of water that are likely to be available over the short term
  - the volumes of water required to meet a dry year design case
  - the impact that new storage will have on their operations
- Agent bid management
- Calculation of the Market Balancing Price in small / thin markets.

Agent characterisation

7.61 We found that the results for an individual catchment are sometimes dominated by the impact of a small number of economically significant agents. Within each sector distributions are highly skewed in terms of size of abstraction and economic significance. So while the characterisation may be right for most agents in a sector, one or two individual agents may continue to drive the overall economics. We therefore carried out a review of agent characterisation and implemented improvements to:

- Horticulture - Modelling of rain water storage
- Industrial - Water quality and process usage issues
- Business services - Especially high margin/small volume water users
- PWS agents who only have a very small WRZ overlap with the modelled catchments
- Default agents - Improvements to agent sector classification has reduced the number of agents given default behaviour (and who simply carry on doing what they have always done).
We also found that the results could be sensitive to production decisions that had nothing to do with water. We therefore examined the modelling of production processes and implemented improvements in the areas of cost-cutting processes and consideration of the economics of stopping production.

**Transition**

Finally, detailed examination of model outputs suggested that the licence transition process described in Chapter 5 had been incorrectly applied to the transition of summer licences. This had led to a greater increase in licensed volumes under Current System Plus for some agents than was warranted. A correction was applied in the ABM to remove this effect.

**Overall impact of changes**

It was difficult to predict how each of these changes would affect the results. But overall we expected them to lead to an increase in the benefits attributed to the reform options (Current System Plus and Water Shares) relative to the current system.

Again the importance of testing the sensitivity of the results to the key assumptions and simplifications was recognised and a number of additional sensitivity tests were devised in the areas of:

- Environmental limits
- Additional behavioural tests, and
- Trading inertia.

**Case study findings**

The full aggregation was not repeated so the focus of this work was on the case study modelling. We generated summary results showing the reform options compared to the current system and compared each to the other for a catchment under all 16 climate change and socio-economic combinations under consideration. The results were also compared to the catchment level results that were used to support the Consultation IA for two of the catchments. We then ‘drilled down’ into the more detailed results to explore the different features and effects that could be observed in the higher level results including providing individual agent examples of particular effects where relevant.

We are just beginning to ‘get to grips’ with the richness of data available from the models. Our current focus has been on confirming the model is adequately capturing the many hydrological, behavioural and economic processes at work, and exploring the way the options are working at the abstractor level. We have had limited time to process the outputs in detail but hope that the results presented here give a flavour of what is possible from the model.

We have focussed on three catchments: The Stour, the Hampshire Avon and the Cam and Ely Ouse. We have generated similar results for the Usk, however, these revealed an issue with the set-up of the reservoirs in the catchment that we will continue to explore going forward.

For each catchment we first present a single sheet graphical overview of the results in the standard formats shown in Figure 21, Figure 22 and Figure 23.
Figure 21: Net benefit of each reform option compared to the current system presented by socio-economic (SE) and climate change (CC) scenario

Figure 22: Net benefit of each reform option compared to the current system presented by increasing net benefit
Policy Comparison: Ordered by decreasing net benefit under Water Shares

Current System Plus
Water Shares

In this example, most scenarios show net benefits.
Red exposed = WS better
Blue exposed = CSP better
Purple = position of other policy

Four scenarios when WS has net cost, but CSP has net benefit

Three scenarios when both policies show net dis-benefit

Figure 23: Policy comparison – comparison of net benefits of Current System Plus and Water Shares
The Impact of Water Abstraction Reform

The Stour

**Figure 24: Stour overview**

In the policy comparison plot for positive benefits:
- Red exposed = Water Shares better
- Blue exposed = Current System Plus better
- Purple = position of other policy

The scenario combinations marked with * were chosen for more detailed investigation and sensitivity analyses.
7.70 Figure 24 shows that:

- Reform provides benefits in all scenarios
- Most of the benefit arises from production growth factors
- Variation in benefits are due to investment timing. This is dominated by PWS investments being brought forward
- The variability of the results is greater between climate change scenarios, that it is between socio-economic scenarios except under unconstrained demand (UD)
- Water Shares in general delivers less benefit than Current System Plus.

7.71 It is not surprising that Water Shares performs less well than Current System Plus in this catchment. This is because the opportunities for abstractors to take advantage of some of the key aspects of this option are limited. Most agricultural abstractors are in the Level Managed Areas which in this catchment fall below the last Assessment Point. Thus they are not allocated shares under the Water Shares policy and are not able to trade with others in the catchment. Since most abstractors are located in the managed levels, put and take trading could be particularly useful in this circumstance. However, this mechanism is not currently included in the model. This has been identified as an important mechanism for inclusion for the Final Impact Assessment.

Comparison with the Consultation IA results

7.72 The figures show that in general the calculated benefits have increased. The results are more consistent, due to improvement in the production process algorithms and agent characterisation, which reduces the likelihood that agent decisions not directly related to water availability under each option, are affecting the results. This still remains a possibility however, and this has a more significant impact where the economics in a catchment are dominated by a few large players. We revisit this below.
Results by sector

Climate Change: C
Socio Economic: Uncontrolled Demand

Figure 26: Average annual benefit by sector

7.73 The figure shows the sectoral distribution for C-UD. Agriculture, the PWS, and Sports and Recreation make the most significant gains under reform compared to the current system. All other sectors perform very similarly under reform as under the current system.

7.74 Agriculture and Sports and Recreation gains come from improved productivity (primarily driven by agents being able to make use of high flows water, and increased trading resulting in better matching of licensed water/allocation with actual demand). It should be noted that in Figure 26 inter-sectoral trading is separately identified (Intra-sectoral trading is not).

7.75 PWS gains occur because they are able to use trading to either directly delay their own investment, or to ensure that at a catchment level PWS investment is provided at the lowest overall cost (e.g. one PWS agent buys water from another PWS agent. The first one delays an expensive option, while the second brings forward a cheaper one).

Investment costs/benefits in the Stour

7.76 The principal contributor to this category is the variation in PWS option investment costs. The main trigger of large scale investment is licence reductions imposed by the Environment Agency or Natural Resources Wales to limit environmental damage. Where a reform option allows investment to be delayed, this delivers benefit. In the majority of the scenarios modelled, we see investments being delayed under reform compared to the current system. The investment benefit is generally very similar under Current System Plus and Water Shares. The exception is scenario J-UD where the investment benefits under Current System Plus are much higher than under Water Shares as shown in Figure 26.

7.77 Figure 27 shows what is happening in more detail. The figure compares the situation as modelled under the Current System Plus with the situation under Water Shares for one water company in the catchment.

7.78 Increased demand and a drier climate lead to increasing pressure on water resources in the catchment. Under both reform options take back processes are triggered in 2040 resulting in significant reductions to PWS licences. In response, the PWS agent illustrated in this example implements a number of measures to reduce the shortfall. A second take back occurs in 2046.

---

20 The average annual benefit is the equivalent annual amount that, when entered into the Impact Assessment template, generate the same overall NPV
The amount of water taken back from each of the three PWS agents operating in the catchment varies with each option and in each scenario. In the scenario shown the particular combination of the timing, level and location of environmental damage means that this PWS agent bears a larger proportion of the take back in 2040 under Water Shares compared with Current System Plus.

This highlights an issue that needs further analysis for the Final Impact Assessment. The available options collated from water companies’ WRMPs tend to include a range of smaller low cost options and larger more expensive capital projects. Initial shortfalls are typically resolved using a combination of the smaller options to produce a solution that is just big enough. Later shortfalls then have to be addressed using a smaller subset of the remaining larger options, which consequently often cannot be used as efficiently. In reality, water companies often find that additional smaller options emerge at each progressive WRMP cycle, and the larger capital projects can get pushed back in time. The model does not currently anticipate this discovery process, and so may be over-estimating both the size and less efficient application of options to meet the shortfalls that occur in later years. When fewer, larger options remain, a small change in shortfall between options can trigger a significant change in the cost and/or timing of investment choices. Thus the predicted investment benefits can be sensitive to small changes in water availability.

We propose addressing these effects in the next phase of work by updating the options lists to include information from the most recent WRMPs and by adding ‘discovery options’ that only become active from, say, 2040.

Figure 27: Example of investment prompted by environmental protection measures

The total volume required is similar but a greater volume is required for this PWS agent to reduce its shortfall. The agent has to select a larger and more expensive transfer option compared with CSP.
The Hampshire Avon

Figure 28: The Hampshire Avon overview

In the policy comparison plot for positive benefits: Red exposed = Water Shares better, Blue exposed = Current System Plus better, Purple = position of other policy.
7.82 Figure 28 shows that:

- Reform produces benefits in all but one scenario. In scenario A-UD both Current System Plus and Water shares show a small reduction in benefit compared with the current system.
- Production benefits are fairly constant between scenarios with the variation being driven by differences in investment timing.
- Water Shares generally delivers higher benefit than Current System Plus.
- Variability of the results is greater between climate change scenarios, than it is between socio-economic scenarios.

7.83 In the Hampshire Avon catchment there are greater opportunities for agents to benefit from the extra flexibility provided by Water Shares compared with the Stour catchment (where most agricultural abstractors are located below the last Assessment Point and are therefore not allocated shares).

Results by sector

<table>
<thead>
<tr>
<th>Climate Change:</th>
<th>Socio Economic:</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Uncontrolled demand</td>
</tr>
</tbody>
</table>

![Figure 29: Average annual benefit by sector](image)

7.84 In the Hampshire Avon, the largest benefactors are the PWS and aquaculture. While aquaculture is highly non-consumptive, many aquaculture agents have 10% consumptive licenses, and also have other licences with some consumptive element associated with other aspects of their operations (e.g. salad growing). The sector is a very large volume abstractor and so even a small change in productivity can realise significant economic benefits in the model.

**Investment costs/benefits in the Hampshire Avon**

7.85 Environmental take back in 2046 for the current system and two reform options is shown in Figure 30 for Scenario C-UD. Less water is taken back under reform than under the current system meaning that less investment is required to make up the shortfall and investments can be delayed.

---

21 The average annual benefit is the equivalent annual amount that, when entered into the Impact Assessment template, generate the same overall NPV.
We see the impact of this on Figure 31 below.

Figure 31: Example of PWS investment

Large take backs towards the end of the modelling period are not untypical, and these are generally accompanied by PWS investment to address the shortfall in supply the take back creates. If an option allows investment to be delayed this delivers investment benefit. This can therefore be a key driver of benefit. It is also an indicator of the efficacy of the option in protecting the environment. We therefore examined the model and model results carefully to ensure that the key processes were being captured.

We found that in many incidences the environmental protection measures are not particularly effective in preventing environmental damage. Examination of the ABM, and some simple tests for example running the model under an unchanging climate sequence, suggest that a large part of the explanation is the worsening climate and time lags inherent in the licence take back processes. However, this does not explain why e.g. the 14 day allocation system under Water Shares does not appear to be having a greater impact. This may be a real feature of the option design, or elements of the transitioning process. However, it could, at least in part, be a modelling artefact and in particular may be related to the modelling of groundwater.
Groundwater and surface water are regulated differently under the reforms meaning that when surface water allocations are reduced, agents will turn to groundwater to manage deficits or facilitate growth where they can. We observe this happening in the modelling. If the groundwater aquifers are coupled too tightly to surface water base flows this means that this ‘rush to groundwater’ observed in the modelling is having a more immediate impact on flows in rivers than it would in practice and that the model is seeing breaches of environmental limits and subsequent triggering of buy back which in reality wouldn’t happen. It would not be possible to implement sophisticated groundwater modelling, but there are some improvements that we are currently exploring which may enable the modelling to more accurately represent the delay between ground water abstraction and base flow impacts which is known to occur for some systems. We plan to include this in the modelling for the Final Impact Assessment, or as a minimum to explore the sensitivity of the results to assumptions made in the current approach.
The Impact of Water Abstraction Reform

The Cam and Ely Ouse

In the policy comparison plot for positive benefits: Red exposed = Water Shares better, Blue exposed = Current System Plus better, Purple = position of other policy.

Figure 32: The Cam and Ely Ouse overview
7.90 Figure 32 shows that:
- Benefits are predominantly due to production growth factors
- Current System Plus generally delivers higher benefit than Water Shares
- Variability of the results is greater between climate change scenarios, than it is between socio-economic scenarios.

7.91 Looking at these results and the other two case studies presented above we see no strong, consistent pattern of results across the scenario combinations. Intuitively we would expect that the reform options would provide more benefit in the more challenging scenarios e.g. G-UD, J-UD, and the least benefit in the least challenging scenarios e.g. A-SB. We do not see this. There are several reasons for this:
- All the climate scenarios represent drying climates, some are more extreme than others, but the impact varies geographically. Within each climate sequence there is a pattern of wet and dry years, and within years changing seasonal patterns (wetter summers, drier winters and vice versa).
- In very dry years, or periods of high demand (e.g. following a large environmental take back) there may be a shortage of abstractors willing to sell or lease their entitlements, meaning that the options cannot operate as effectively in very challenging scenarios.
- Water challenges often do not really begin to bite until the end of the modelling period, at which time the take back/buy back environmental protection mechanisms are triggered. The size of the take back experienced by each individual agent will vary depending on a wide range of factors (for example, the location at risk, the nature of their abstraction). As described above, the ‘lumpy’ nature of PWS responses may be masking some of the impact of the reforms.
- Finally, in a similar vein, decisions by some large economically significant agents can differ between options, and the consequences of these may dominate the economic results at the catchment level. While these decisions (e.g. whether to grow or not) are related to their judgement of the reliability of water and their options under the reforms, they are not necessarily fully economically rational and will not be based on perfect knowledge of the unfolding climate. They may mask differences between the options. This is particularly the case in the Cam and Ely Ouse where there are a small number of highly economically significant agents, but may also occur in other catchments.

7.92 All these factors confound easy comparison of results for the different catchments and scenarios.

**Comparison with the Consultation Impact Assessment**

![Comparison with previous analysis](image)

7.93 Again the figures show that in general the calculated benefits have increased. The results are again more consistent, due to improvement in the production process algorithms and agent characterisation. However, this catchment has a small number of large economically significant agents that can impact the results, and although the modelling of these agents has
improved since the Consultation Impact Assessment the results will be sensitive to their decision making as described above.

**Results by sector**

<table>
<thead>
<tr>
<th>Climate Change</th>
<th>Socio Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Sustainable Behaviour</td>
</tr>
</tbody>
</table>

![Figure 34: Average annual benefit by sector](image)

7.94 The example sectoral split shown in the Figure 34 demonstrates the extent to which industry is dominating the results. This sector is dominated by a small number of large agents. Production growth benefits for these agents are greater under Water Shares than under the current system, and greater under Current System Plus than under Water Shares. This does not mean that industrial agents are growing more strongly under reform. It may be that growth is remaining constant or falling less rapidly than under the current system, or as agent growth can be a surrogate for new entrants in the model, it may be that there is sufficient water available under reform to allow new industrial agents to enter the catchment.

7.95 Detailed examination of the results suggests that the option comparison may be being affected by agent decisions influenced by factors other than water availability and the options, and that this may be affecting in particular the comparison between Water Shares and Current System Plus. These effects do not invalidate detailed exploration of how the options are supporting or constraining agents, but may be affecting the catchment level economic comparisons. To be confident in these comparisons we have to remove any remaining biases. This will be an important task for the Final Impact Assessment.

![Figure 35: Average annual benefit by sector](image)

---

22 The average annual benefit is the equivalent annual amount that, when entered into the Impact Assessment template, generate the same overall NPV.

23 Trading income from Intra-sector trading is not shown as it nets to zero.
Investment costs/benefits in the Cam and Ely Ouse

7.96 In J-UD we see that under Current System Plus the PWS companies bring investment forward overall. Examination of the detailed results shows that the PWS is able to defer investment in the early years compared to the current system. However a large environmental take back in 2046 results in more water being removed from the PWS and less off agriculture and industry compared to the buy back occurring under the current system. The differences may arise for a number of reasons. For example, the damage may be occurring in different places, or the price people are willing to accept for their water may be different under the different regimes. This means the PWS have to invest more heavily in the later years, and at this stage they only have large scale investment options available. This again highlights the importance of including 'discovered' items in PWS option lists.

7.97 Under Water Shares PWS is able to defer investment over the whole period. The lower observed benefit in this scenario is due to the industrial sector not managing to grow as quickly. We have not subjected this output to further analysis at this stage but possible explanations of the poorer performance (relative to the current system) of Water Shares in this scenario are that these industrial agents are short of water at certain times of the year due to the allocation limits or they are less ambitious in their growth plans because their assessment of future reliability is different.

Analysis of Trading Patterns in the Cam and Ely Ouse

7.98 At the start of the project, we highlighted the Cam and Ely Ouse as the modelled catchment where trading was most likely to be significant. The ABM model includes three types of trade between abstractors:

- Lease of permissions (for example, licences or shares)
- Permanent transfer (sale) of permissions
- Trading of allocation for a 14 day period

7.99 All these trades involve the transfer of permission to consume a volume of water. Thus an abstractor who has a licence to take 1000 m$^3$ but consume 60% of it can only sell 600 m$^3$ of water to someone who wishes to consume all of the water they take. Further, having sold the consumptive element of their permission the seller would then only be able to take water for non-consumptive use.

7.100 Lease of permissions is available to abstractors who temporarily have access to more water than they need, if they can find a buyer. This type of trade is modelled as an annual lease, though in practice the leases may be let for more than one year at a time (e.g. over five years). In the model we often see agents renewing the lease every year.

7.101 Permanent transfer (sale) of permissions is possible under all policy options. This type of trade provides long term access to water, and new entrants may prefer the security provided by buying permanent permissions. Abstractors may offer permissions for permanent sale when business requirements change their long term requirements. In the model abstractors will permanently sell permissions where their decision making suggests that the realised value of a sold licence is worth more than the NPV of future production income.

7.102 Trading of allocation for a 14 day period is only possible under Water Shares. This type of trade has no effect on an abstractors long term abstraction permissions. It provides a guaranteed quantity of water over a period that is not affected by the weather over that period.

Differences between options

7.103 Under the current system abstraction trading is possible but not straightforward. Each individual trade is subject to 3 month approval procedures by the regulator and abstractors have to find willing trading partners independently. Short term trades are generally not feasible due to the slowness of the system. Trading is currently rare.

7.104 Under Current System Plus low risk water trades would be pre-approved so some trades would be processed almost immediately. The majority of low risk trades that could be pre-
approved would be temporary trades involving abstractors trading with other abstractors down stream of them. The system would inform all abstractors which trades were pre-approved to facilitate trading.

7.105 Under Water Shares it will be possible to pre-approve trades upstream as well as downstream. Abstractors will also be able to make short-term trades during the period of allocation, or by transferring water through put and take trading, without impacting their long term entitlements. So a wider range of trades will be possible with low transaction costs than under the current system or Current System Plus.

7.106 The different trading mechanisms and rules are included in the model with the exception of ‘put and take’ trading, which is not currently implemented. We also model the differences in relative ease of trading between the options:

- Trading between water companies already happens through a range of formal agreements and so the model assumes that the reform options have no effect on the likelihood of such trades happening in the future
- For non PWS agents:
  - The existence of pre-established low-risk trade rules, and arrangements to make it easier to match buyers and sellers, under both reform policies is considered to be far more effective at enabling trading than under the current system
  - Selling/leasing of shares under Water Shares is modelled as being easier than selling/leasing of abstraction permissions under Current System Plus because of the greater number and value of trades anticipated under Water Shares. This is expected to lead to more available and useful brokerage services and a more widespread culture of trading.

7.107 These differences are included in the modelling by:

1. Limiting possible trading partners under current system to those in the same sector, or within 50km of each other
2. Modelling a transaction barrier cost that each trading agent needs to overcome (which varies between policies for non-PWS agents). This effectively increases the price a seller is willing to accept, and reduces the price a buyer is willing to pay, and in turn reduces the likelihood of successful matches being made in the market. The inertia values selected at present are intended to represent both the legal and management costs associated with arranging trades, but also the inertia associated with the perception of additional difficulty. They are smallest for Water Shares, and largest for the current system.

7.108 In general these inertial costs suppress the number of small volume trades since the costs are more material compared to the absolute value of the water being traded. It was considered important to subject these to further sensitivity tests.

7.109 Leasing of permissions is currently possible under all policy options in the model, although in retrospect it would be very unlikely to happen under the current system as the trades would not be pre-approved. For the final Impact Assessment model runs, we recommend that leasing is prevented under the current system.

**Trading patterns**

7.110 The analysis in this section focusses on three scenario combinations from Figure 32 that exhibit different patterns of trading activity.

7.111 **Scenario A-I.** This shows low benefits from reform. Climate scenario A has the wettest summers in the Cam and Ely Ouse and the Innovation socio-economic scenario has a moderate amount of demand growth.

7.112 **Scenario J-UD.** This shows low to medium benefits from reform, and is the only combination where Water Shares outperforms Current System Plus in the current runs. Climate scenario J has the driest summers in the Cam and Ely Ouse and the Unconstrained Demand socio-economic scenario has the highest demand growth, especially for the PWS sector.
7.113 **Scenario C-SB.** This shows high benefits from reform. Climate scenario C has the biggest variation in wet and dry summers in the Cam and Ely Ouse, but the Sustainable Behaviour socio-economic scenario has the lowest demand growth.

7.114 Figure 36 shows the value of the different types of trade recorded in the current model runs for the three scenarios. The financial value and water volumes of lease transactions are small and do not materially affect the results. They are not therefore analysed further here. We will explore why lease trading appears relatively unattractive in the next phase of work.

**Figure 36: Value of trading 2025 - 2050 in the Cam and Ely Ouse, by type of trade**
The permanent transfer of abstraction permissions

7.115 The permanent transfer of permissions from one agent to another generally occurs under one of three circumstances:

- Non-PWS agents that need access to additional consumptive water to increase their production levels, for example to take advantage of increasing prices. This is potentially a bigger issue for agents that have had their licences curtailed due to the transition process.

- PWS agents that have an emerging supply-demand deficit due to demand growth, when trading for a permission is cheaper than bringing forward one of their own supply options

- All agents (but especially PWS) that need to compensate for licence volumes that have been removed through the environmental take back process, when trading is cheaper than investing in a new supply option or reducing production.

7.116 As we have outlined above, permanent transfers between agents are equally likely to be approved or not approved by the regulator under all three policy options so this is not a discriminator between policies. However, we have assumed that the other barriers to trading (such as management time) are slightly lower for non-PWS agents in Current System Plus and Water Shares compared to the current system, which affects prices and therefore trade volumes. It also important to note that the need to trade is a separate issue from the ease of making the transaction.

7.117 Figure 37 compares the cumulative annual volume of permanent transfers under each reform option for the three scenario combinations. We show the cumulative total because, for example, a sale of 100 m$^3$ in 2025 transfers access to 100 m$^3$ of water for every subsequent year.

7.118 Table 4 to Table 6 complement this view by showing the total value of trades over 25 years (undiscounted) and which sectors are trading the most.

7.119 In Scenario A-I the cumulative volume curves for the two reform options are coincident with the current system curve. This is because (i) the trades are 95% by volume and 99% by value from one water company to another (see Table 4), and (ii) PWS to PWS trades are equally likely to occur in all reform options if all other factors are the same. There is an almost constant rate of trades (400 ML per year) until 2036 because PWS to PWS trades are conducted in units of 200 ML at a time in the model.$^{24}$ Almost all of these trades are for ground water licences.

7.120 Because the cumulative volume curves are coincident there is no significant trading benefit from reform for the water companies. There is also very little difference in the environmental take back of licences required in either reform option compared to the current system in this scenario. Thus the water companies are responding in exactly the same way under each reform option, trading with each other purely in response to the moderate PWS demand growth in the Innovation scenario. This probably explains why Scenario A-I has the lowest net benefit from reform overall.

7.121 In Scenario J-UD a much larger licence volume is traded, with the cumulative volume curves climbing to between 6,000 ML and 8,500 ML by 2049 compared to the 4,000 ML reached in Scenario A-I. Almost 100% of these trades are for ground water licences. Table 5 shows that the most significant trade under each reform option is still from one water company to another, and the PWS sector as a whole is the biggest buyer, which is consistent with the high PWS demand growth in the Unconstrained Demand scenario.

7.122 However, the differences between the reform options are now more marked. There are environmental licence take backs in 2034, 2040 and 2046 that trigger licence trades in the one

---

$^{24}$ This was a simplification introduced to help make the modelling tractable, because we found that the marginal value of water sometimes falls as larger volumes are traded, and the model’s trading mechanism is not currently able to manage conditional trades (where a second batch is offered at a lower price if the first batch is traded). This simplification will be addressed in the next phase of work, and it is anticipated that between-PWS trading will increase and/or occur sooner.
or two years following (as can be seen by the kinks in the cumulative volume curves). As was noted previously, proportionally more water is taken back from the PWS agents under Current System Plus in this scenario even though the total buy back volume is smaller than under the current system; as well as triggering investment this also triggers additional licence trades to compensate.

Current System Plus and Water Shares also show higher levels of trading activity for the agriculture and industry sectors in this scenario, reflecting their desire to grow production and take advantage of the higher prices available in an Unconstrained Demand world.

Figure 37: Cumulative annual volume of permanent transfer trades
In **Scenario C-SB** the cumulative volume curves show much lower levels of licence trading, reaching a maximum of 1,500 ML by 2049. Almost all of these trades are for ground water licences. Table 6 shows that the reason for this is a much lower need to trade by the PWS sector, which is consistent with the almost flat PWS demand growth in the Sustainable Behaviour scenario. The environmental licence take backs in 2034, 2040 and 2046 do still trigger licence trades in the one or two years following however under all policy options.

This scenario has the highest overall benefit from reform from production growth (i.e. the largest green bar in Figure 32), and Table 6 suggests that part of this growth is due to licence trading by the agriculture sector, especially for Current System Plus.

### Current System

<table>
<thead>
<tr>
<th>Selling Sector</th>
<th>Buying Sector</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>PWS</td>
<td>16 2,958</td>
<td>2,974</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32</td>
<td>2,990</td>
</tr>
</tbody>
</table>

### Current System Plus

<table>
<thead>
<tr>
<th>Selling Sector</th>
<th>Buying Sector</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>31 2,990</td>
<td>3,021</td>
</tr>
<tr>
<td>PWS</td>
<td>2,990</td>
<td>3,021</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>31</td>
<td>3,021</td>
</tr>
</tbody>
</table>

### Water Shares

<table>
<thead>
<tr>
<th>Selling Sector</th>
<th>Buying Sector</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>PWS</td>
<td>28 2,969</td>
<td>2,997</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>49</td>
<td>3,018</td>
</tr>
</tbody>
</table>

**Table 4: Scenario A-I total value of licence trades over 25 years (undiscounted)**

The figures in the columns are the value of licences bought over the period by each sector from the sector shown in the row.
## Current System

<table>
<thead>
<tr>
<th>Sum of Value £k Selling Sector</th>
<th>Buying Sector</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Industry</td>
<td>PWS</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>368</td>
<td>318</td>
<td>14</td>
<td></td>
<td>700</td>
</tr>
<tr>
<td>Industry</td>
<td>44</td>
<td>70</td>
<td></td>
<td></td>
<td>114</td>
</tr>
<tr>
<td>PWS</td>
<td>216</td>
<td>4,888</td>
<td></td>
<td></td>
<td>5,104</td>
</tr>
<tr>
<td>Others</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>654</td>
<td>0</td>
<td>5,276</td>
<td>14</td>
<td>5,944</td>
</tr>
</tbody>
</table>

## Current System Plus

<table>
<thead>
<tr>
<th>Sum of Value £k Selling Sector</th>
<th>Buying Sector</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Industry</td>
<td>PWS</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>857</td>
<td>6,038</td>
<td>64</td>
<td></td>
<td>6,959</td>
</tr>
<tr>
<td>Industry</td>
<td>659</td>
<td>967</td>
<td>3,221</td>
<td></td>
<td>4,847</td>
</tr>
<tr>
<td>PWS</td>
<td>1,691</td>
<td>8</td>
<td>11,492</td>
<td></td>
<td>13,191</td>
</tr>
<tr>
<td>Others</td>
<td>172</td>
<td></td>
<td>2,219</td>
<td></td>
<td>2,391</td>
</tr>
<tr>
<td>Total</td>
<td>3,379</td>
<td>975</td>
<td>22,970</td>
<td>64</td>
<td>27,388</td>
</tr>
</tbody>
</table>

## Water Shares

<table>
<thead>
<tr>
<th>Sum of Value £k Selling Sector</th>
<th>Buying Sector</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Industry</td>
<td>PWS</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>303</td>
<td>23</td>
<td>1,888</td>
<td>64</td>
<td>2,278</td>
</tr>
<tr>
<td>Industry</td>
<td>326</td>
<td>3,560</td>
<td></td>
<td></td>
<td>3,886</td>
</tr>
<tr>
<td>PWS</td>
<td>1,671</td>
<td>53</td>
<td>13,130</td>
<td></td>
<td>14,854</td>
</tr>
<tr>
<td>Others</td>
<td>63</td>
<td>1</td>
<td>502</td>
<td></td>
<td>566</td>
</tr>
<tr>
<td>Total</td>
<td>2,363</td>
<td>77</td>
<td>19,080</td>
<td>64</td>
<td>21,584</td>
</tr>
</tbody>
</table>

Table 5: Scenario J-UD total value of licence trades over 25 years (undiscounted)

## Current System

<table>
<thead>
<tr>
<th>Sum of Value £k Selling Sector</th>
<th>Buying Sector</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Industry</td>
<td>PWS</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>Industry</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>PWS</td>
<td>22</td>
<td></td>
<td>40</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>105</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>145</td>
</tr>
</tbody>
</table>

## Current System Plus

<table>
<thead>
<tr>
<th>Sum of Value £k Selling Sector</th>
<th>Buying Sector</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Industry</td>
<td>PWS</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>2,137</td>
<td>1</td>
<td>25</td>
<td>12</td>
<td>2,163</td>
</tr>
<tr>
<td>Industry</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2,137</td>
<td>1</td>
<td>25</td>
<td>12</td>
<td>2,175</td>
</tr>
</tbody>
</table>

## Water Shares

<table>
<thead>
<tr>
<th>Sum of Value £k Selling Sector</th>
<th>Buying Sector</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Industry</td>
<td>PWS</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>112</td>
<td></td>
<td></td>
<td>12</td>
<td>124</td>
</tr>
<tr>
<td>Industry</td>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>PWS</td>
<td>1,170</td>
<td>40</td>
<td>1,724</td>
<td>162</td>
<td>3,096</td>
</tr>
<tr>
<td>Total</td>
<td>1,345</td>
<td>40</td>
<td>1,724</td>
<td>174</td>
<td>3,283</td>
</tr>
</tbody>
</table>

Table 6: Scenario C-SB total value of licence trades over 25 years (undiscounted)
Short term allocation trading of surface water

7.126 Surface water allocation trading is used by agents when, under the Water Shares policy option, they see benefit in buying extra two week allocations or selling some of their allocations. This is particularly likely to be true for agents that have a variable water demand such as for spray irrigation.

7.127 Figure 38 shows a summary of the value of allocation trades over 25 years for the three scenario combinations. The pattern of trading is highly variable, with some years seeing no trades and other years seeing trading values of up to £1.4 million.

Figure 38: Summary of the value of allocation trades (undiscounted)

7.128 An agent’s need to buy (or willingness to sell) depends on a number of factors, for example:

- Recent rainfall and the corresponding need to irrigate water sensitive crops
- Production choices made at the start of the year (how much product to make, which crops to grow and over what area)
- The level of water currently available in storage or from other sources.

7.129 The volumes of water offered for sale, and the bid and offer prices in the various trading unit markets, also affect the total value of trades in a year. Not all buyers will be successfully matched to sellers if the market in a particular trading unit is very ‘thin’.
7.130 Figure 39 shows the value of allocation trades in each year and the effective rainfall in the summer months (June – August) for the three scenario combinations. The picture is affected by the other factors listed above, but we often see summers with high rainfall exhibit lower trade values and vice versa. These graphs also show that climate change Scenario A has the wettest summers, Scenario J has the driest summers and Scenario C has the biggest variability between wet and dry summers.

Figure 39: The value of allocation trades and summer rainfall
7.131 Figure 40 shows the volume-weighted average price of all allocation trades in each year and the effective rainfall in the summer months. There is some evidence that the average price increases with time in Scenario J-UD, which reflects increasing demand coupled with a dry climate. Average prices in A-I are generally lower, reflecting the higher rainfall. Average prices in C-SB are more variable, with the peak prices occurring quite early in 2029 and 2037, reflecting the greater variability in rainfall and the flat demand growth.

Figure 40: Volume weighted average trade price and summer rainfall
7.132 Table 7 to Table 9 show summaries of the total volume and total traded value of Water Shares allocation trading over 25 years for each scenario combination. They also show which sectors are engaging in trading. One key point to note is that Agriculture is the main beneficiary of trading as they dominate trading.

<table>
<thead>
<tr>
<th>Selling Sector</th>
<th>Buying Sector - Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of Volume ML</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1,285</td>
</tr>
<tr>
<td>Horticulture</td>
<td>29</td>
</tr>
<tr>
<td>Industry</td>
<td>54</td>
</tr>
<tr>
<td>PWS</td>
<td>60</td>
</tr>
<tr>
<td>Others</td>
<td>42</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,469</strong></td>
</tr>
</tbody>
</table>

Table 7: Scenario A-I total volume and undiscounted value of Water Shares allocation trades over 25 years

<table>
<thead>
<tr>
<th>Selling Sector</th>
<th>Buying Sector - Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of Volume ML</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2,011</td>
</tr>
<tr>
<td>Horticulture</td>
<td>45</td>
</tr>
<tr>
<td>Industry</td>
<td>281</td>
</tr>
<tr>
<td>PWS</td>
<td>16</td>
</tr>
<tr>
<td>Others</td>
<td>314</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,666</strong></td>
</tr>
</tbody>
</table>

Table 8: Scenario J-UD total volume and undiscounted value of Water Shares allocation trades over 25 years

<table>
<thead>
<tr>
<th>Selling Sector</th>
<th>Buying Sector - Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of Volume ML</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2,958</td>
</tr>
<tr>
<td>Horticulture</td>
<td>43</td>
</tr>
<tr>
<td>Industry</td>
<td>117</td>
</tr>
<tr>
<td>PWS</td>
<td>148</td>
</tr>
<tr>
<td>Others</td>
<td>169</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,435</strong></td>
</tr>
</tbody>
</table>

Table 9: Scenario C-SB total volume and undiscounted value of Water Shares allocation trades over 25 years

7.133 Scenario A-I is relatively wet so the volume of water traded and total trade value is the lowest of the three scenarios. The fact that the volume traded in J-UD is lower than in C-SB, but the total value of these trades is higher, suggests that J-UD is more constrained than C-SB. You would perhaps expect to find a greater proportion of unfulfilled trades in the J-UD data due to not enough agents offering water for sale.

7.134 This market liquidity effect is something that will be of interest when considering the design of a future market. The model is capable of generating a record of all bids and offers to trade as well as the record of successful trades, which would give an indication of liquidity in each trading unit. However the data files that are generated are very large and significantly affect model run time so they were not enabled for these model runs. A small selection should be examined for the full Impact Assessment.
Sensitivity analyses

7.135 We explored eight sensitivities in this phase of the work focusing on economic growth, behaviours, environmental protection, the PWS trading and trading inertia. We focused the runs on two of the 16 possible SE/CC combinations G-LR and J-UD in the Stour, Hampshire Avon and Cam and Ely Ouse. G-LR generally delivers good benefits under reform compared to the current system. J-UD delivers lower or more median benefits compared to the current system depending on the catchment.

7.136 We tested the sensitivity to the results to changes in assumptions about economic growth, behavioural characteristics, environmental limits and trading. The table summarises the cases explored.

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Base case</th>
<th>Sensitivity test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Growth</td>
<td>Sector growth capped at 3%</td>
<td>Sector growth capped at 1%</td>
</tr>
<tr>
<td>Higher Independence</td>
<td>90% agents categorised as followers</td>
<td>All agents make their own decisions</td>
</tr>
<tr>
<td>Lower Rationality</td>
<td>Agents are fully rational and will sell spare/less profitable water and make independent decisions about changing production levels</td>
<td>Agents are reluctant to sell spare/less profitable water or change production levels</td>
</tr>
<tr>
<td>Lower rationality, high independence ‘Independent irrationality’</td>
<td>Agents are fully rational and will sell spare/less profitable water and make independent decisions about changing production levels 90% agents categorised as followers</td>
<td>Agents are reluctant to sell spare/less profitable water or change production levels Neither do they follow others. Under this sensitivity tests agents will tend to continue doing what they have always done.</td>
</tr>
<tr>
<td>Lower environmental limits</td>
<td>Intervention occurs when flows fall more than 5% below the NGBF for more than 5% of the time</td>
<td>Intervention occurs when flows fall more than 10% below the NGBF for more than 10% of the time</td>
</tr>
<tr>
<td>Full PWS trading</td>
<td>PWS will sell allocation only if supply exceeds demand by &gt;5%.</td>
<td>PWS will sell allocation if supply exceeds demand.</td>
</tr>
<tr>
<td>No PWS trading</td>
<td>PWS trading allowed</td>
<td>No PWS allowed of any type</td>
</tr>
<tr>
<td>Licence trading</td>
<td>Can occur in current system</td>
<td>No current system Licence Trading</td>
</tr>
</tbody>
</table>

7.137 The rationale for carrying out these tests is described in the following sections.

Reduced growth

7.138 The absolute level of the benefit is sensitive to assumptions made about the maximum levels of growth that agents can achieve. Growth is a function in the model of decisions made by agents (which in turn are influenced by a wide range of factors). However, constraints on growth such as physical or funding constraints are not explicitly included in the model. To account for this the model assumes that no individual agent can grow more than 3% a year (year on year, not accounting for inflation). It was important to explore whether lower growth rates would significantly reduce the benefits available from reform. We therefore applied for this round of sensitivities a cap of 1%.

7.139 While low growth rate caps may be appropriate at sector level, it does not reflect the ability for individual agents to grow more rapidly than this. Also agent growth at higher rates may act as
a surrogate for new agents entering the market. For these reasons we suggest that for the Final Impact Assessment we carry out additional runs to test the sensitivity of increasing the maximum rate to 10% per year.

**Additional behavioural tests**

7.140 As described above, non-Public Water Sector agents are not represented as purely profit maximising, in the same way as they would be in a traditional economic model. In the tests carried out for the Consultation Impact Assessment described above, we found that assuming that the majority of agents are more autonomous and economically rational, and are prepared to more regularly consider the most profitable product selection and production volumes significantly increased economic benefit under Water Shares. It was considered important to revisit this with the improved decision making algorithms in place and to look at lower rationality as well as higher.

**Environmental protection**

7.141 For the Consultation Impact Assessment we assumed that in order to prevent environmental deterioration the quantity of water reserved for the environment in 2025 is maintained for the entire modelling period to 2050. As described above, this is a simplification of a more complex process. In reality environmental standards could be adjusted as water ecosystems adapt to the impacts of a changing. Modelling such evolving environmental limits is not straightforward. To determine whether this effect was likely to be important or not we carried out a simple sensitivity test using less restrictive trigger points for environmental damage responses and water buy back.

**PWS trading**

7.142 The PWS are dominant players in all the catchments. Peer reviewers were concerned that the PWS may be reluctant or unable to participate in some trades.

7.143 In the base case we have assumed that the PWS will sell allocations (in Water Shares) only if supply exceeds demand by >5%. This assumption was adopted to allow for the fact that PWS companies must manage resources at a water resource zone level. So a catchment may be in surplus but the PWS may require the water to address deficits elsewhere. This ‘barrier’ to trading was chosen arbitrarily.

**Trading Inertia**

7.144 In general the inertial costs described above suppress the number of small volume trades since the costs are more material compared to the absolute value of the water being traded. It was considered important to subject these to further sensitivity tests. For this phase of the work we explored what would happen if the difficulty of trading under the Current System was such that no trading takes place (little trading is observed in practice). We recommend that a critical review of the relative ease of trading is carried out prior to the Final Impact Assessment to establish the most appropriate base case and sensitivities.

**Results overview**

7.145 The sensitivities carried out are summarised on Figure 41 and the results are provided in overview on Figure 42. More detail is provided on Figure 43 to Figure 45.
7.146 In general we find that the sensitivity tests do not materially affect the policy preference.

7.147 Reduced economic growth generally reduces the overall scale of benefits, sometimes very materially but does not reverse the policy preference. The impact is greater under G-LR than J-UD. Because growth choices in the model are made based on an agent’s assessment of water availability, reduced growth means there is less demand for any spare water, and lower competition for water that people are willing to sell. This may:

- Reduce water usage (relative to the higher growth model) and therefore increase availability
- Reduce the market balance price (lower demand) which may make it easier for others to get access to traded water.

7.148 There are circumstances where these factors offset the lost production growth benefits and this would be more likely to happen where the production benefits are small.

7.149 Preventing trading under the current system systematically improves the benefits of reform relative to the current system, demonstrating that the greater ease of trading under reform is delivering benefits in these catchments. The smallest impact is seen in the Stour where the opportunities for trading, especially under Water Shares in the absence of put and take trading, are limited. The greatest change is seen in Cam and Ely Ouse where the opportunities for trading are greatest.

7.150 A similar pattern of results is seen when the PWS is prevented from trading under all three policies. In the Stour there is little impact. In Cam and Ely Ouse the impact is very significant leading to reform performing more poorly than the current system. PWS trading can also affect the timing and choice of future investment options, and we have already shown that the model can be sensitive to these small changes when there are a limited number of large options available in later years. This again underlines the sensitivity of the result to PWS decisions.

7.151 Removing the restrictions on PWS allocation trading has very little impact on the results.

7.152 Changes in behavioural characteristics may increase or decrease the benefits of reform but generally the variations are small especially in catchments and scenarios where PWS investment benefits dominate. The ‘independent irrationality’ test – which tests a situation where agents are highly economically irrational and are reluctant to adopt new practices leads to lower benefits from reform compared to the Current System except under Water Shares in Cam and Ely Ouse. In cases of higher economic irrationality, there will be less licence/share trading in the model, so more agents with potential problems of shortfall. These emerge because the actual climate experienced is drier than the historical climate on which they base their assessments and decisions. Allocation trading would be beneficial in these circumstances and this may account for the improved performance of Water Shares in Cam and Ely Ouse. Further investigation of this is possible using the model.
Figure 43: The Stour sensitivity tests

In the policy comparison plot for positive benefits: Red exposed = Water Shares better, Blue exposed = Current System Plus better, Purple = position of other policy.
Figure 44: The Hampshire Avon sensitivity tests

In the policy comparison plot for positive benefits: Red exposed = Water Shares better, Blue exposed = Current System Plus better, Purple = position of other policy
The Cam and Ely Ouse

Figure 45: The Cam and Ely Ouse sensitivity tests

In the policy comparison plot for positive benefits: Red exposed = Water Shares better, Blue exposed = Current System Plus better, Purple = position of other policy
Understanding the options

7.153 The construction of the ABM has involved an on-going dialogue between the team designing the options and the modellers. This has served two purposes:
- It has helped ensure that the key differences in the options are captured in the model – the mechanistic modelling of interactions at individual abstractor and time step level makes this possible; and
- It has imposed a level of discipline, and depth of quality, in thinking about how the options will work in practice at the individual abstractor level. This would have been hard to replicate in any other way.

7.154 In this section we describe observations from the modelling on the operation of the reforms.

Constraints and responses

7.155 The modelling has allowed us to explore in detail how the licence conditions will constrain abstractors under the three options, the water shortage challenges they may face and the practical ways abstractors can respond.

Licence constraints between policies

7.156 Abstractors are constrained in three ways:
- Daily limit (gross abstraction)
- Periodic limit (consumption or net abstraction)\(^{25}\), and
- Low flow limits.

7.157 The way these are applied differ between the options.

Daily limits

![Figure 46: Example of how Daily Limit can constrain abstraction](image)

7.158 The daily limit constrains abstraction when the daily demand exceeds it.

7.159 Daily limits are seasonal under the current system (so are generally more restrictive). Under reform the proposal is that seasonality will be removed, and the daily limit will be no lower than at present. Under all three policies abstractors can respond to shortfalls by applying to the EA or Natural Resources Wales for an increase in their daily limit. Storage may be an attractive adaptation as it effectively allows an abstractor to increase the total water available to meet short term spikes in demand but could be expensive.

\(^{25}\) Under the current system the periodic limit is actually based on gross abstraction, but for the purpose of modelling we consider the consumptive element of the licence
The periodic limit constrains abstraction when the total volume of consumptive abstraction in the relevant period reaches the limit. Under the current system and Current System Plus the time period that the constraint operates over is 365 days, under Water Shares, as modelled, the time period is only 14 days. In Water Shares a 1 m$^3$/annum share therefore equates to 1/26 m$^3$ in an allocation period. The actual amount of water available to the abstractor in that period will depend on the allocation for that period.

Basic licensed volumes are reduced under the reform options compared to the current system as some unused licensed volume is removed. However, under Current System Plus abstractors can access High Flow ‘bonus water’ and under Water Shares, abstractors’ share of the available water will be higher during periods in which high flow is anticipated (see below).

Under Current System Plus abstractors faced by constraints can apply for more annual limit, trade annual limit or, when available, rely on High Flow water.

Under Water Shares abstractors can apply for more shares, trade shares or trade periodic allocation.
7.164 Flow based limits constrains abstraction when the observed flow falls below some predefined flow. Under the current system and Current System Plus the flow limits are HOF based. Abstractors can take unlimited amounts of water (provided they do not exceed their annual licensed consumption or pumping limit – see above) and provided there are no HOF conditions in place. When flows in rivers are low, HOF conditions will apply and abstractors will be restricted and may have to cease abstraction altogether. The frequency of restriction will depend on the reliability threshold associated with their licence.

7.165 Under Water Shares an abstractor’s annualised shareholding is distributed across the 14 day allocation periods as described above. When flows in the river are low, an abstractor’s allocation is reduced in proportion to their shareholding. Shares in less reliable water are reduced first. Figure 50 shows how water share groups are distributed.

7.166 When flow levels in the river are low, constraints on abstraction under both Current System Plus and Water Shares are likely to be similar. However, when flows in the river are higher, abstractors who want to take large volumes of water in short time periods, could become more restricted under Water Shares, because they are limited by the amount of water they can take in a 14 day period.

7.167 Abstractors can respond to constraints under the current system and Current System Plus by applying for more reliable water, trading for more reliable water or building storage. Under Water Shares abstractors can apply for more reliable shares, trade for more reliable shares, or trade for periodic allocation.
In Summary

7.168 It can be seen that the challenges that abstractors face vary between policies:

- Daily limits are more restrictive under the current system, for some abstractors, due to seasonality

- Periodic volume limits are more restrictive under Current System Plus and Water Shares than under the current system, because of the reduction of some unused licensed volumes on transition. However they are even more restrictive under Water Shares, because the restrictions operate over 14 day allocation periods rather than over a full year, thus reducing abstractors’ flexibility as to when they can take water (see Figure 47 and Figure 48).

- At low flows, abstraction constraints will be more restrictive that the current system for abstractors not currently subject to HOFs, but could be less restrictive for other abstractors due to the introduction of soft HOFs (Current System Plus) and access to shares of the available water under Water Shares. At higher flows, abstractors wishing to take large amounts of water over short periods will be more constrained under Water Shares.

7.169 The potential responses open to abstractors also vary between the policies:

- Under all options abstractors can:
  - Take measures to reduce gross abstraction and/or consumption
  - Apply for higher daily limits, more annual limit (or more shares) or more reliable water (or more reliable shares)
  - They can build storage, although under the current system seasonal licences can make this less viable as an option
  - They can trade permanent licences (or shares under Water Shares), although under the current system this is difficult and only happens in any volume between PWS companies.
• Under the Current System Plus abstractors can additionally take advantage of bonus water e.g. to fill storage (when flows in the river are high) or trade for additional water through a lease.

• Under Water Shares abstractors can take advantage of high flows and trade for additional allocations.

7.170 Trading and building of storage is affected by both economic and hydrological considerations.

7.171 We see in the model abstractors who need to abstract large amounts of water in short time scales using both allocation trading and investment in storage to manage the restrictions imposed by the allocation periods under Water Shares. Storage provides a reasonably certain solution – but at a cost. Allocation trading is less certain in terms of the volumes available and the price but when there are no flow restrictions it will not tend to be expensive.

7.172 In reality, secondary markets would be likely to develop in allocations so that abstractors with variable and predictable demands for water (e.g. for raising potatoes in the autumn), could buy ahead extra allocations for that period to reduce the risk of restrictions. Effective secondary markets should increase the benefits of water trading and the Water Shares option. In the next phase of modelling we will explore whether this market can be modelled.

Exploring the options

7.173 In each catchment and in each sector we see agents making different decisions depending on their particular water needs, water availability, their experience in previous years, the responses available to them and whether they are defined in the model as an innovator or follower. We can follow these through in the model to identify undesirable or unintended outcomes of reform and determine which features of the option design should be subject to further scrutiny. We have used this as a basis for discussing with the project board and the options design team potential ways of mitigating adverse impacts.

7.174 The modelling has demonstrated for example:

• The impact under Water Shares of spreading out allowed volumes for abstractions over the year, resulting in ‘high volume over short period’ abstractors being more critically affected

• The fact that water use slips to the bottom of the catchment under Current System Plus trading. This is because it is once an abstractor trades an abstraction permission downstream, there is no mechanism by which that permission can be returned upstream again.

7.175 This work has shown the potential for the model to be used to help optimise the design of the reforms, including for example, designing and testing a hybrid option that seeks to build on the best elements of both reform options.

The top down model

7.176 The top down model is very simple. The work has however revealed a number of useful insights into trading and the benefits of trading that we can explore further using the Integrated ABM.

• The top down and the agent based model report that the value of the efficient allocation of water increases as demand grows and the water available shrinks. The catchments with faster demand growth and larger cuts in water availability exhibit the highest prices. The agent based model demonstrates that the situation is not as simple as this implies. In periods of high demand and low availability, the market becomes constrained because there are too few buyers.

• The top-down model indicates that key catchments, particularly some in the south east of England, contribute a large part of the national value released from trading. This supports a policy of geographically selective promotion of trading
Both models underline the significance of moving from a system of control based on gross abstraction to one based on net abstraction. In the top down model, the unit value of water in use is much higher on a net basis than a gross basis, revealing the willingness of abstractors to pay for investments expanding water supply. It further suggests that investments which reduce consumptiveness could be financially attractive.

Both models incorporate additional supply developed by water companies. Both anticipate additional supply to meet the needs of households and non-households on the public pipe network. The ABM will in due course allow water companies to put water into and take water from the river using additional supply and thereby trade with other abstractors. The top down model finds that many abstractors may wish to purchase additional supply from water companies through this sort of mechanism. The supply options are sufficiently cheap to be an attractive option for abstractors, and often cheaper than purchasing abstraction rights from other abstractors.

The exercise of constructing models has revealed the importance of abstractor characteristics such as consumptiveness and value in use and shines a light on the risk of substantial reduction in water availability suggested by the Environment Agency’s Case for Change scenarios.

Both models rely on assumptions on the consumptiveness of abstractors which play a central role in the model calculations. The value in use figures which have been published and are used in the top down model all relate to gross consumption, but the values on a net consumption basis are much higher, and introduce a new perspective on water management. The ABM constructs value in use estimates from scratch from bottom-up cost models and finds high unit values. These differences in values between gross and net forms indicate that the introduction of trading of net consumption is a paradigm shift in the approach to water management. When this change in value is placed alongside a reduction in water availability, both models show the economic importance of efficient water management, and thus the potential impact of appropriate institutional arrangements.

Because of the lack of consideration of hydrology and spatial relationships and constraints the top down model will significantly over-estimate the benefits of trading. It also is designed to compare a regime with trading, with one without, rather than explicitly modelling and comparing the reform options. It is not therefore appropriate to try to compare the model outputs quantitatively.

The ABM modelling has demonstrated that considerations of constraints introduced by hydrology and the needs of environmental protection, and agent interactions with each other and the hydrology are very important. We find that the situation is often more complex than the simple picture painted by the top down model suggests. For example, we find trading can decrease in dry years as buyers fail to find people willing to sell in the markets they are permitted to enter. We generally find levels of trading are lower than those observed in the top down model and we also see people beginning to invest in adaptation. The top down model does not currently consider adaptation. Modelling of the system complexity is therefore important when trying to get a handle on the absolute level of the cost and benefits of reform, to distinguish meaningfully between options, and to understand how they will work in practice.

A full description of the top down modelling and the results can be found in the companion report: The Impact of Abstraction Reform: A simple top down water abstraction economic model for England and Wales.
8 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Consultation Impact Assessment

8.1 The initial results presented in the Consultation Impact Assessment were based on an early version of the model, but this nevertheless was able to offer insights into the potential performance of the reform options:

In England
- The modelling suggests that reform options will provide economic benefits compared with the current system in all scenario combinations. The benefits are relatively small; estimates ranged from about £100m up to about £500m net present value (NPV) over 25 years.
- The numbers of catchments falling into the Basic or Enhanced category varied with time and depends on both the reform option and the scenario combination under consideration. On average, around 50% of catchments fall into the Enhanced category by 2050.

In Wales
- The case is more variable, with estimates ranging from net benefits of £30m to net costs of £10m.
- A much higher percentage of catchments are classified as Basic than in England, reflecting higher water availability. The case for reform depends on whether the benefits in a particular scenario outweigh the increase in administrative costs.

Current System Plus compared to Water Shares

8.2 The modelling carried out for the Consultation Impact Assessment suggested that there is no significant difference in benefits between the two reform options. However simplifications in the model could be leading to a systematic under-reporting of the level of trading that might be expected, particularly under Water Shares. We applied some simple corrections to try to compensate for this, but concluded that further work was required to improve the modelling of trading, and in particular share and allocation trading.

Drivers of performance

8.3 The modelling demonstrated that reform can provide benefits in a number of ways, and (depending on the catchment and scenario combination) different factors become more or less important.

8.4 We generally found that the variation in impacts calculated being greater across climate change scenarios than socio-economic scenarios. Benefits of enhanced reform accrue from better access to high river flows and improved facilitation of abstraction trading providing increased profits and more efficient investment profiles in water management infrastructure while delivering the similar levels of water security.

8.5 Water companies appeared consistently better off. Benefits often coming from companies being able to defer investments.

8.6 We see other agents with regular steady demand for water (generally industrial agents) are growing and agents that are highly dependent on within year rainfall (for example spray irrigators) able to access water when they need it. We see reservoir building increasing to support this.
8.7 Trading levels vary between scenarios and catchments. As expected they are highest in Cam and Ely Ouse, with agricultural agents being the most active. Agriculture to agriculture trades are most common, with some trading between agriculture and horticulture. Levels of trading however at this stage were being under reported.

Environmental benefits

8.8 All the options are designed to achieve the same environmental outcomes set in legislation. Early results suggested the reform options may more quickly achieve outcomes however the data were difficult to interpret.

Work following the Consultation Impact Assessment

Additional work

8.9 Following publication of the Consultation Impact Assessment we carried out some additional modelling and analysis to tackle some of the elements of the model that we, in conjunction with Peer Review and the project board, felt to be of high priority. This was to allow us to gain better understanding of the results and to help plan for work to support the Final Impact Assessment.

8.10 The main areas of model improvement have included:

- Trading (particularly share and allocation trading) and related decision processes including
- Agent characterisation: We carried out a review of agent characterisation and implemented improvements to a variety of agents. We also found that the results could be sensitive to production decisions that had nothing to do with water. We therefore examined implemented improvements in the areas of:
  - Cost-cutting processes
  - Consideration of the economics of stopping production.
- Transition: A correction was applied in the ABM to remove the effect of incorrectly transitioning summer licences.

8.11 It was difficult to predict how each of these changes would affect the results. But overall we expected them to lead to an increase in the benefits attributed to the reform options (Current System Plus and especially Water Shares) relative to the current system.

Results

8.12 We did not rerun the aggregation model so results focused on the catchment case studies.

8.13 We used the models to explore:

- Whether reform delivered benefits compared to the current system
- How the options are working in practice, and
- The extent to which we could distinguish reliably between Current System Plus and Water Shares

In order to identify areas in the modelling where further improvements would help:

- Improve confidence in the results, or
- Allow more agile development and testing of options.

Does reform deliver benefits?

8.14 The findings of the latest work are consistent with the Consultation Impact Assessment findings, with reform seen to deliver benefits across a wide range of climate and socio-economic scenarios in the case study catchments. Improvements in the modelling have resulted in increased estimates of the benefit of reform at the catchment level.
8.15 We subjected the results to a range of sensitivity tests. We found that these did not materially affect the conclusions.

**How do the reforms work in practice?**

8.16 We are able to identify elements of each reform option that are particularly beneficial or which lead to unintended outcomes. The model can therefore be used to help optimise the design of the reforms, and has delivered significant insight already. For example the work has exposed:

- Constraints under Water Shares on ‘high volume over short period’ abstractors
- Water slipping to the bottom of the catchment under Current System Plus trading
- The movement from surface water to less highly regulated groundwater sources

**How do Current System Plus and Water Shares compare?**

8.17 We find that performance of the options is affected by a complex series of interacting drivers, with the ‘best’ option dependant on how these play out in each catchment and scenario. Depending on the catchment and scenario combination different factors become more or less important.

8.18 Detailed examination of the catchment level results allowed us to identify two sensitivities with the potential to affect the comparative performance of the options: These are:

- The modelling of environmental protection and groundwater, and interactions with PWS investment decision making
- Characterisation of some economically significant agents and their decision making processes.

8.19 Some further exploration of these factors is recommended prior to the Final Impact Assessment to increase confidence that the model is reliably distinguishing between the options.

**Overall**

8.20 Overall reform is seen to deliver benefits across a wide range of climate and socio-economic scenarios in the case study catchments. Improvements in the modelling have resulted in increased estimates of the benefit of reform at the catchment level and greater confidence in the ability of the model to support meaningful comparisons of the reform options.

8.21 We find that performance of the options is affected by a complex series of interacting drivers, with the ‘best’ option dependant on how these play out in each catchment and scenario. A small number of areas have been identified where further examination of the model approach would help improve confidence in the result. Four particular areas requiring additional scrutiny are:

- The modelling of environmental protection and groundwater
- The characterisation of economically significant agents to ensure that non-water related decisions unrelated to the options are not masking performance of the options
- The calculation of PWS deployable outputs on implementation of reform option controls at low flows, and
- PWS investment option lists to make sure these reflect the process of discovery of new options.

8.22 The model can be used to help optimise the design of the reforms, and has delivered significant insight already. However, further work to streamline the data process of transitioning licence details to any new regime would provide greater flexibility to, for example, help design and testing a hybrid option that seeks to build on the best elements of both reform options.

8.23 The models generate a lot of data, which provides a very rich picture of the way the climate, hydrology, hydrogeology and abstractors are interacting with the reform options. This is a very
complex, highly interconnected system, and we are just beginning to ‘get to grips’ with the richness of data available from the models describing the behaviour of this system. Our current focus has been on confirming the model is adequately capturing the many hydrological, behavioural and economic processes at work, and exploring the way the options are working at the abstractor level. We have had relatively limited time to process the outputs in detail given the huge task involved but hope that the results presented here give a flavour of what is possible from the model. A key task going forward will be to generate tools that will automate the process of extracting information from the model data but substantial time will need to be allowed to fully analyse the data for the Final Impact Assessment.

8.24 The wide consultation carried out (and which is on-going) in support of the reform programme has helped us anticipate many of the impacts of the reforms and capture these in the model. However, in reality there will of course be some unanticipated effects, both positive and negative, which cannot be anticipated and modelled in advance.

Recommendations

8.25 Our recommendations fall into five categories:
- Improving aggregated results
- Basic model improvements
- Adding mechanisms to the model
- Modelling changes to policy options
- Further validation

8.26 These have been discussed initially with the project board. Actions marked Essential should be implemented to support the Final Impact Assessment. Other actions should be implemented if this can be achieved before the end of the modelling cut-off date for the Final Impact Assessment in the priority order: Important, Medium, Low.

Improving aggregated results

8.27 Modelling the Trent and Derwent: Modelling of the Trent and Derwent is required for two reasons. Firstly it will permit inclusion of benefits to the power sector, and secondly it will increase the size of the evidence base. Both in turn will improve the aggregation process. In particular the Trent and Derwent includes sub-catchments that are:
- More surface water dominated (particularly helpful for characterising many Welsh catchments) -
- More highly managed than the other English case study catchments (helpful for both English and Welsh catchment characterisation) and
- A corridor catchment (helpful for providing some insight into other similar systems such as the Thames and Severn).

8.28 However, the catchment is very large so we will need to modify the model so it runs in reasonable timescales. The feasibility of doing this has been investigated and an approach agreed. This will be tested at the beginning of the next phase of work. Essential

8.29 Modelling the Dee: Modelling the Dee is being considered. However, there are concerns that it will be difficult to model realistically. Excellent models of the system exist, but these are not currently in a form suitable for integration with the ABM. It is a highly managed river, and reforms may not deliver benefit over and above the current approach. It would be interesting to explore this but other project requirements may take precedence. TBD

8.30 New approach to aggregation: The aggregation approach could be adapted to take into account hydrological factors instead of sectoral mix in the catchment weighting algorithm. This could be carried out as a sensitivity. Important
The Impact of Water Abstraction Reform

Basic model improvements

8.31 Environmental impact and groundwater: We need to carry out further investigations of the environmental protection measures as these are not currently having the impact expected. There are a number of reasons why this might be the case related to the modelling approach, the licence transition assumptions and the specific policy design. One area we need to investigate is whether groundwater simplifications are contributing to this and (if so) implement some simple improvements to address the effect. Essential

8.32 Consideration of PWS deployable outputs: Policy options which constrain access to water at very low flows may affect the calculation of PWS deployable outputs and hence their investment decisions. As the impact results are sensitive to PWS investment profiles, this needs to be addressed as a matter of priority either within the model or in the design of the options. Essential

8.33 Large agent sensitivities: We need to investigate whether non-water related economic decision processes are still introducing biases unrelated to the options and to switch-off these features if appropriate. Essential

8.34 Resilience to drought and a drying climate: Defra have committed to investigating the performance of the options in drought conditions, and their potential to improve the resilience of catchments to drought. This will involve modelling drought regulations and carrying out sensitivity runs using drought scenarios developed by HR Wallingford. It will be important to talk to PWS and EA/Natural Resources Wales officials in the catchments. Essential

8.35 Extending the modelling of benefits: This will allow the cost or benefits of PWS investment decisions made late in the modelled period to carry greater weight in the NPV calculations. The technique of terminal values can be used to improve the modelling of longer term investments. Important

8.36 Additional outputs: Improved metrics are required to help monitor the water that abstractors have access to and actually use and the damage to the environment. Essential

Adding mechanisms

8.37 PWS discovery: PWS option lists should be updated to reflect the 2013 WRMPs and allowed to evolve to include ‘discovered’ options and re-use schemes (water pumped up stream from sewage discharges) Essential

8.38 Water release (or put and take) trading: It should be cheaper for PWS to build additional capacity and supply through put and take trading. Put and take trading could also be important for non-PWS agents, especially in catchments with Level Managed Areas (e.g. Stour and Cam and Ely Ouse). Essential

8.39 Reservoir building as an asset: Agents do not currently take into account the potential to trade excess water from storage. This may be important, as we observe that some agents are not building storage in the modelling (as they cannot make the economic case) but also cannot access traded allocation as none is available. Important

8.40 Secondary markets: Secondary markets may be important as they could help mitigate some of the constraints experienced under Water Shares by enabling abstractors to secure future allocation ahead of time, without needing to purchase an entire shareholding. Effective secondary markets should increase the benefits of water trading and the Water Shares option. We recommend exploring whether these markets can be modelled in the next phase of work. We recommend that before attempting to include them the effectiveness of the options in their absence is fully explored. Medium

8.41 Learning agents: Agents do learn from their experience of weather and flows over the last 18 years and recent profitability. However droughts 17 years ago have an equal impact to one last year. Increasing learning brings the risk of introducing biases from randomised choices that are unrelated to the options. However simple ways of introducing learning without these risks include lowering the barriers to trading as agents gain experience and weighting more recent experience (e.g. of drought) more heavily. Low
Modelling of change to policy options

8.42 **Transition and policy option definition:** This is required to streamline the modelling of new catchments and allow potential policy modifications to be considered. Modifications to options that may be considered include evolving environmental limits, alternative transition options, different lengths of allocation period under Water Shares, different HOF and minimum regulatory limit designs, potential for altering daily pumping limits as well as periodic limits as part of buy back/take back, and hybrid options. It will be important to prioritise these for coding and model runs to ensure the work programme can be achieved. **Essential**

Continuing validation

8.43 **Comparisons with the literature** Reviewing the range of trading bid prices, offer prices and clearing prices in each sector to see if the model is generating the sorts of ‘willingness to pay’ figures that would be expected. **Medium**

8.44 **‘Ground truthing’ Investment choices.** Investment benefits for the PWS are important in many scenarios. Additional consultation with Water Companies will to ensure that the decision making and options choices being made within the model are plausible and best reflect likely actual behaviours. **Important**

Other

8.45 The Integrated ABM generates a large amount of data about the reforms that could be processed to provide a very rich picture of how the options are performing and to generate narratives to generate the result. We recommend that ways of efficiently processing this data are developed. **Important**

8.46 We agree with the peer reviewers that it will be important to ensure adequate time is given to analysing results for the final impact assessment. **Essential**
APPENDIX 1: PROJECT OVERSIGHT

A1.1 Project oversight has been provided by the following bodies as described below:

- A **project board** comprising personnel from Defra, Environment Agency, Natural Resources Wales and the Welsh Government
- the **Abstraction Reform Advisory Group** (ARAG) comprising representatives of abstractors from a wide range of sectors across England and Wales
- **Internal project experts**: sector and technical experts in the fields of modelling, economics, hydrology and hydro-geology, and water use and abstraction
- **Peer reviewers**: leading technical experts in modelling, economics, and hydro-geology and water policy.

A1.2 In addition, we have also sought input and feedback from abstractors through three phases of workshops and one to one meetings and telecons as described in Appendix 2 and worked closely with the team developing the reform options.

A1.3 These interactions have helped us ensure that the model is fit for purpose and that the modelling is capturing, as far as is possible, the key aspects of the options, catchments and abstractor behaviour relevant to distinguishing between the options.

A1.4 This process is ongoing and we are planning more meetings with the peer reviewers and ARAG members and abstractor representatives from the catchments, to support the Final Impact Assessment.

### The Project Board

<table>
<thead>
<tr>
<th>NAME</th>
<th>ORGANISATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henry Leveson-Gower</td>
<td>Chair, Defra</td>
</tr>
<tr>
<td>Clare Dinnis/Nicola Poole/John Poole</td>
<td>Environment Agency</td>
</tr>
<tr>
<td>Jonathan Dennis</td>
<td>Environment Agency</td>
</tr>
<tr>
<td>Anthony Wilkes</td>
<td>Natural Resources Wales</td>
</tr>
<tr>
<td>Phil Chatfield</td>
<td>Welsh Government</td>
</tr>
<tr>
<td>Nicola Stirling</td>
<td>Defra</td>
</tr>
<tr>
<td>Maniv Pathek</td>
<td>Defra</td>
</tr>
</tbody>
</table>

A1.5 The project board met frequently, often on a monthly basis throughout the project providing advice and direction to the project team. Periodically special meetings were held to discuss e.g. aggregation or the design of engagement workshops.
# The Abstraction Reform Advisory Group (ARAG)

<table>
<thead>
<tr>
<th>NAME</th>
<th>ACTIVITY</th>
<th>ORGANISATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Adlam</td>
<td>Crop production</td>
<td>HTA</td>
</tr>
<tr>
<td>Adam Comerford</td>
<td>Waterways</td>
<td>Canal and River Trust</td>
</tr>
<tr>
<td>Susanne Baker</td>
<td>Manufacturing and metals</td>
<td>EEF (Manufacturing trade body)</td>
</tr>
<tr>
<td>David Bassett</td>
<td>Fisheries</td>
<td>British Trout Association</td>
</tr>
<tr>
<td>David Bellamy</td>
<td>Food and drink</td>
<td>Food and Drink Federation</td>
</tr>
<tr>
<td>Chris Brett</td>
<td>Hydropower</td>
<td>Inter Hydro Technology Ltd</td>
</tr>
<tr>
<td>Dr Ian Brown</td>
<td>Public Water Supply</td>
<td>Dwr Cymru Welsh Water</td>
</tr>
<tr>
<td>Philip Burston</td>
<td>Wildlife</td>
<td>RSPB</td>
</tr>
<tr>
<td>Jackie Coates</td>
<td>Chemicals and chemical products</td>
<td>CIA</td>
</tr>
<tr>
<td>Mr A Gurney / Rhian Nowell-Phillips</td>
<td>General agriculture and/or horticulture</td>
<td>Farmers Union Wales</td>
</tr>
<tr>
<td>Paul Hammett / Diane Mitchell / Jenny Bashford</td>
<td>General agriculture and/or horticulture</td>
<td>NFU</td>
</tr>
<tr>
<td>Derek Holliday</td>
<td>Land management</td>
<td>CLA</td>
</tr>
<tr>
<td>Andy Limbrick</td>
<td>Energy</td>
<td>Energy UK</td>
</tr>
<tr>
<td>Sarah Mukherjee</td>
<td>Water and wastewater utilities</td>
<td>Water UK</td>
</tr>
<tr>
<td>Nicola Owen</td>
<td>Minerals and construction materials, Mining and quarrying</td>
<td>Mineral Products Assoc</td>
</tr>
<tr>
<td>Debbie Stringer</td>
<td>Paper and paper products</td>
<td>CPI (Confederation of paper industries)</td>
</tr>
<tr>
<td>Christine Tacon</td>
<td>External Regulatory Scrutiny</td>
<td>Defra</td>
</tr>
<tr>
<td>Rose Timlett / Lucy Lee</td>
<td>Wildlife</td>
<td>WWF</td>
</tr>
<tr>
<td>Luke De Vial</td>
<td>Public Water Supply</td>
<td>Wessex Water</td>
</tr>
<tr>
<td>Simon Wood</td>
<td>Energy</td>
<td>EDF Energy</td>
</tr>
</tbody>
</table>

**A1.6** We met with ARAG in July 2012 and June 2013 to discuss progress and presentation of results.
## Internal project experts

<table>
<thead>
<tr>
<th>NAME</th>
<th>AREA</th>
<th>ORGANISATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Core project team experts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jon Pocock</td>
<td>Agent-based modelling</td>
<td>Risk Solutions</td>
</tr>
<tr>
<td>Chris Rees</td>
<td>Aggregation</td>
<td>Risk Solutions</td>
</tr>
<tr>
<td>Siôn Jones / James Suter / Charlotte Duke</td>
<td>Behavioural economics</td>
<td>London Economics</td>
</tr>
<tr>
<td>Steven Wade/ Darren Lumbroso</td>
<td>Hydrology</td>
<td>HR Wallingford</td>
</tr>
<tr>
<td>Chris Counsell</td>
<td>Hydrological modelling</td>
<td>HR Wallingford</td>
</tr>
<tr>
<td>Simon Wilson</td>
<td>Facilitation and Engagement</td>
<td>Wilson Sherriff</td>
</tr>
<tr>
<td>Paul Brand</td>
<td>Facilitation</td>
<td>Risk Solutions</td>
</tr>
<tr>
<td>Robin Smale</td>
<td>Regulatory economics</td>
<td>Vivid Economics</td>
</tr>
<tr>
<td><strong>Technical experts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professor Mike Acreman</td>
<td>Assessment of environmental flows</td>
<td>CEH</td>
</tr>
<tr>
<td>Dr Christel Prudhomme</td>
<td>Impact of climate change on river flows</td>
<td>CEH</td>
</tr>
<tr>
<td>Dr Andrew Hughes</td>
<td>Groundwater modelling</td>
<td>BGS</td>
</tr>
<tr>
<td>Dr Simon Less</td>
<td>Regulatory policy for the UK water sector</td>
<td>Simon Less Consulting</td>
</tr>
<tr>
<td><strong>Sector experts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bill Hume-Smith</td>
<td>Water engineering, water resource planning and economic regulation</td>
<td>Mott MacDonald</td>
</tr>
<tr>
<td>Andrew Keiller</td>
<td>Water resources planning</td>
<td>Mott MacDonald</td>
</tr>
<tr>
<td>Harry Hogg</td>
<td>Electricity generation</td>
<td>Mott MacDonald</td>
</tr>
<tr>
<td>Christopher Davis</td>
<td>Chemical and pharmaceutical industrial process</td>
<td>Mott MacDonald</td>
</tr>
<tr>
<td>James Newton</td>
<td>Water engineering and costing</td>
<td>Mott MacDonald</td>
</tr>
<tr>
<td>Simon Groves</td>
<td>Crop irrigation</td>
<td>ADAS</td>
</tr>
<tr>
<td>John Atwood</td>
<td>Nursery stock and fruit growers</td>
<td>ADAS</td>
</tr>
<tr>
<td>David Harris</td>
<td>Irrigation and sustainable water use in agriculture and horticulture</td>
<td>ADAS</td>
</tr>
<tr>
<td>David Brydon</td>
<td>Water efficiency and sustainable effluent disposal, SMEs</td>
<td>Blackwell Water Consultancy</td>
</tr>
<tr>
<td>Dr Keith Weatherhead</td>
<td>Water trading and agricultural use of water</td>
<td>Centre for Climate Change Adaptation, Cranfield University</td>
</tr>
</tbody>
</table>
A1.7 The lead experts in the project oversaw their areas of work. The project technical experts provided advice and input in their specialist areas to the core team at appropriate points in the project both by attending workshops and meetings, including a joint meeting with ARAG (see above) and the peer reviewers (see below), and providing data and inputs for the models.

### Peer reviewers

<table>
<thead>
<tr>
<th>NAME</th>
<th>AREA</th>
<th>ORGANISATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jon Stern</td>
<td>Policy decision making</td>
<td>City University</td>
</tr>
<tr>
<td>Rob Soley</td>
<td>Hydrological modelling</td>
<td>AMEC</td>
</tr>
<tr>
<td>Kieran Conlan</td>
<td>Various</td>
<td>Cascade Consulting</td>
</tr>
<tr>
<td>Scott Moss</td>
<td>Agent-based Modelling</td>
<td>Scott Moss Associates</td>
</tr>
</tbody>
</table>

A1.8 Plenary peer review meetings were held in November 12, March 13, May 13 and September 13. A number of more focussed individual meetings were held throughout the project. The aims and main findings of the plenary meetings are described below.

#### Peer Review Meeting – 12 November 2012

A1.9 The 12 November peer review meeting discussed comments arising on the report of the first, scoping, phase of the project. Present at the meeting were:

- **Peer reviewers:** Kieran Conlan, Scott Moss, Jon Stern, Rob Soley
- **Project team:** Jon Pocock, Charlotte Duke, Siôn Jones, James Suter, Robin Smale, Darren Lumbroso, Chris Rees, Helen Wilkinson (by telephone), Michelle Boath
- **Commissioners:** Henry Leveson Gower, Zoe Hodgson, Nicola Poole, Maniv Pathak.

A1.10 Useful discussion around several aspects of the methodology included:
- Scaling between the different geographical scales of analysis (catchment level and water resource zone level),
- The modelling of drought periods, and
- Modelling trading and markets.

A1.11 These discussions were very helpful in developing thinking in these areas.

A1.12 The meeting also discussed:
- Top down modelling (optimising) versus bottom up (descriptive) modelling, and
- Demonstrating the plausibility of the model.

A1.13 The Integrated ABM is largely a mechanistic, descriptive approach. These are not generally used in Impact Assessments, but can be provided they are justified. In this case, it was considered important to take account of:
- Non-rational (in an economic sense) decision making
- The way people may filter information they receive and ignore some information
- The complex way the system is expected to behave with complex behaviours emerging from the interactions of individuals.

A1.14 These cannot be modelled using top down optimising approaches.

A1.15 The need for a simple top down model of some sort to accompany the detailed modelling was discussed, particularly given the difficulty of validating bottom up models. In response Defra decided to commission the work presented in this report on top down modelling from Vivid Economics.
A1.16 The [continuing] process of exposing model assumption, intermediate and final outputs to scrutiny by peer reviewers, other experts and abstractors helps test the plausibility of the results. It was noted that the model will provide more accurate evidence on the relative costs and benefits of different options than on the quantum of costs and benefits of the options.

Peer Review Meeting – 13 March 2013

A1.17 The 13 March peer review meeting aimed to:
- Review the most important outstanding Peer Review issues, and
- Agree the action ‘status’ of the most highly ranked items.

A1.18 Present at the meeting were:
- Peer reviewers: Kieran Conlan, Scott Moss, Jon Stern
- Project team: Sion Jones, Jon Pocock, Robin Smale, Steven Wade, Helen Wilkinson
- Commissioners: Henry Leveson Gower, Nicola Poole, Anthony Wilkes, Nicola Stirling, Malcolm Peters, Maniv Pathak.

A1.19 The meeting was facilitated by Paul Brand and represented the culmination of a number of communications between the peer reviewers and the project team. In addition samples of the code had been supplied to peer reviewers where appropriate. Rob Solely was unable to attend but had had frequent discussions with HR Wallingford and the British Geological Survey about the hydrological modelling, and in particular the ground water modelling.

A1.20 Peer reviewers were asked to rank comments and concerns in terms of:
- Their potential impact if not remedied, and
- The difficulty or effort associated with the required remedy.

A1.21 The concerns were then placed on a matrix, shown in Figure 51 below; this helped us prioritise discussions at the meeting.

![Figure 51: Peer review prioritisation framework](image)

A1.22 The meeting concluded that:
- There were no show stoppers
- The modelling is at the cutting edge of work in this area
- The model is complex and difficult to validate however this is NOT about attempting to capture a single vision of ‘truth’ or accurate forecast; it is about giving a sense of what might change and how – a plausible reality within which to assess the comparative costs, risk and benefits of the reform options
- The process of building the model is providing a framework for organising thinking around reform and forcing a much greater discipline on the process of exploring who will be affected and how.

A1.23 The peer reviewers identified the following priorities:
We should as far as possible exploit the strengths of agent based modelling to explore the impact of e.g. changing social interactions and risk perceptions over time, on how the options will play out in the catchments.

It would be important to recognise stakeholder perceptions of e.g. their inability to pass cost increases through to their customers, but while the impact of different stakeholders’ perspectives can be explored through sensitivity analysis and scenarios, policy must be based on best evidence.

The model must allow us to capture the ‘stories’ that lie behind the model results – to generate understanding and provide evidence. It was felt that the narratives emerging from the model that would most clearly communicate the outcomes to stakeholders.

The project team should review and address all the high and medium impact concerns where it was possible in the time scales of the project. It would be important to keep a record of the simplifications adopted and to carry out sensitivity analysis to ensure we understand how key uncertainties/assumptions affect the results.

This helped us prioritise work on the modelling going forward.

**The peer review and experts meeting – 21 May 2013**

The 21 May peer review and experts meeting reviewed interim outputs emerging from the abstraction reform modelling. Present at the meeting were:

Peer reviewers: Rob Soley (AMEC), Kieran Conlan (Cascade), Scott Moss, Jon Stern (City University)

Experts: Andrew Hughes (BGS); Simon Grove, John Atwood, David Harries (ADAS); James Dodds (Envireau Water); Keith Weatherhead (Cranfield)

Project team: Jon Pocock, Siôn Jones, Robin Smale, Helen Wilkinson

Commissioners: Henry Leveson Gower, Lisa Oakes, Nicola Stirling (Defra); Nicola Poole, Karen Saunders, Jonathan Dennis, Claire Bonds, Malcolm Peters (EA); Anthony Wilkes (Natural Resources Wales).

The meeting was facilitated by Paul Brand.

We explored three themes: PWS decision making, non-PWS abstractor behaviour and some specific aspects of the modelling approach.

Participants were asked to identify key issues following each presentation and to categorise them as shown in the figure.

The key concern raised at the meeting was the very short time the team have to complete the models, carry out a wide range of analyses, interpret the results, construct a narrative and share the results with the peer reviewers. The project plan was subsequently amended to reflect this, but this remained a challenge.

Other issues raised included some detailed considerations around modelling of low flows and ground water aquifers, farmer behaviour, modelling PWS and non-PWS options selection and general considerations relating to decision making.

Many of these could be addressed in the modelling and analyses going forward – although not necessarily within the time constraints. The potential impact on the results of issues not addressed would be described as far as possible in the report.
Peer Review Meeting – 03 September 2013

A1.32 The peer review meeting on 03 September discussed a range of issues.

A1.33 Attending were:

- Peer reviewers: Rob Soley (AMEC), Kieran Conlan (Cascade), Scott Moss, Jon Stern (City University)
- Project team: Jon Pocock, Chris Rees, Siôn Jones, Steven Wade, Robin Smale, Helen Wilkinson
- Commissioners: Henry Leveson Gower, Nicola Stirling, Marilena Pollicino (Defra); Nicola Poole, Karen Saunders, Jonathan Dennis, Malcolm Peters (EA)
- Other: Rachel Wright (Ofwat)

A1.34 Issues discussed included:

- Hydrological modelling: In particular the challenges of calibrating models at low flows, the adequacy of the groundwater modelling and the approach to environmental protection. These latter could not be addressed on the timescales of the Consultation IA.
- Modelling the PWS: Particularly the need for the option lists to reflect the full range of options the companies could adopt, to adequately represent transfers, to take into account the requirement for the Strategic Environmental Assessment (SEA) of options and to include options for selling non-regulated PWS supply of water to the non-PWS and to reflect barriers to PWS participating in trading, the impact of this on the results should be examined. As many of these concerns as possible were reflected in the modelling prior to generating outputs for the Consultation IA, however short term allocation trading and the process of discovering new options for consideration at each PWS investment planning round were not implemented.
- Non-PWS reservoir building: Non-PWS might build reservoirs on the back of a single bad year that affected their production, this is not modelled. This could not be implemented in time to inform the Consultation Impact Assessment.
- Agricultural decision making: Drought resistant crops are not included as an option but a good range of crop choices with different water requirements, margins etc are included and this should be sufficient to test whether options provide sufficient flexibility for farmers. The model does not reflect the inelasticity of agricultural demand on the basis that price elasticity is a short term effect.
- Aggregation: The challenges of scaling water company costs and benefits, as there are only a very few water companies in each catchment, and their plans are often different in nature, was noted.
- Transition: A number of issues around transitioning of licences and definition of the base comparison case were discussed and clarified.

Peer Review Meeting – 03 February 2013

A1.35 The 03 February peer review meeting reviewed outputs emerging from the abstraction reform modelling at that stage with the aim of eliciting views on the current modelling, analysis and results and obtaining their top recommendations for improvements to modelling that would add value or credibility to the Final Impact Assessment (IA). Present at the meeting were:

- Peer reviewers: Kieran Conlan (Cascade), Scott Moss, Jon Stern (City University), Robin Smale (Vivid Economics)
- Project team: Jon Pocock, Steven Wade, Helen Wilkinson, Chris Rees
- Commissioners: Maniv Pathak (Defra), John Poole (EA), Jonathan Dennis (EA), Anthony Wilkes (Natural Resources Wales) and Dominic Hemming-Brown (Welsh Government)

A1.36 Apologies were given in person by Henry Leveson-Gower (Defra). The meeting was facilitated by Paul Brand (Risk Solutions).
A1.37 The key sensitivities and assumptions identified that required further investigation to ensure that results were valid and not an artefact of modelling assumptions or agent set up were:

- Large agent sensitivities arising from changes in production that are not directly related to water
- Simplifications in modelling, in particular groundwater modelling, that could be contributing to the appearance that environmental protection measures have little impact
- Large benefits arising from PWS investment delays observed in some catchments and scenarios, due to smaller take back of licences causing environmental damage.

A1.38 These last two are related in that large scale PWS investment is often triggered by reduction of licences under environmental protection controls and therefore this is an important area of the modelling to explore.

A1.39 In addition to these, the meeting identified a number of areas where the modelling could be enhanced.

- Issues raised that are straightforward to address are: PWS option lists should evolve to include ‘discovered’ options, put and take trading should be implemented and resilience to drought and a drying climate should be explored using the drought sequences generated by HR Wallingford.
- Issues that may be more difficult to address include: modelling secondary markets, increasing the degree of learning by agents, reservoir building as an asset, including exempt small users, various approaches to validation and ways of extending the modelling period. Their usefulness and feasibility needed to be further explored.
- Issues raised that were already scheduled for further discussion included the feasibility of implementing evolving environmental limits and of integrating transition processes in the modelling.

A1.40 The meeting focused on catchment level results, but noted some challenges for aggregation, especially scaling up PWS investment benefits and representing Wales. These will be mitigated to some extent by inclusion of Trent and Derwent.

A1.41 Finally a number of issues relating to presentation of the results in the impact assessment and design and implementation of the options were raised. An issue for the modelling was the need for further consideration of outputs to help show the performance of options in terms of environmental protection.

A1.42 The meeting recommended three months should be reserved for analysis and reporting of model outputs prior to the Final Impact Assessment.
APPENDIX 2: ENGAGEMENT

A2.1 Engagement with real abstractors, and with abstractor representatives, was crucial, helping us understand the challenges abstractors face, what drives decision making around water in their industry, and how they might respond to new constraints and opportunities. Engagement activities were carried out in three phases as described below.

Phase I engagement

A2.2 The first phase of consultations involved three main activities:
- Six sector workshops held during April and May 2012
- Provision of ‘DIY packs’ for people who could not attend the workshops
- Two feedback workshops at which findings were fed back to previous participants to be checked for completeness and accuracy, and

A2.3 We also presented to ARAG.

A2.4 The purpose of the engagement was to understand how potential changes might affect different abstracting sectors. The workshops were designed to help us:
- Understand how abstractors currently use water and how future water availability challenges would affect them
- Explore how different abstractors might adapt to future water availability challenges, and what might signal the need for adaptations or prevent them happening
- Examine the impact on abstractors of possible changes to abstraction licensing and/or the introduction of a water market (for both abstraction and returns) and what threats and opportunities reform might present
- Develop the models to (as far as possible) quantify the impacts of any changes.

A2.5 Each workshop nominally focused on a different sector grouping. The principal groupings chosen are shown in Figure 52

A2.6 A detailed summary of our findings was presented in a feedback booklet\(^\text{26}\), which we circulated to all those who had attended the workshops. It was also presented to an expert workshop and to a significant group of abstractors who attended two feedback workshops. Their input was extremely helpful in making sure that our summary findings had not missed any significant issues, or lost important detail in the synthesis process.

\(^{26}\) D5221-01-49 - Sector Workshop Feedback Booklet
A summary of workshop attendance (including people who returned ‘DIY packs’) is provided below.

<table>
<thead>
<tr>
<th>‘Activity’</th>
<th>No of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramics</td>
<td>4</td>
</tr>
<tr>
<td>Chemicals and chemical products</td>
<td>2</td>
</tr>
<tr>
<td>Consultancy</td>
<td>5</td>
</tr>
<tr>
<td>Fisheries</td>
<td>4</td>
</tr>
<tr>
<td>Food and drink</td>
<td>9</td>
</tr>
<tr>
<td>Manufacturing and metals</td>
<td>4</td>
</tr>
<tr>
<td>Paper and paper products</td>
<td>5</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>2</td>
</tr>
<tr>
<td>Sports irrigation</td>
<td>3</td>
</tr>
<tr>
<td>Textiles and leather</td>
<td>3</td>
</tr>
<tr>
<td>Waste</td>
<td>1</td>
</tr>
<tr>
<td>Agriculture and horticulture</td>
<td>31</td>
</tr>
<tr>
<td>Canals and waterways</td>
<td>3</td>
</tr>
<tr>
<td>The environment</td>
<td>1</td>
</tr>
<tr>
<td>Construction and construction materials</td>
<td>10</td>
</tr>
<tr>
<td>Electricity</td>
<td>7</td>
</tr>
</tbody>
</table>
Phase II engagement

Catchment based engagement

A2.8 The second phase of engagement involved two workshops in each of our case study catchments to bring together abstractors from different sectors, operating in the same catchment. The first workshop in each catchment introduced the different potential reform options, explored how policy reform might affect abstractors and how they might operate their abstraction in response both as individuals and working together. At the second workshop we hoped to discuss findings emerging from the modelling as well as exploring responses to developing thinking on the options. However, in the event delays to the modelling prevented us showing final outputs, although it was possible to share some emerging intermediate outputs.

A2.9 Prior to each of the first workshops we carried out telecons with local EA, EA Wales (now Natural Resources Wales) and PWS representatives to establish an initial understanding of the catchment.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>No of participants</th>
<th>1st workshop</th>
<th>2nd workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cam and Ely Ouse</td>
<td>37</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Dee</td>
<td>18</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Hampshire Avon</td>
<td>26</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Stour</td>
<td>35</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Tees</td>
<td>25</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Trent and Derwent</td>
<td>41</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Usk</td>
<td>17</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>199</td>
<td>144</td>
<td></td>
</tr>
</tbody>
</table>

PWS engagement

A2.10 We carried out direct engagement with the specific water companies concerned with our catchments to determine:

- Key aspects of their operation within the catchments we are modelling
- Operating rules/tactical decision making processes that are currently used for managing normal operations, in particular the actual abstraction profiles for different hydrological and demand conditions
- Special considerations relating to drought
- What operating rules and decision making processes might be anticipated in the face of the specific climate change and socio/economic scenarios that we are considering
- The nature and level of current inter-WRZ transfers that already occur
- Likely operating rules for currently identified new infrastructure options.
Engagement activities included interviews, telecons and a workshop involving 16 representatives from water companies and OFWAT.

**Phase III engagement**

A2.12 In the final phase of engagement we ran four multi-sector workshops to give abstractors, especially those who had not been involved since the sector workshops early in 2012, an opportunity to discuss some of the key issues relating to reform. This was one of the final opportunities for abstractors to influence the proposals for reform before they would be finalised for wider public consultation. The workshops also aimed to help design the formal consultation by testing new ways of explaining the options including use of multi-media.

A2.13 Workshops were held in Peterborough, Warrington, Cardiff and London. Numbers of participants are shown in the table.

<table>
<thead>
<tr>
<th>No of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peterborough</td>
</tr>
<tr>
<td>Warrington</td>
</tr>
<tr>
<td>Cardiff</td>
</tr>
<tr>
<td>London</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

**Continuing engagement**

A2.14 Plans continue to engage with stakeholders through preparation of the Final Impact Assessment.
APPENDIX 3: CASE STUDY CATCHMENTS

A3.1 This appendix contains brief descriptions of the modelled case study catchments.

Kent Stour catchment

A3.2 The Stour CAMS area covers approximately 1,100km². In addition to the River Stour and its tributaries, this area includes the River Dour and the Dover Chalk block, the Isle of Thanet, and the Lydden Valley which receives water from the catchment of North and South Streams. The principal urban centres in the catchment are Ashford, Canterbury, Dover, Deal, Ramsgate and Margate. Beyond these towns, agriculture forms the main land use with the highest quality agricultural land lying in the north of the catchment.

Hydrology, geology and hydrogeology

A3.3 The River Stour has two main tributaries. The Upper Great Stour originates at Lenham near Maidstone and the East Stour begins at Postling, near Folkestone. After the confluence of these two watercourses at Ashford, the river flows north-eastwards in a steep sided valley through the North Downs Area of Outstanding Natural Beauty to Canterbury. The tidal limit is just downstream of Canterbury, determined by the weir sited at Fordwich. The channel extends for a further 33km, passing through the lowland Stour Marshes before reaching the estuary at Pegwell Bay. The Stour acts as a source of water for the lowland marshes through the operation of a number of pumping stations and gravitational feeds, controlled by sluices. Water levels within the private ditches, Internal Drainage Board sewers and main river channels within the marshes are carefully managed for agricultural and environmental needs.

A3.4 The Little Stour drains much of the Chalk block south of Canterbury and joins the tidal Great Stour at Plucks Gutter, 13km downstream of Fordwich. Subsidence in this area, caused by historic coal mining, has resulted in the need to pump the Little Stour into the Great Stour, via the Environment Agency’s West Stourmouth Pumping Station. In the upper reaches of the Little Stour, the high permeability of the underlying Chalk means that surface flows are rare, occurring only in response to heavy rainfall. When conditions are wet and groundwater levels
are high, the river can extend 37km beyond its perennial source at Well Chapel Springs, upstream of Littlebourne.

A3.5 The River Dour is an important groundwater-fed chalk stream, although it has only a small catchment of around 80km². The Alkham and Watersend ephemeral reaches rise 7km northwest of Dover, before merging at Kearsney Gardens and then discharging into the English Channel via the outfall at Wellington Dock (Dover Harbour - Western Docks).

A3.6 Chalk clearly dominates the geology of the catchment in terms of water bearing potential. However, the Lower Greensands in the Upper Great Stour and the East Kent Tertiaries in the Wingham catchment are also a significant source of base flow to the rivers. The presence of the less permeable strata of the Gault and Weald Clays underlying the southern parts of the catchment limits the contribution of base flow to those upper reaches of the Great Stour. The geology determines the river’s flow regime, leading to low flows during summer and rapid runoff and flooding during the wetter months.

Land use

A3.7 The dominant land use is agriculture with arable farming and horticulture in the north-eastern half of the catchment where there is high quality soil. In this area the demand for water for spray and trickle irrigation is high with potatoes, soft fruit and salad vegetables being grown. The south western half of the catchment and is mainly grassland and arable crops such as oil seed rape and wheat. There are around 15 golf courses in the catchment that require irrigation including Sandwich Bay that has two championship links.

Water resources pressures

A3.8 The majority, around 65%, of water abstracted each year in the Stour catchment is drawn from groundwater sources. Around half the water abstracted from the environment is for public water supply.

A3.9 Agriculture is the second largest water using sector, representing a quarter of all abstraction in the catchment, and placing the largest demand on surface water sources.

A3.10 There is generally a shortage of water in the Stour catchment and hence direct summer abstractions are discouraged. In most cases, surface water abstraction licences are subject to HOF conditions. When river flows drop below this rate, abstraction must cease in order to protect the base flow of the river.

A3.11 The latest licence strategy is available at: Environment Agency, Stour Abstraction licensing strategy, February 2013, LIT 2048
A3.12 The Cam and Ely Ouse catchment is approximately 3,600 km² extending from Swaffham in the north to Royston and Saffron Walden in the south and from Potton in the west to Attleborough in the east.

A3.13 The area is characterised by the East Anglian Chalklands in the south, Brecklands in the north and the South Level fenland to the west of the area. Land use is predominantly arable agriculture and there is a strong rural feel to the area.

A3.14 The area comprises the natural surface water drainage catchment of the Ely Ouse system, the tributaries include the River Cam, Little Ouse River, the River Lark and the River Wissey. It also includes the South Level Fenland area. This is an area that has been actively drained and consists of a highly managed network of drains and dykes that allow the highly productive fenland peat soils to be farmed.

Hydrology, geology and hydrogeology

A3.15 The Ely Ouse River drains a catchment of approximately 3640 km² upstream of Denver, north-west of the area. It is fed by four main tributaries.

- The Cam, which receives tributary water from the River Granta, the Lodes (which form a part of the South Level system), the River Rhee and Bourn Brook.
- The River Lark
The Little Ouse and its tributaries which include the Thet and the Sapiston/Black Bourn

The River Wissey and its tributaries

A3.16 The tributaries of the Ely Ouse contribute different proportions of flow. On average the River Lark contributes 10%, Wissey 16%, Cam 21% and Little Ouse 25%, with the remainder coming from the Lodes, Old West and South Level fenland areas. The sluices at Denver retain all these rivers at a similar level in the South Level area. Water is discharged into the Tidal River at Denver and reaches the Wash at King’s Lynn. In periods of high flows, water can be diverted from the Lark, Wissey and Little Ouse into the Cut Off Channel and then into the Flood Relief Channel at Denver. Water can also be discharged directly into the Relief Channel via the Head Sluice at Denver.

The low lying lands of the Fens are protected from inundation by the sea and fluvial floods by the Denver Complex. The Denver Sluice and the A G Wright (or Head) Sluice perform the flood defence role. In the summer months the river flows may be reduced as water is drawn off into the low-level drains for crop irrigation.

A3.17 In addition to natural flows, the river flows are also augmented by effluents from sewage treatment works and the discharge of industrial cooling water. This ‘return’ of water can be valuable during the summer months. Runoff from paved surfaces and roads in the urban areas can also contribute to the river flows.

A3.18 The Ely Ouse to Essex Transfer Scheme (EOETS) exists to augment river flows and reservoir levels in South Essex, by transferring surplus water from the Ely Ouse system. EOETS diverts water at Denver from the Ely Ouse River into the Cut Off Channel and subsequently pumps it at Blackdyke through a series of pipelines into Essex watercourses. The water is then abstracted into reservoirs for public water supply. The transfer is limited by a minimum flow requirement to the Tidal River Ouse.

A3.19 At times of low flow there is insufficient water for the transfer scheme to operate. As a result a supplementary scheme has been developed using a series of groundwater boreholes (the Great Ouse Groundwater Scheme) and a transfer into the Cut Off Channel from the River Little Ouse.

A3.20 There are two important aquifers in this catchment. The largest is the Chalk which underlies the eastern and central part of the area and is primarily exploited for public water supply and spray irrigation. The groundwater in the Chalk generally discharges either at discrete springs or gradually along the length of rivers providing valuable base flow.

A3.21 The other principal aquifer is Lower Greensand (known as the Woburn Sands) which outcrops further west and is separated from the Chalk by a layer of Gault Clay. Although the Greensand unit underlies the whole area, the dip of the strata means that it is only important for water supply along the outcrop and to a distance of about 15km to the east.

A3.22 Towards the east, the solid geology is overlain by an increasing thickness of Boulder Clay (Till) and quaternary sands and gravels, the latter acting locally as important secondary aquifers. In the far west the geology is Clay.

Land use

A3.23 The catchment is predominantly rural and includes high-grade agricultural land.

A3.24 The population is estimated to be over 600,000. The main urban areas within the Cam and Ely Ouse catchment area are Cambridge, Royston, Saffron Walden, Newmarket, Bury St Edmunds, Ely and Swaffham.

A3.25 The major urban areas are the focus of non-agricultural industry with large industrial bases around Cambridge and Saffron Walden. Industrial abstractors include golf courses, mineral extraction, chemicals manufacturing, brewing and food production as well as a large number of more minor uses.
The Impact of Water Abstraction Reform

Water resources pressures

A3.26 There are over 800 licensed abstractions in this catchment. Around a third of all abstraction is for public water supply and a further quarter for water transfers. Over three quarters of public water supply abstractions are sourced from groundwater. Balancing the requirements of abstractors, environment and recreational users of the water resources is key in this catchment. There is extensive abstraction as well as many water dependent conservation areas and extensive recreational use of the watercourses.

A3.27 The main water resource pressures are extensive public water supply abstractions from groundwater sources and spray irrigation of agricultural land particularly in the South Level. Other key pressures are river support (Lodes Grant and Rhee support schemes) and water transfers (Ely Ouse to Essex Transfer and the Great Ouse Groundwater Scheme).

A3.28 Three public water undertakers abstract water in this catchment. Anglian Water Services Limited abstract from groundwater mostly to the west of the catchment. They also have one surface water abstraction from the River Wissey/ Cut-Off Channel. Cambridge Water abstract groundwater from areas around Cambridge to the south west of the catchment. Affinity Water have a few groundwater abstractions also to the south west of the catchment around the Royston and Saffron Walden areas.

A3.29 It is predicted that with the growth agenda there will be increased demand for public water supplies in this catchment, particularly in the Ely and Bury St Edmunds areas. Anglian Water predict they will require additional resources and are currently investigating how they can source additional supplies.

A3.30 The latest licence strategy is available at:

The Usk catchment is located within Natural Resources Wales’ operational boundary. It covers an area of approximately 1,400 km² and it has a population of approximately 200,000. The River Usk flows over relatively low permeability minor aquifers and is dominated by flashy, surface water flow responses, with reservoirs built to support public water supply. It is a river of considerable ecological diversity and is important for many nationally and internationally important species.

**Hydrology, geology and hydrogeology**

The River Usk at 121 km long is one of the longest rivers in Wales. Its headwaters and some of its tributaries are impounded by the Usk, Crai, Talybont and Gowyne Fawr reservoirs in the upper catchment. Llandegfedd Reservoir, located on the Sor Brook in the lower catchment, is a storage reservoir for water pumped from the lower River Usk. The catchment is long and narrow with the Usk running through its centre. The tributaries are short. At Brecon some of the River Usk’s flow is abstracted to supply the Monmouthshire and Brecon Canal, which runs parallel to the river until the flood plain widens at Abergavenny. Here the canal veers to the south west, while the river continues its course south easterly via Usk town towards the centre of Newport where it discharges into the Usk Estuary.

Two of the River Usk’s tributaries - the Sor Brook and Malpas Brook - also flow directly into the Usk Estuary. Over most of the area, the groundwater contributions to river flows are modest, emanating from the Old Red Sandstone, the Coal Measures or from sands and gravels along the river channels. As a result, river flows fluctuate dramatically with changes in rainfall. Groundwater is, however, an important local contributor in the Clydach catchment. The karstic carboniferous limestone underlying this tributary is a major aquifer.

**Land use**

The catchment includes the towns of Newport, Abergavenny and Brecon. The Usk area is an important farming region. Very little other industry exists within the catchment. Angling takes place throughout the catchment.
A3.35 The River Usk is an important salmon fishery and brown trout fishery. Recreation and tourism is a great asset within the Usk catchment and an important contributor to the area’s local economy. The area also has an intense, diverse and important archaeological and heritage history with a number of water related Scheduled Ancient Monuments and Parks and Gardens. The Monmouthshire and Brecon Canal (completed in 1777) is itself a heritage feature.

**Water resources pressures**

A3.36 Water is abstracted for public water supply, navigation, agriculture, commerce/industry, domestic use, spray irrigation, horticultural watering, lake/pond maintenance, fish farming and hydropower generation. Its headwaters and some of its tributaries are impounded by the Usk, Crai, Talybont and Grwyne Fawr reservoirs in the upper catchment. The Usk catchment is an important farming region. Agriculture is the major land use with hill farming dominating in the upland northern and western areas and dairy, beef, poultry, mixed and arable farming in the south and east. Industry demand within the catchment is fairly limited.

A3.37 The Usk is an important resource for Dŵr Cymru Welsh Water (DCWW), particularly as part of the South East Wales Conjunctive Use System ‘SEWCUS’ water resources zone, which supplies Cardiff.

A3.38 The main water resource zones in the catchment are forecast to be in deficit due to a number of drivers such as population growth, climate change and environmental requirements under the EU Habitat’s Directive. Natural Resources Wales have concerns about water availability in the main River Usk. A range of supply and demand-side options are being considered to close the supply-demand deficit.

The latest licence strategy is available at:

_EA Wales CAMS, December 2010_
The Hampshire Avon catchment covers approximately 1,800 km². The population is approximately 200,000. The River Avon is considered to be one of the most biodiverse rivers in lowland Britain, supporting a very rich flora, fish and invertebrate fauna. The ecological value of the river is recognised through the designation of a number of Sites of Special Scientific Interest (SSSI) which cover most of the river, its tributaries and associated wetlands. The international importance of the site has been recognised through the designation of most of the Avon System SSSI as a Special Area of Conservation (SAC) and the Avon Valley (Bickton to Christchurch) SSSI as a Special Protection Area (SPA).

Hydrology, geology and hydrogeology

The main tributaries of the Avon are the River Nadder, River Wylye, River Ebble and the River Bourne. There are also numerous streams draining to the Avon from the New Forest. The River Mude drains directly to Christchurch Harbour at the base of the catchment.

The headwater tributaries of the catchment are crossed by the Kennet and Avon Canal, which is managed by the Canal and River Trust.

A number of rivers in the catchment including the Chitterne Brook, River Till, Nine Mile River, River Bourne and River Ebble all have winterbourne stretches. In summer, flow in the winterbournes retreats to the permanent spring head further downstream leaving the upper reaches dry.
A3.43 The area predominantly drains from chalk downland, giving rise to the characteristic flow regimes and bio-diverse habitat. The Chalk provides spring and base flows to maintain a relatively stable discharge regime throughout the year. South of Fordingbridge, the geology changes as the chalk becomes overlain by clay, sand and gravel deposits, resulting in a noticeable increase in stream density towards Christchurch. The Upper Greensand is also important, forming the lower relief headwater vales of the Upper Avon, Wyllye and Bourne; and a central area within the Nadder catchment. The Nadder catchment is geologically complex and includes Chalk along its northern valley flanks drained by the Fonthill Brook, as well as the relatively impermeable Kimmeridge Clay Formation in the headwaters.

A3.44 The topography gently dips in a southerly direction towards the coast. To the North and West the catchment is delimited by a ridge of high ground of around 200-250m above ordnance datum (mAOD). The rivers and streams have created valleys with a minimum elevation of the order of 100mAOD. Below Salisbury, the Avon valley becomes considerably wider and flatter with elevations of zero to 25mAOD. To the East of the River Avon, the New Forest Streams drain from a maximum elevation of 125-150mAOD.

A3.45 The area is dominated by two major aquifers – the Chalk and the Upper Greensand which supply water to feed the upper catchment tributaries. The aquifers are highly productive and of regional importance for large public water supply abstractions. The Chalk streams of the upper Avon catchment are generally well connected to the underlying aquifers which provide base flow to the river system. Any consumptive groundwater abstraction will result in the reduction of base flow somewhere and at some time within the Avon catchment system.

**Land use**

A3.46 Much of the area is characterised by rolling chalklands and the sheltered valleys of chalk rivers. A considerable part of the upper catchment comprises Salisbury Plain, which contains the important Stonehenge World Heritage site and consists of arable fields, unimproved grassland and small hilltop woodlands. Land is used for farming, tourism and by the MOD for military activity. Historically, water meadows were also an important feature of the landscape. The majority of systems are now abandoned, but many are being restored to be managed as areas of floodplain grazing marsh.

A3.47 South of Salisbury the Avon valley flattens out to form a broad floodplain containing low-lying pastures and groups of large water bodies created within areas of former sand and gravel extraction including the Blashford Lakes Complex north of Ringwood. This comprises extensive nature conservation lakes, amenity areas and public water supply reservoirs.

A3.48 Important commercial and residential areas are around Salisbury, Fordingbridge, Warminster, Amesbury, Ringwood and Christchurch. Salisbury, with its commercial development and flourishing tourism, is an important employment centre. The harbour town of Christchurch is an important tourist and recreational centre.

**Water resources pressures**

A3.49 Water resources within the Hampshire Avon catchment are extensively exploited, and used for a number of purposes, the biggest of which is public and private water supply. Other activities include general agriculture, spray irrigation, watercress, fish farming and mineral activities. The upper catchment is dominated by abstraction from Chalk mostly for public water supply. Below Salisbury, there is an increase in surface water abstractions as the flow in the river increases.

A3.50 The public water supply abstracts almost half its water from groundwater sources. The Hampshire Avon includes river support schemes to offset impacts on groundwater abstraction in headwaters of the Wyllye, and leakage of canal water into the Vale of Pewsey at the headwaters of the Upper Avon.

A3.51 The latest licence strategy is available at: Hampshire Avon, Licensing Strategy, and 22 December 2012
APPENDIX 4: HYDROLOGICAL MODELLING

A4.1 This appendix presents some more detail about the hydrological model. Additional information is provided in the report: HR Wallingford: The Impact of Abstraction Reform: Hydrological modelling.

Background to the hydrological model

Objectives of the hydrological modelling

A4.2 The objectives of the hydrological modelling were to provide the following on a 1 km x 1 km grid throughout the case study catchments:
- Daily naturalised river flow series
- Naturalised flow duration curves based on daily flows

A4.3 A naturalised flow is defined as the flow that would occur in a watercourse in the absence of abstractions and discharges or the operation of flow regulating reservoirs (i.e. in the absence of any anthropogenic influences).

A4.4 A flow duration curve is a graphical representation of a ranking of all the flows in a given period, from the lowest to the highest, where the rank is the percentage of time the flow value is equalled or exceeded.

Introduction to the CatchMOD hydrological model

A4.5 The conceptual hydrological model known as CatchMOD was used to carry out the hydrological modelling of the case study catchments. CatchMOD is a catchment hydrological model with a long history of use. In the UK, it has been adopted by the Environment Agency and a number of water companies for water resources modelling.

A4.6 CatchMOD uses three conceptual stores representing soil moisture and upper and lower catchment storage. These are as follows:
- A soil moisture module with a soil moisture store, designed to calculate the water leaving the upper and lower soil moisture stores by saturation percolation (when the soil moisture deficit is zero) or direct percolation.
- A storage module, which comprises two sequential conceptual stores, to represent the retention and translation of precipitation leaving the soil moisture stores by saturation or direct percolation as it moves to the catchment outlet via different surface or subsurface pathways.

A4.7 Figure 53 provides an overview of the representation of the different components of the CatchMOD hydrological model.
Use of a gridded hydrological model

A4.8 CatchMOD hydrological models are most widely used as ‘lumped’ models by the Environment Agency and water company hydrologists in England and Wales. A lumped model is one which does not consider any spatial variability across the area being modelled. In this work a gridded CatchMOD hydrological model has been set up for each case study catchment. The main differences between a standard lumped CatchMOD hydrological model and the gridded CatchMOD models used in this work are as follows:

- The model uses gridded precipitation and potential evapotranspiration (PET) estimates that have been based on Met Office gridded precipitation and MORECS (Met Office Rainfall and Evaporation Calculation System) data or Future Flows data.
- The soil moisture stores are distributed across the catchment on a 1 km x 1 km grid.
- The model estimates surface runoff and base-flows on all watercourses at any point on the 1 km x 1 km grid within the catchment.
- The model for each case study has been calibrated to develop a good fit at low flows across the entire basin rather than the best fit at one gauge at the catchment outlet.
- The model routes flows using a simplified version of the Muskingham-Cunge equations. This routing procedure has been used to model the translation and attenuation of the generated daily flow hydrograph in the river channel as it moves downstream. It is...
important to model the effects of translation and attenuation of the flow hydrograph for large catchments such as the Trent and Derwent.

**A4.9** Figure 54 provides a representation of the gridded CatchMOD hydrological model used.

![Figure 54: Overview of the CatchMOD gridded model](image)

**A4.10** The gridded CatchMOD model was written in '.Net'. This is computationally efficient so that large numbers of runs can be undertaken to model uncertainties or to deal with stochastic elements in the Agent Based Model (ABM – also referred to as the Abstractor Behaviour Model). The CatchMOD models run at a daily time step, which is appropriate for linking to the ABM and sufficiently detailed for developing catchment scale impact measures, such as 'unmet demand', river flow percentiles and changes in groundwater recharge.

**A4.11** The model is designed with the soil moisture models on a 1 km x 1 km grid. The upper and lower storage modules (which represent the underlying aquifer) have been sized to cover entire CAMS Assessment Point units or 'groundwater response areas' as defined in the Catchment Abstraction Management Strategies (CAMS). A single groundwater level across each groundwater response area is produced at each time step that the model is run at. In effect recharge to the groundwater and base flows have been represented by lumped models at a CAMS Assessment Point sub-catchment level. Because a lumped approach has been used, the spatial distribution of groundwater abstraction impacts across the Water Framework Directive surface water body sub-catchment draining each CAMS AP groundwater response area being modelled has been simply taken into account using the assumptions that are recorded in the CAMS Ledgers.

**A4.12** An example of how the catchments were schematised is shown in Figure 55. This example is based on the Kent Stour. Details of the construction and application of the CatchMOD
hydrological model to each of the case study catchments are given in the companion report by HR Wallingford: Abstraction licensing reform: Hydrological modelling.

Figure 55: Schematisation of the gridded hydrological model for a typical catchment

**Input data for the hydrological models**

A4.13 The gridded CatchMOD hydrological model used the following data as inputs:
- Land use maps with six land use classes based on the Land Cover Map (LCM) 2000
- Details of the underlying geology based on the British Geological Survey (BGS)
- Gridded rainfall, temperature and evapotranspiration data
- Environment Agency’s digital river network
- GIS shape files defining CAMS AP surface water management units, and WFD surface water body sub-catchments in each of the case study catchments taken from the Water Resources (WR) GIS
- Catchment boundaries provided by the Environment Agency
- Naturalised flow series at key points in the catchment provided by the Environment Agency.

**Combined hydrological and ABM model and its effect on the overall modelling approach**

A4.14 Because the hydrological models are combined with an ABM this means that the overall approach to certain aspects of the modelling results are subtly different from standard hydrological models. The main differences are as follows:
The hydrological models link to the CAMSLedgers spread sheets and completes a process of ‘snapping’ abstractions and discharges to the hydrological models’ 1 km x 1 km grid.

The models apply abstractions and discharges at the grid cell scale (rather than at a downstream flow gauge) and may distribute the impacts of groundwater abstractions across several impacted water bodies based on WR GIS data.

Large public water supply reservoirs are modelled as a mass balance in the ABM so these will impact surface flows, storing water in the autumn and winter and releasing compensation flows as per licence conditions.

The ABM models each Internal Drainage Board area explicitly and incorporates an IDB Agent which seeks to maintain a target water level across the IDB area via off-take points within the hydrological model that link the river topology. Agents are able to abstract and discharge to the level as required. Small on-farm reservoirs have been modelled in the ABM. These collect some local runoff and abstract from rivers and hence will have a very small impact on flows.

**Calibration of the hydrological models**

A4.15 The parameters for the gridded CatchMOD model were calibrated against naturalised river flow series provided by the Environment Agency. The number of calibration points used was dependent upon the size and the nature of the catchment being modelled and the availability of naturalised flow series. The accuracy of the hydrological models in terms of its representation of the naturalised flow series was measured by the Nash-Sutcliffe coefficient. The model was also calibrated against one day flow duration curves and the results checked for volume conservation. In addition, the model was run for the calibration period, with abstractions and discharge patterns based on CAMSLedger data in order to check that the de-naturalisation calculations built into the ABM-hydrology model were operating credibly – i.e. both CAMS Ledger Natural and Recent Actual flow duration curves (FDCs) were compared with modelled flows from calibration period runs as part of the model review process.

A4.16 The development stages in the production of each of the CatchMOD hydrological models are shown in Figure 56.

---

**Figure 56: Development stages of CatchMOD hydrological models**
Details of the CatchMOD soil moisture and catchment storage modules

Soil moisture module

A4.17 The soil moisture module provides a calculation of the rainfall that percolates directly or via saturation by dividing inputs of rainfall into losses (i.e. actual evapotranspiration), change in storage (i.e. soil moisture deficit), and water which is output to the catchment storage module (i.e. direct and saturation percolation).

A4.18 The soil moisture module is based on the conceptual water balance structure of Penman’s drying curve shown in Figure A1. This concept assumes that actual evapotranspiration occurs at the potential rate while water is readily available in the soil root zone. The upper soil store has a capacity equal to the drying constant \( D_c \) in mm and from this store, water is lost to evaporation at the potential rate. The drying constant represents the point of inflection in the drying curve, about 80 mm in the example shown in Figure A1. Evapotranspiration demands are met first from the upper soil store. The lower soil store is only depleted by evapotranspiration when the upper soil store is empty. Evaporation from the lower soil store is defined by the model parameter slope of the drying curve, \( K \). This is typical 0.3 as shown in Figure 57. The actual rate of evapotranspiration decreases to a percentage of the potential rate beyond the drying constant \( D_c \) depth. This percentage decrease is defined by the slope of the drying curve parameter, \( K \).

A4.19 The rainfall fills the upper soil moisture store first before the lower soil store is replenished.

A4.20 Saturation percolation to the catchment storage module occurs only when the upper store is full i.e. when there is the soil moisture deficit is zero. In addition when the rainfall is greater than the potential evapotranspiration, a proportion of that excess water can bypass the soil store as an immediate direct contribution to sub-soil recharge, even when the upper soil store is not full (i.e. when the soil moisture deficit is greater than zero). The proportion of excess rainfall that can directly percolate to the soil moisture store is controlled by the direct percolation parameter, \( D_p \) (%). This parameter is only relevant where soils cover permeable rock strata.

![Figure 57: Typical drying curve indicating how the parameters \( D_c \) and \( K \) are defined](image-url)
**Catchment storage module**

A4.21 The two-store catchment storage module represents the retention and translation of the water that leaves the soil moisture stores by either saturation or direct percolation.

**Upper catchment storage module**

A4.22 The upper catchment store represents the unsaturated zone of the sub-strata and comprises a simple ‘linear’ reservoir, where the outflow is directly proportional to the storage volume. The upper catchment store discharges to the non-linear lower catchment store, where outflow is proportional to the square of the storage volume. This lower store then produces the discharge into the river. CatchMOD’s structure does not allow any direct discharge to the river from the soil or the upper catchment stores. There is only outflow from the lower catchment store.

A4.23 The equation defining outflow, $R$, from the linear upper store is of the form: $RC_r = V_r$

A4.24 Outflow from this upper catchment store to the non-linear lower catchment store is calculated as follows:

$$R_1 C_r = V_r$$

$$R_m = P - \frac{C_r (P - R_1)(1 - e^b)}{t}$$ where $b = -\frac{t}{C_r}$

$$R_2 = P - (P - R_1)e^b$$

Where:

- $R_1$ is the initial outflow (or recharge) from the upper linear storage module at the start of the time interval
- $R_m$ is mean outflow (or recharge) from the upper linear storage module during the time interval
- $R_2$ is the final outflow (or recharge) from the upper linear storage module at the end of the time interval
- $C_r$ is the upper store decay constant usually defined as number of days
- $V_r$ is the volume in upper storage
- $t$ is the time interval
- $P$ is the direct and saturation percolation from the soil moisture module during the time interval $t$
- $R_2$ becomes $R_1$ at the end of the time step. The calculations are normally performed with $P$ and $R$ in units of mm/day or mm/hour. To obtain a flow rate it is necessary to multiply by the grid area being considered.

**Lower catchment storage module**

A4.25 The lower catchment storage module represents the saturated zone of the strata (i.e. the aquifer). Outflow from this lower store is controlled by the lower store decay constant parameter, $C_{qu}$ in km$^2$/day. For the lower catchment module store the equation defining the outflow ($Q$) from the non-linear lower store is:

$$QC_{qu} = V_q^2$$

Where:

- $C_a$ is derived from the model parameter $C_{qu}$ by multiplying by the area.

A4.26 The outflow from this lower catchment module store is calculated by the equations below. The solutions depend on the initial state of the storage (giving positive or zero outflow) and on the net inflow to the lower store (i.e. flow from the upper catchment store minus any abstractions, giving positive, zero or negative net inflow).
\[ I = R_m - A \]

Where:
- \( R_m \) is the mean outflow (or recharge) from the upper catchment module storage during the time interval \( t \)
- \( I \) is the net inflow into lower store during the time interval \( t \)
- \( A \) is any abstractions from this lower catchment module storage during the time interval \( t \)

A4.27 The final flow \( Q_2 \) from the lower storage module at the end of the time interval \( t \) is given by the following equations for the following situations:

**Positive initial flow, zero net input to the lower storage module**

\[ Q_2 = \frac{C_q}{\left( \frac{C_q}{Q_1} \right)^{0.5} + t} \]

**Positive initial flow, negative net input to the lower storage module**

\[ a = \tan^{-1}\left( \frac{Q_1}{-I} \right) - \left( \frac{-I}{C_q} \right)^{0.5} \]

If \( a \) is positive then \( Q_2 = -I \tan^2(a) \)

If \( a \) is negative then \( Q_2 = 0 \)

**Zero flow**

\[ V = V + It \]

If \( V \) is negative then \( Q_2 = 0 \)

If \( V \) is positive then flow after time \( t_{end} \) where \( t_{end} = t - \frac{V}{I} \)

and \( Q_2 = I \left( \frac{1 - e^b}{1 + e^b} \right)^2 \)

where \( b = -2\left( \frac{I}{C_q} \right)^{0.5} (t - t_{end}) \)

Where:
- \( Q_1 \) is the initial runoff from the lower storage module at the start of the time interval
- \( Q_2 \) is the final runoff from the lower storage module at the end of the time interval
- \( C_q \) is the lower store decay constant
- \( V_3 \) is the volume in the lower storage

**Zero flow**

\[ V = V + It \]

If \( V \) is negative then \( Q_2 = 0 \)

If \( V \) is positive then flow after time \( t_{end} \) where \( t_{end} = t - \frac{V}{I} \)

and \( Q_2 = I \left( \frac{1 - e^b}{1 + e^b} \right)^2 \)

where \( b = -2\left( \frac{I}{C_q} \right)^{0.5} (t - t_{end}) \)
Where:
- $Q_1$ is the initial runoff from the lower storage module at the start of the time interval
- $Q_2$ is the final runoff from the lower storage module at the end of the time interval
- $C_q$ is the lower store decay constant
- $V_q$ is the volume in the lower storage

**Typical values of the CatchMOD physical parameters**

Details of the range of the five physical parameters that must be specified for the CatchMOD model are given in Table 10. The minimum and maximum values for each parameter will be based on Environment Agency guidance and previous work that we have carried out for 70 catchments throughout England and Wales.

**Table 10: Typical values of the CatchMOD parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum value</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential drying constant, $D_c$ (mm)</td>
<td>0 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>This is the value of soil moisture deficit above which evaporation occurs at a reduced rate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope of the drying curve, $K$</td>
<td>0</td>
<td>0.6</td>
</tr>
<tr>
<td>Direct (bypass) percolation, $D_p$ (%)</td>
<td>0%</td>
<td>45%</td>
</tr>
<tr>
<td>This is a fixed fraction of the precipitation that bypasses the soil horizon even during periods of soil moisture deficit and directly percolates to the storage module.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear storage constant, $C_r$ (days)</td>
<td>0 days</td>
<td>30 days</td>
</tr>
<tr>
<td>This represents the temporary storage in the unsaturated zone.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-linear storage constant, $C_{qu}(\text{days}/\text{km}^2)$</td>
<td>0 days/\text{km}^2</td>
<td>5,000 days/\text{km}^2</td>
</tr>
<tr>
<td>This represents the storage in the saturated zone (i.e. aquifer).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Bibliography**


APPENDIX 5: ABSTRACTOR BEHAVIOURAL MODELLING

A5.1 This appendix provides more detail on the ABM, the approach to modelling PWS and non-PWS decision making and how we approached modelling of the options. Further information is provided in the companion reports:

- London Economics/Risk Solutions: The Impact of Abstraction Reform: Non-PWS agent behaviour
- HR Wallingford: The Impact of Abstraction Reform: Public water supply operations
- AMEC: Support to Abstraction Reform Programme, Hydrological Aspects of Regulatory Inputs to Trial Catchment Modelling.

Introduction

A5.2 The behavioural model calculates the abstraction and return flows in the next time step for each hydrological model cell based on abstractors' demand requirements, adaptation behaviour and responses to licensing options. In particular it considers how abstractors might react to price signals to make adaptations, and how they might interact with each other as individual abstractors make choices about cooperation, investment and market opportunities.

A5.3 A picture of this process at work is shown in Figure 58.

A5.4 In order to manage spatial variations each 1km grid cell is allocated to geographic areas or zones. Multiple zone/area definitions are supported, to replicate the varieties that exist in practice. Thus each 1km square is classified as belonging to:

- A CAMS catchment
- A PWS Water Resource Zone
- A WFD surface water body or CAMS AP: this will define which specific surface water HOF restrictions exist and when they should be applied
- A trading unit: These are geographic regions (based on river reaches or aquifers) within which low risk trading may be allowed
- A river reach: the specific surface water abstraction and return points that an abstractor has access to
- An aquifer: the specific ground water abstraction points that an abstractor has access to.

**A5.5** This appendix describes how we have modelled:
- Non-PWS behaviours
- PWS behaviours, and
- The policy options.

**Non-PWS behaviours**

**A5.6** Three levels of non-PWS behaviours have been accommodated within the models:

- **Tactical responses**: These behaviours are concerned with short term (daily/weekly/monthly) choices about when to abstract or release water from currently available water sources, and how to manage short term production or other water uses to match changes in demand or water availability. Examples would be abstracting to fill reservoirs in periods of high flows, seeking to minimise business costs by sourcing water from the cheapest sources first (balancing use of river abstraction and local storage), reducing production levels to reduce water consumption, trading unused water allocation with another abstractor etc.

- **Seasonal responses**: These behaviours are concerned with medium term (monthly/yearly) choices about particular production behaviours or other water usage to match anticipated water availability or to guarantee supplies in order to meet current demands. Examples would be varying crops or growing seasons to match water availability or spreading out the demand for water in a locality, acquiring water allocation rights to ensure there will be a secure supply of water to deliver the planned production this year.

- **Investment cycle responses**: These behaviours are concerned with long term (yearly/investment cycle period) choices about capital expenditure, production levels, location, land usage, acquiring long term water access rights etc. Examples would include investing in irrigation equipment to allow transition away from rain-fed crops, moving to dry land cropping, investing in water recycling technology to reduce trade effluent costs and reduce water usage, buying long term water entitlement rights.

**Choices available to abstractors**

**A5.7** The choices each abstractor can make are defined in terms of:

- **Production process/service provision choices** – how water is used within the business or organisation
- **Water source choices** – where abstractors obtain the water they need
- **Licence requirement choices** – decision making about acquiring (or releasing) rights to or temporary allocations of water, and
- **Adaptation choices** – long term decisions investment opportunities to reduce long term business costs, secure access to more water, change production processes to reduce water demand, replace aging assets with more water efficient options, or allow production growth.

**Production processes**

**A5.8** In order to accommodate these various effects we have built models of each abstracting agent based around the concept of production processes (which can also be adapted to other water uses such as service provision – we have used term production process to apply to all water
usage including e.g. manufacturing and service provision). This approach is illustrated in Figure 59.

**Figure 59: Underlying modelling processes within an abstractor agent**

A5.9 At the heart of each agent are a number of production process choices. These describe the basic use (or uses) of water within the business or organisation. Thus variations in total demand for water can be generated from the combination of processes assigned to each agent, and parameterisation of the models has been supported by data derived from observed abstractions, catchment consultation, and the other associated projects that have looked at broader long term water demand in individual sectors.

A5.10 The CAMSLedgers provide information about the location of each water abstraction, including an estimate of the amount of water abstracted and consumed by the licensed abstractor at this location. A licence code is also available for each location, indicating the purpose of the abstraction (e.g. animal watering, spray irrigation, general use) and a sector (e.g. agriculture, environmental, industrial, water supply, production of energy). But the CAMSLedgers do not provide information about the product created by the abstracting agent (e.g. type of crop, type of livestock, aggregate, food, sport, leisure service, etc.).

A5.11 The ABM requires this information to enable it to model the impact changing water availability and price on production and profit.

A5.12 In order to do this we identified a set of generic modelling products and agents were characterised by their production of these products. Additional sector specific information was used to calculate and characterise unit production costs, profit margins, and the volume of water required for each unit of product. Each abstractor was allocated products and production volumes which would result in the water actually abstracted as estimated in the CAMS ledgers. This general principle was applied to all abstractors. The unit used depended on the sector, for example in the energy sector we used the amount of water required per Mega Watt of energy produced, in the agricultural sector the unit used was hectares of crop produced.

A5.13 The water needed for each product unit was calculated using information from a range of sources. For example, the mix of crops in each 1 km modelling square was used to allocated crop products to agents, a livestock census was used to allocated livestock mix to agents, the area of glasshouses was used to allocate growing areas to horticultural agents. The production volumes for each agent were then calculated to ensure that the water being abstracted by each agent in the model matched the information provided in the CAMS ledgers.
Using the CAMSLedgers the model is able to represent all licensed agents listed in the CAMS ledgers, and then using this additional information about products the model is able to represent the water required for production by each agent in the initial conditions, and then over time, given various economic and climate scenarios.

**Water source choices**

Choices may be constrained by both water quality, licence and cost considerations. Some water sources may require pre-treatment in order to ensure it has the correct quality for use in a process. Thus agents will select their actual choice of water based on a mixture of available sources, current licence limits, and their ability to appropriately pre-treat the water. Thus if an abstractor has access to both surface water and a local reservoir, but the current flow conditions are such that the licensing regime prevents abstraction (or the marginal cost of abstracting is higher than the marginal cost of the water in the reservoir) then the agent would choose to use reservoir water to meet their demand today.

In this way very short term decision making is supported.

**Licence requirement choices**

Further anticipated water demand for the next week or month can be determined, which would help to generate information to determine whether the current licence limits are adequate. Knowing the cost of failing to meet the production demand allows an agent to calculate the value that additional water is worth to the business, which in turn determines the price that an abstractor would be willing to pay. This can then be used to bid for water in a trading regime, or to help make choices about production levels.

Thus decision making about accessing short term supply is supported.

**Production process choices**

Abstractors who have access to a range of production processes (for example farmers who may be able to grow a range of different crops on their land) are assigned multiple production processes. Thus seasonal choices about the scale and nature of production are accommodated. This again is driven by the agent selecting the most economically advantageous mix of production processes given the current availability of water.

Thus medium term decision making is supported.

**Adaptation choices**

For each production process modelled, water is classified as either being:

- used within the product (in-product)
- lost from the system (by evaporation, run-off or soak away), or
- output from the system.

Similarly, water that is output could be:

- passed on to a sewerage system agent (and ultimately returned to the environment downstream or elsewhere),
- treated in some way to allow it to be returned to the river (or perhaps the ground), or
- recycled in some way to allow reuse within the business.

Some of these options will only be available if the appropriate systems or assets are in place.

Thus water can only be recycled if the agent has access to a recycling treatment process. Water can only be stored locally if there is suitable storage (tanks or reservoirs) present. Data on the typical costs of being able to invest in such assets, enables agents to consider a range of investment opportunities that they might be able to implement to reduce long term business costs, secure access to more water, change their production processes to reduce water demand, replace aging assets with more water efficient options, or allow production growth. By considering these in order of incremental cost, the model can determine the most
likely sequence of investment and adaptation choices that would make economic sense to abstractors. Agents are also to reduce or cease production if it is no longer economically viable.

A5.25 Thus long term decision making can be supported.

Modelling abstractor decision making

A5.26 A range of factors drive choices including:
- Demand for their products or services
- Water quality requirements
- The differential cost of different water sources
- The desire to increase profit
- The share of water in the cost of production
- The need to control business risk, etc.

A5.27 The starting point is to suppose that agents are rational producers who make decisions in order to increase their profit. We assume that as an agent increases the quantity he produces his production costs rise at an increasing rate. Agents face a market price for their product(s), which they cannot influence (i.e. they are price-takers), and when making production and investment decisions agents form expectations about what market prices will be.

A5.28 Under these circumstances, economically rational agents would maximise their profit by, for example, setting production at the highest level at which marginal revenue (i.e. the expected price of a unit of output) still exceeds marginal cost (i.e. the cost of producing an additional unit of output). However, a benefit of agent-based modelling is that this approach can be augmented using lessons from behavioural economics; the impact of for example social interactions and learning over time on decision making can be taken into account.

Accounting for real life behaviours

A5.29 Concepts that we have integrated into agent behaviour in the model include:
- **Using rules of thumb**: For example, if a firm’s last increase in output increased their profit, then they should increase their output again. In the ABM, agents use rules of thumb for decisions such as what range of production levels they will consider (e.g. within a certain range around their current level), which investment options to consider (e.g. a random selection of a certain number of options), and when to assess these investment options (e.g. after a given number of periods, or when their price expectations change by a certain degree).
- **Delays in decision making**: The complexity of a firm’s business environment may also mean that important decisions are taken with a significant delay. This is reflected in the ABM in the timing of agent investment decisions. Agents do not continually reassess their investment options on an ongoing basis, but instead make assessments only after pre-defined intervals or significant changes in the economic outlook.
- **Imitation of peers/rivals**: Instead of computing their own optimum strategies firms may decide to imitate their peers. Imitation of peers is included in the ABM through the process by which some agents decide to consider their investment options. Some agents choose to follow what others in their sector are doing rather than what is economically rational for them individually.
- **Satisficing behaviour**: Due to the complexity of calculating optimal strategies and limits to their managerial resources, firms may seek satisfactory profits (rather than maximum profits). In the ABM, some agents only consider production levels that are close to their current level, which is similar to a situation where a firm views their current profit level as satisfactory. Furthermore, some agents choose the most profitable investment option from a subset of potential options, which would represent settling for the best within a group rather than pursuing the optimum strategy.
• **Over-optimism** (and over-pessimism): Over-optimism about the likelihood of a positive result or one’s own ability is well documented in psychology literature and appears to be more common among entrepreneurs than the general population. This is reflected in the ABM by some agents having a propensity to believe that observed price trends (upwards or downwards) will continue for many periods (which will impact on the profitability of strategies and projects).

• **Default positions**: A behavioural bias commonly associated with individuals, rather than firms, is that individuals appear to be heavily biased in their decision-making by their default (i.e. current) position. As a result of this bias, individuals may fail to properly consider alternatives to the status quo. This is reflected in agent behaviour in the ABM by some agents only considering production levels ‘close’ to their current levels.

A5.30 Important concepts included in the modelling are reliability of supply, flexibility and management time.

• **Management time**: While some agents will devote considerable time to thinking about investment decisions and determining the best way forward in economic terms, many will not. This factor can be varied within the model to see how it affects the results.

• **Reliability**: Reliability of supply carries differing levels of importance to different sectors and agents depending on the importance of water for their product and the availability of alternatives. Agents consider how likely their various sources of water will be based on the historical patterns of flow and weather. They seek appropriate sources and value and protect more reliable sources more highly.

• **Agent flexibility**: Different agents may be more or less flexible, and this is accommodated in the modelling through consideration of the costs associated with non-availability of water that will drive abstraction choices. Thus the costs of not operating a power station are likely to be very large and so the incentives to access water immediately will be high, whereas the damage to crops from delaying irrigation may be lower, and so delayed irrigation may be the most attractive choice at a particular point in time. However, long term lack of water could result in complete loss of a large part of a crop and so these factors also influence behaviours.

A5.31 More detail of the approach to modelling is given in the companion report: The Impact of Abstraction Reform: Non-PWS agent behaviour.

**PWS decision making**

**PWS operational decision making**

A5.32 The ABM allows specific operational behaviours of water companies to be modelled. It includes the ability for PWS agents to:

• **Prioritise sources**: Water companies often have multiple sources, and for operational reasons choose to operate some in preference to others, and to share the daily abstraction load across multiple simultaneous sources. The ABM allows a PWS agent to prioritise the order in which sources are used, and to share out the abstraction demand based on existing (or otherwise) ratios.

• **Account for hydrological or operational constraints**: As well as licence constraints applied to individual sources, the ABM can handle group licence constraints (whereby the total abstraction across a range of sources is also subject to a limit that is smaller than the sum of the individual limits), and hydrological limits (e.g. in situations where a ground water source is no longer able to deliver the licensed volumes).

• **Manage reservoir levels, deliver compensation releases and maintain minimum downstream rules**: The ABM allows rules to be designed that describe how filling, emptying and transfers to/from reservoir storage are managed. This ensures that
reservoirs (and controlled rivers) are managed in a similar way to actual operational practice.

A5.33 Details of the PWS operations that have been implemented in the model are given in the companion report: Abstraction licensing reform: Public water supply operations.

PWS investment decision making

A5.34 This section discusses the modelling of long term PWS investment decision making.

A5.35 In each catchment, PWS (Public Water Supply) agents use water from the environment to provide public water supply services and also provide sewage treatment services leading to the discharge of treated water back into the environment.

A5.36 PWS agents take decisions about how to invest in water resource management schemes in a way that is intended to broadly follow the approach that water companies in England and Wales are currently required to take in their Water Resource Management Plans (WRMPs).

A5.37 Below we describe:
- the way in which PWS agents take investment decisions;
- our data sources and adjustments to the data;
- key assumptions and constraints.

The investment decision

A5.38 In the ABM model, PWS agents’ investment decisions are taken at the level of the water resource zone (WRZ).

A5.39 In taking investment decisions PWS agents seek to fully meet any projected dry year deficits in the supply-demand balance at least cost, taking into account environmental and social costs. The supply-demand balance is the difference between the projected excess of supply over demand (‘actual headroom’), and ‘target headroom’ - an additional buffer of supply over demand to reflect risks. They take these investment decisions every five years, in order to reflect the actual WRMP process.

A5.40 The main data inputs that enable the PWS agents to take these decisions are a projection of dry year demand (defined as ‘Distribution Input’); a projection of dry year supply (defined as ‘Water Available for Use’); a projection of ‘target headroom’; and a list of water resource management options that they could potentially use to meet any projected supply-demand deficits. The sources for these data are described in the next section.

A5.41 Water resource management options are a range of projects that PWS agents can undertake in order to address supply-demand balance deficits. They include options such as increasing the capacity of water treatment works; increasing water storage capacity; importing water from water resource zones elsewhere in the company’s area; importing water from other companies; desalination; additional leakage control; additional role out of water meters; changes in water meter price structures; and provision of water efficiency information and support to customers.

A5.42 PWS agents decide which water resource management options to pursue in three steps.
- First, they calculate the AISC (Average Incremental Social Cost) for each option and rank the options, with the option that has the lowest AISC first. Options are then selected for implementation in that order until all deficits over the planning period are met. The NPV cost of this programme of options is then estimated and forms the basis of an initial cheapest complete solution for the second stage.
- Second, they use a selective brute force algorithm to consider all the possible combinations of options that would address all deficits over the planning period. Each combination is considered in turn, and the emerging NPV cost of this programme is then estimated. However, as soon as the total NPV is greater than the current cheapest complete solution, the combination is abandoned and the next combination is selected. If
a complete solution is found that is better than the existing cheapest solution, this new solution becomes the target to beat.

- Third, the individual options in the cheapest complete solution that are required within the next WRMP period are committed to (although they are actually implemented when the plan indicates).

A5.43 If, between WRMP periods, the PWS agent is observed to be struggling to meet its dry year demand due to the emerging climate, or other environmental protection mechanisms result in licences being curtailed, then the supply curve is modified appropriately and another interim assessment of the options required to address the revised shortfall is undertaken, and the new lowest cost combination of option is implemented as above.

Data sources and adjustments

A5.44 The main data items required are:

- Projections of demand for water (‘Distribution input’) to 2050
- Projections of the supply of water (‘Water Available for Use’ – WAFU) to 2050
- Projections of target headroom to 2050
- Details of the cost and water volume characteristics of a range of relevant water resource management options

A5.45 The main sources for these data are the data tables that support the water company WRMPs submitted to the Environment Agency in the period 2009-10 (Tables WRP2 and WRP4-FP). Updated tables in support of new WRMPs were submitted to the Environment Agency during 2013. We included the updated data that underlies the Severn Trent Water WRMP for water resource zones relevant to our Trent & Derwent catchment. The decision to include these updated data was based on advice from the Environment Agency that there were significant changes to the WRMP for these zones and that changes to other zones in our modelled catchments were unlikely to be significant.

A5.46 Three principal adjustments were made to the data from the water company data tables:

- The company data tables provided supply/demand/target headroom projections to 2034/35. We have extended these projections to 2050.
- We adjusted the company data in order to generate supply/demand/target headroom assumptions under the four socio-economic scenarios being used for our modelling.
- The water resource management options data available to us were based on NPV costs. For the modelling we needed to build a profile of option costs over time.
- Water resource management options were not presented in detail in some water resource zones because companies were not projecting supply-demand balance deficits in those zones. The application of our socio-economic scenarios means that we are projecting deficits in some scenarios in those zones and so we needed to create water resource options for those zones.

Extension of projections to 2050

A5.47 In order to produce our projections to 2050, WAFU and Distribution Input were disaggregated into their components using the water company WRMP data tables. Different components were then projected forward using different methods. Some components (as well as target headroom) were set equal to the value for 2034/35 in each year of the remaining period to 2050; and some were based on an average of the previous five years. Some components are also influenced by the implementation of investment options in previous periods (e.g. leakage is reduced if additional leakage control options are implemented in previous years). The measures of household and non-household consumption are both driven by our socio-economic scenarios.
Production of scenario projections

A5.48 The four socio-economic scenarios ('Innovation', 'Uncontrolled demand', 'Sustainable behaviour', 'Local resilience') used in our modelling influence the household and non-household consumption components of Distribution Input (demand) in our model. The starting point for the assumptions that drive the four scenarios is the analysis produced by The Futures Company for the Environment Agency. They provide national estimates for changes in household and non-household consumption under the four scenarios.

A5.49 In order to apply the information from these national projections to the data for each of the relevant company water resource zones, we take the company dry year projections for household and non-household consumption and use those projections as a central anchor point around which to apply the spread of national consumption under the four scenarios. This enables us to introduce the range of demands implied by the scenarios to the specific circumstances of potential demand changes within each resource zone. The figure below provides an example that illustrates the range of demand under the four scenarios for a specific water resource zone relevant for one of the modelled catchments. The supply-demand balance line in the graph is the difference between target headroom and actual headroom (rather than the difference between ‘Total Water Available for Use’ and ‘Distribution Input’).

Water resource option costs

A5.50 The water resource management options data available to us were based on NPV costs. An indication of the type of data available for each option for a particular WRZ is provided in the Figure below. Some of the data shown below were added to the raw data provided in company tables, mainly drawing on written material provided in water company WRMPs. These include the option type description, the column describing conditionality of option implementation on implementation of other options and the Notes column, which was used primarily to provide information about geographic location to aid the modelling of changes in water flows if the option were implemented.
A5.51 For the modelling we needed to build a profile of option costs over time. In order to do this we assumed that annual operating costs are constant over the life of the option and that CAPEX is all incurred in the first year of option implementation. Operating costs are set to vary with the volume of water that the modelled option actually contributes to the supply-demand deficit.

Creating new water resource options

A5.52 Water resource management options were not presented in detail in company data tables in some water resource zones because companies were not projecting supply-demand balance deficits in those zones. The application of our socio-economic scenarios means that we are projecting deficits in some scenarios in those zones and so we needed to create water resource management options for those zones.

A5.53 The example shown in the figure above illustrates this. This company’s projection of the dry year supply-demand balance was similar to the projection in our ‘Innovation’ scenario, which shows no deficit. Our ‘Uncontrolled demand’ scenario, however, shows a deficit from 2036-37 onwards and so water resource management options need to be implemented in order to meet the projected deficit in this scenario.

A5.54 Additional water resource management options were also created for some water resource zones where the water company was projecting a deficit, but the water resource management options they presented data for where insufficient to meet the larger deficits projected in some of our socio-economic scenarios.

A5.55 We created additional water resource management options by using the data from real water resource management options from other companies and WRZs and then scaling these data to the size of the problem being addressed. We developed a range of types of water resource management options (e.g. new resources, demand management, leakage).
Key assumptions/constraints

A5.56 The investment decision process described here relies on a number of key assumptions. These are briefly described below.

1. The key features of the current regulatory regime remain broadly the same, or any changes do not have a significant impact on the way water resources planning is undertaken by the PWS sector. In particular, the WRMP process continues and any changes in the price regulation regime, including those currently planned but not yet implemented, do not significantly change the way water resource investment decisions are undertaken.

2. Our modelling does not fully capture all of the features of the current WRMP process in order to avoid further complexity in the modelling. Perhaps the main feature that is not modelled directly is the requirement for company programmes of planned water resource management options to undergo a Strategic Environmental Assessment (SEA). This process has the potential to significantly change the choice of options. For our modelling we take as our starting point the lists of ‘feasible options’ that the companies have developed from longer lists of potential options. It is likely that most companies have undertaken some screening for environmental impacts in arriving at the lists of feasible options, though this is not the same as a full SEA.

3. The timetables for our modelling and for the last WRMP process meant that we relied on supply, demand and option data from the last round of WRMPs (2009-10) rather than the draft plans submitted by April 2013.

4. In our modelling agents go through the investment decision process every five years throughout the period to 2050. The projections for supply and demand and the options data used at the beginning of the process are influential throughout. However, the options available from the start are not available for later decisions if they have already been implemented and we have added new options where existing options were not sufficient to meet planned deficits in later periods. Supply and demand projections are also adjusted to reflect the implementation of options in earlier periods in the model, e.g. demand is adjusted downwards where demand management measures have been taken and supply is adjusted upwards where new resources have been developed. No further adjustments to supply, demand or the options have been made.

5. Our characterisation of the water resource management options available to PWS agents is a relatively simple one that does not take account of all the complexities of water resource planning decisions in reality. For example, the focus of the modelling on individual WRZs and transfers from neighbouring WRZs doesn’t capture the scope for transfers across several WRZs. It is also possible that some of the additional options that we have developed would not in reality be practical to implement in the specific location that we have assumed and, separately, that we have not captured the full range of options that may be available in future.

6. The behaviour of PWS agents within a catchment will (to a large extent) be driven by issues associated with management and investment within a WRZ. The abstractor behaviour modelling is focused on models of catchments (since these are the principal regions in which trading can occur). We have therefore had to scale the behavioural responses of agents between the catchment and WRZ levels so that WRZ-driven PWS behaviour can be fully accommodated. The relationship between WRZs and catchments is illustrated in Figure 62\textsuperscript{27}. More details of the scaling method are provided in the companion report: The Impact of Abstraction Reform: Non-PWS agent behaviour.

\textsuperscript{27} Even this can be an over simplification. There may be abstractions located within a catchment that supply a WRZ that does not include that catchment.
A5.57 Policy options are modelled as constraints and rules within which abstractors are allowed to operate.

A5.58 For example, an abstractor may wish to abstract 18Ml of water to meet their production demand in the current time-step, but the current policy constraint (a licence to abstract 20Ml/day, but with an activated soft HOF) would restrict the abstraction to 9Ml.

A5.59 The policy options have been designed to incorporate the following features:

**Consumptiveness**

A5.60 The ABM considers both the actual abstractions made by an abstractor and the volume of water returned. Thus it can accommodate the current licensing system (which is based on the volume of water that can be abstracted) and the two policy options (which will be based on controlling total consumption).

A5.61 The ABM considers the daily pumping limit (which remaining in all three policies) to be a total usage limit. But it also maintains a period usage limit and a period consumption limit.

A5.62 In Current System, the periodic usage limit is set to the licence volume, and the periodic consumption limit is calculated using the assumed consumption factor in the CAMSledgers.

A5.63 In Current System Plus, the periodic consumption limit is set to the licence volume, and the periodic usage limit is calculated using the assumed consumption factor in the CAMSledgers.

A5.64 In Water Shares, the periodic usage limit is not used (since total abstraction is still constrained by the daily pumping limit), and it sets the periodic consumption limit every 14 days based on the shareholding and the observed flow.

**Shareholdings and allocations**

A5.65 Three key concepts are introduced under Water Shares.

A5.66 Firstly, abstractors may hold shares in the trading unit in which they actually abstract AND in trading units that are upstream. In effect their upstream shareholding ensures that enough water is left in the higher reaches so that they can abstract it lower down the catchment. But this also means that they can (within the share design limits) sell water upstream, and buy water from downstream – a situation that is not allowed under Current System or Current System Plus.
A5.67 Secondly, a shareholding is used to determine how much consumptive allocation is awarded over a short term period (currently 14 days). The allocation awarded for the next 14 days represents the total volume that may be abstracted over the period (subject to the daily pumping limit). The size of allocation is determined by the current flow in the river.

A5.68 Finally, different classes of shareholding are available based on how reliable the allocation is. Shares in Group-0 have the highest reliability, and thus an abactor holding such shares will be guaranteed their full 14-day allocation under the low in the river is very low.

A5.69 Share in Groups 1 to 3 have decreasing reliability. Thus Group-2 shares only guarantee a full allocation up to medium flows; beyond that the allocation is reduced until at low flows the allocation falls to 0.

Figure 63: Example of how water share group are distributed

A5.70 The actual flow values at which allocations start to fall and finally reach 0 depend on the size of the available water resource, so are water body specific.

A5.71 For the purposes of maintaining parity of approach between the three policies, the ABM constrains licence, share and allocation trading within the trading units introduced by water shares.

A5.72 This effectively mimics the process of such trades being considered low risk (and therefore pre-approved).

A5.73 Further existing licences with HOF conditions are classified into reliability bands that mimic the Group reliability bands. This enables agents to trade licences with HOF conditions knowing they are buying a less reliable licence.

**Setting environmental abstraction limits and reformed licence conditions**

A5.74 Having set up the operating rules for managing entitlements in the model it was necessary to establish reformed licence conditions for each of the case study catchments and assign licences to units suitable for trading for each of the reform options. The steps in the process are shown in Figure 64.

A5.75 The Environment Agency worked with AMEC and Risk Solutions to establish how the abstraction reform options would function in the catchment models and AMEC followed this...
agreed approach to define individual licence conditions and operating rules compatible with the models.

**Figure 64: Setting environmental abstraction limits and reformed licence conditions (source AMEC)**

**Defining the environmental baseline and water availability**

A5.76 Once each catchment assessment model was ready it was run without any abstractions or discharges to generate natural river flows. The models were also run using annually repeated patterns of abstractions and discharges to provide a simulated flow regime including the influence of recent pressures in the context of the climate experienced over the last 20 years. These data were then passed to AMEC who have knowledge of and access to the Environment Agency’s Water Resources Geographical Information System (WRGIS) and CAMSLedger spreadsheets. AMEC checked these simulated Natural and Recent Actual flows against the Environment Agency’s datasets in order to:

- Estimate a range of changes to licences that might be necessary prior to the start of the modelling period in 2025 to support environmental flow standards within the models, as required by the WFD and RSA reviews. These decisions were based on simple principles that have been developed for the purposes of using the catchment models to compare abstraction management systems and agreed with the project team. For example, where Recent Actual low flows from water bodies are in non-compliance Bands 2 or 3 compared with Environmental Flow Indicators, abstraction quantities (Recent Actual and Licensed) were reduced to bring estimated flows up to the Band 1 / 2 boundary.

- Adjust the current HOFs detailed in the Environment Agency’s Water Resources GIS and CAMSLedger datasets to fit with the flows simulated by the HR Wallingford model. This is to make sure that the licence ‘OFF’ levels are triggered for about the same proportion of the time in the Risk Solutions model as they are in the CAMSledgers, to account for differences in natural flow regime between these two datasets.

A5.77 AMEC then sent details of estimated assumed WFD-related abstraction reductions and adapted HOF levels to Risk Solutions.
Moving licences into the reform options for modelling

A5.78 HR Wallingford and Risk Solutions re-ran the catchment models to produce another set of data for AMEC that took into account the predicted impacts of ‘Recent Actual’ abstractions and discharges including WFD reductions and HOF model adjustments.

A5.79 AMEC used the ‘Recent Actual (post WFD reductions) data’ to develop spreadsheets detailing how each abstraction licence would look under each of the two proposed abstraction reform options (Current System Plus – CSP, or Water Shares – WS). This includes both surface water and groundwater licences. Changes that AMEC made to the licences included:

- Adjusting each annual abstraction limit to equal recent average water use plus 20 per cent of licensed volume, capped by licensed volume
- The removal of monthly (seasonal) restrictions on licences by:
  - Using information on months of pumping to assign whether each licence is a summer licence, a winter licence or an all year licence
  - Increasing the annual abstraction volume of summer licences to compensate for the reduction in flexibility arising from fixed period allocations
  - Adding HOF conditions to winter surface water licences as a replacement for seasonality.
- Ensuring maximum daily abstraction is at least twice an abstractor’s annual limit / 365 (to provide flexibility for trading, and in the knowledge that actual daily limits may not be accurately pinned down in the datasets used)
- Transferring any local, ‘point-of-abstraction’ HOFs to management units and assessment points
- Assigning licences to management units.

A5.80 AMEC then set up groundwater licences. This process included:

- Defining groundwater units that are suitable for trading and assigning groundwater licences to appropriate units;
- Characterising the potential ability of each groundwater abstraction to develop local storage without causing unacceptable drawdown at sensitive receptors. This is based on simple estimates of the volume of pumping which might be possible at peak daily rates before associated additional drawdown would impact on local wetlands, rivers, other abstractors or on intrusion of saline groundwater from the coast. This simple GIS-based analytical assessment is used to define a trading envelope for each abstraction point;
- Determining which non-consumptive GW abstractions should not be allowed to trade because all of the water abstracted from the ground is returned locally to support river flows (e.g. for fish farms, cress beds, or river support schemes.

A5.81 The changes described above for the two reform options were not made for the baseline current system option that was also modelled.

Linking abstraction to water availability (Current System Plus)

A5.82 AMEC set up water availability related controls for surface water under the Current System Plus option by:

- Defining individual trigger levels for surface water abstractors at CAMS Assessment Point (AP) management unit outflow points. This involved the translation of HOFs set more locally to management unit outflow points. These HOFs define flow levels at which abstractors must reduce abstraction, as river flows decrease (Soft HOFs), before ultimately stopping (at the regulation minimum limit). The way the model implements the Soft HOFs defined in this way is described below.
- Defining high flow trigger levels at which abstractors can safely take extra water (bonus water) and levels at which abstraction must cease for all relevant surface water abstractors;
• Defining critical downstream water bodies in each trial catchment. The flow at this point is what the model looks at to determine whether river levels are hitting triggers.

**Linking abstraction to availability (Water Shares)**

**A5.83** AMEC set up the availability related controls for surface water under the Water Shares option by:

• Defining how much water is available in each sub-unit of a catchment. This defines the capacity of a catchment for consumptive abstraction
• Defining up to 5 groups of water shares with differing levels of reliability (in each group all shares have equal reliability)
• Assigning existing licences to groups of shares, taking into account the reliability of their previous licence and based on consumptive abstraction rates
• Determining share ownership including specifying the management unit and group that shares are held in. During this process shares in upstream units are allocated to upstream abstractors first. Only after upstream abstractors have been allocated their shares are upstream shares awarded to downstream abstractors.

**Defining the ‘no go below flow’ limit**

**A5.84** As well as establishing a 2025 projection of baseline patterns of abstraction the process also defined the quantity of water required to be reserved for the environment, following improvements to achieve the RSA programme and comply with the Water Framework Directive. Given that a key requirement of the Water Framework Directive is to not deteriorate the status of the environment, this set the environmental threshold that should be maintained for the entire modelling period (2025-2050). But in locations that are projected to have spare water a threshold is needed to set the upper bounds of additional abstraction in order to protect the environment. This means that the environmental threshold in the modelling is defined as either:

• In locations that are only just achieving Water Framework Directive requirements – the environmental threshold is set at the modelled recent actual abstraction that maintains that status.
• In locations that have spare water (which may not be for all of the time, only when it is wet) the allowance for additional new abstraction is capped by the Environmental Flow Indicator\(^{28}\) (EFI) in order to protect the environment.

**A5.85** This combined threshold is termed the **no go below flow** (NGBF) in this report. Should modelled abstraction take flows or levels significantly below this NGBF threshold, with an associated deterioration of ecological status, Water Framework Directive requirements would no longer be met.

**A5.86** The model simulates each abstraction management system (either the current system or the two reform options) intervening to permanently adjust abstraction limits if there is a significant breach of the NGBF. For the purposes of modelling, we have defined a ‘significant breach’ as having occurred where modelled actual abstraction is more than five percent below the NGBF, for more than five percent of the time, over five of the last six years as illustrated in the figure below. We have explored sensitivities around this. Again, any changes needed to abstraction limits to preserve the NGBF are applied equally to licences across catchments. Groundwater licences are reviewed at set time periods (six years).

---

\(^{28}\) The EFI is adapted from flow standards proposed by the WFD UK Technical Advisory Group (UKTAG) to support good ecological status. If flows are above these thresholds we can be confident that abstractions are acceptable and good ecological status requirements will be met from a flow perspective. If flows are below these thresholds there is a risk of ecological damage.
Implementing Soft HOFs

**A5.87** Soft HOFs are implemented as shown in the figure. They are applied to each licence constraint individually. They are applied to the licence if the flow at the relevant assessment point falls below the Soft HOFF limit or regulation minimum limit and no other HOF conditions are in place.

![Diagram showing the implementation of Soft HOFs](image)

**Figure 66: Implementation of Soft HOFs**

Environmental Improvement Unit Charge (EIUC)

**A5.88** The model simulates each abstraction management system (either the current system or the two reform options) intervening to permanently adjust abstraction limits if there is a significant breach of the no go below flow (NGBF) level as described above.

**A5.89** Under the current system compensation is payable to abstractors if licence levels must be reduced or revoked to protect the environment; in these circumstances an *Environmental Improvement Unit Charge (EIUC)* is made on all abstractors in the area affected in order to recover the costs of compensation. In order to manage the buy-back equitably and minimize compensation payments:
- Environmental investigations are undertaken to identify the abstractions that are causing the damage.
- Buy-back is carried out using a reverse auction process.

**A5.90** The ABM simulates the EIUC bay-back process by identifying:

1. The total volume that needs to be bought back as a percentage of the total volume available.
2. ALL the abstractions that are contributing to the water body being affected.

**A5.91** It then forces each abstractor to offer twice the identified percentage of water at their current marginal production value. The offers are then ordered in increasing value, and the buy-back occurs until the total volume required is recovered. Thus water is bought back from those agents who place less economic value on it.

**A5.92** Under Current System Plus and Water Shares it is envisaged that no compensation will be paid and that water will simply be taken back with the costs being borne by the abstractors. In reality it is anticipated that there will be an intermediate period during which abstractors will trade and negotiate with each other so that the resultant take back is again made from those who value water less highly. Thus the ABM models the take back process in the same way as the buy back reverse auction, in that all abstractors who contribute to the damage are required to offer a fixed proportion of their licence volumes at their current marginal rate and the actual volume taken back is collated from the lowest offers.

**Implementation of trading**

**A5.93** In order for us to have a working trading mechanism in the model, agents need to be able to decide how much water they want to buy and sell at what prices; and there needs to be a market mechanism that enables buy offers to be matched with sell offers. Agents also need to decide whether to source their water needs through the trading mechanism or from another source of water.

**A5.94** The trading mechanism needs to work in the rather complex policy scenarios involving trading across trading units in the catchment. For the current version of the model we have focused on developing a trading mechanism that seems to work with a reasonable level of effectiveness, rather than on trying to develop a mechanism that would maximise the volume (or value of trades) in real world trading. The mechanism has not been tested using economic experiments or other methods. We have assumed that the trading mechanism does not introduce any barriers to trading, other than a value for transaction costs, and in modelling the outcome of trading we have assumed that there is no collusion in the market, or any anti-competitive practices. Our view is that the mechanism is more likely to over-estimate the volume and value of trades achievable in practice than to under-estimate them.

**Agent decisions on how much water to trade**

**A5.95** As part of their medium term decisions on how much of their products to produce, agents also work out whether they have spare water for the coming year. If they do have access to water that is not planned for use in production, they offer to sell that water for a price that is at least as high as the transactions costs of selling the water.

**A5.96** As a part of their production decisions, agents work out how much water they need to make each product and what profit that generates. They also offer that water to the market at a price that would reflect those lost production profits plus trading transactions costs. They do this for each product that they produce and so they may offer water in tranches at different prices reflecting different profits foregone. However, at this stage the modelling only considers a partial scaling back (10%) of the production of each product. This is because the product cost function is non-linear and so the price offered varies depending on the volume successfully traded. At present the trading mechanism cannot support conditional offers (where one batch is only offered into the market if a previous batch has been traded), but such an improvement will be considered for the final Impact Assessment.
In order to decide how much they might be willing to pay for water from a trading market, agents work out what profit they might make given no constrictions on their current water supply. They offer to buy water on the market at a price that reflects the additional achievable profits less the trading transaction costs.

Agents’ actual choice of production for the coming year is only made after the licence trading market has cleared and so any purchases or sales on that market are taken into account in the final production decision.

The market mechanism

The market for abstraction licences in each catchment is made up of a number of smaller markets at a trading unit level. Each agent’s offers to buy or sell water are submitted to the range of trading units across which that agent is able to trade.

At the start of the market clearing, a balance price is calculated for each trading unit in the catchment. All matched trades in the trading units occur at these prices. The balance price is set equal to the price at which the volume of water bid for above that price is the same as the volume of water offered below that price. It is analogous to the market price in the situation where the whole catchment is treated as one market with no constraints on trading between trading units within the catchment.

In some circumstances, it will not be possible to calculate the balance price in this way. The alternatives are:

- If there are no offers, the balance price is set equal to the second highest bid + 1p
- If there are no bids, the balance price is set equal to the second lowest offer - 1p
- If there are no offers or bids in a market, the balance price is set to be very large (to attract offers next time)
- If the lowest offer is above the highest bid then the balance price is set half way between the two.

Offers to buy and sell are matched in the following way.

The highest offer to buy in the entire catchment is compared with offers to sell in the trading unit that has the lowest balance price. The offer to buy is matched with the lowest qualifying offer to sell and the trade occurs at the balance price for that trading unit.

An offer to buy can only be accepted if

- The seller is connected in some way
- They are selling water of sufficient reliability
- They are selling water that can be accessed (i.e. ground water cannot be bought by someone without a borehole etc.)
- The offer to sell is at or below the offer to buy price

If a sale is made then:

1. The trade occurs at the balance price (so all trades within a trading unit take place at the same price)
2. The volume traded is the smaller of the bid volume and the offer volume.
3. The bid and offer that have been involved in the traded are then modified to reflect the actual volume traded. If the bid and/or offer have no remaining volume associated with them, then they are removed from the trading units in which they are active.
4. The balance price in all affected trading units is then recalculated
5. The next highest offer to buy (or the same one if it was not fully met) is then matched with sell offers in the trading unit with the new lowest balancing price.

If no sale is made then the next highest offer to buy is taken as the starting point for the matching process.
Prioritisation of water sources

A5.107 When an agent makes buy or sell offers into the trading market, these offers influence the price achieved by the agent. This means that before the agent enters the market they do not know what price they can achieve and so this makes it difficult to compare with the prices of other potential water sources. For this reason, the modelled agents prioritise the sources from which they access water, as follows.

- First agents seek to get the right (from the EA) to increase their daily pumping rate (but only if their current periodic allocation has hit their daily pumping limit * 365)
- Then agents seek to get more allocation (from the EA) for Ground Water ahead of Surface Water (if they have access to GW) since this will be better quality and more reliable
- Then agents seek to get more allocation (from the EA) for Surface Water
- Then they consider if there is any unregulated contract water from PWS
- Then they consider if there is any water that can be released upstream from someone else's store
- Then they go to the market to either buy or lease a licence or shares.

A5.108 All these sources except the licence markets are operated as a spot market, i.e. people put their fixed offers on the table and the cheapest offer wins. This means that agents can get an immediate sale without having to wait for the market to clear.

A5.109 At the point when the contract and water release options are considered these have to be cheaper than last years’ market price to be considered.
GLOSSARY

This glossary provides definitions of key terms.

Catchment Abstraction Management Strategy (CAMS) 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
The authorisation granted by the Environment Agency or Natural Resources Wales 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).

Aquifer
A geological formation that can store and transmit groundwater in significant quantities.

Assessment Point
A location in a catchment at which the regulator measures or estimates the hydrological state, usually river flow rate, river level, or aquifer head. This provides an indicator of the health of the local environment. 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.

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

Consumptive abstraction
Abstraction where a significant proportion of the water is not returned either directly or indirectly to the source of supply soon after use. For example water used for spray irrigation.

Discharge
Often used in CAMS documents to describe the release of substances, for example, water, treated sewage effluent and so on into receiving waters, also more generally the flow in a watercourse, usually measured in m³/s.

Environmental flow indicator (EFI)
A flow screening standard used to help establish how much water is available above the amount required for environmental protection.

Exempt abstractions
Abstractions exempt from the current licensing system including abstractions of less than 20m³ per day and a range of uses including dewatering of mines, quarries, trickle irrigation and transfers of water via canals.
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, wells and river base flow. The upper surface of groundwater is the water table.

Groundwater management units (GWMU)
Administrative sub-divisions of aquifers, defined on geological and hydrogeological criteria, which form the basis for groundwater resource management and licensing policy decisions.

Hands off flow (HOF)
A condition attached to an abstraction licence which states that if flow (in the river) falls below the level specified on the licence, the abstractor will be required to reduce or stop the abstraction.

Hands off level
A river level below which an abstractor is required to reduce or stop abstraction.

Small abstraction exemption
The small abstraction exemptions defined by the Water Act 2003 exempt small abstractors whose abstractions do not exceed 20m³.

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

Water body
Units of either surface water or groundwater at which assessments are completed for the Water Framework Directive (WFD).

Water resources management plan, infrastructure and operational terms

Bulk supplies
Supplies of water traded between individual appointed water companies. These supplies are often traded under long-term contracts and on non-standard terms.

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

Conjunctive use schemes
Conjunctive use is the coordinated management of surface water and groundwater supplies to maximize the yield of the overall water resource.

Demand management
The implementation of policies or measures which aim to control or reduce the consumption or waste of water. Demand management strategies include: selective metering; appropriate tariff structures; leakage reduction; and the promotion of water efficiency through either technological or behavioural change.
**Deployable Outputs (DO)**
The Deployable Output (DO) of a source is defined as the output as constrained by the abstraction licence, water quality, environmental impacts, treatment capacity, pumping plant or pipework capacity, or the borehole/aquifer properties.

**Distribution Input**
The amount of water entering the distribution system at the point of production.

**Drought plan**
Statutory plans produced by the appointed water companies that detail the actions each would take to manage the supply of water in a drought. In England, each Environment Agency Region has drought plans in place that set out how they plan for and manage drought. Natural Resources Wales maintain a drought plan for Wales.

**Dry year**
The dry year is a period of low rainfall and unconstrained demand which is only just met by available supplies. It is the basis of a company’s WRMP. A water company should carry out final planning forecasts under the dry year forecast. The dry year forecast is normally developed from base year figures and the company should explain any assumptions or adjustments it has made due to weather patterns experienced that year.

**Dry Year Annual Average**
The Dry Year Annual Average is the annual average value of demand, deployable output or some other quantity over the course of a ‘dry year’.

**Effluent**
Treated wastewater discharged into a river or the sea.

**Groundwater abstraction**
Groundwater abstraction is the process of taking water from an aquifer, either on a temporary or permanent basis.

**Groundwater augmentation schemes**
Some watercourses in England and Wales are under increasing pressure from abstraction of water. In some catchments public water supply companies augment flows in rivers by pumping water into them from groundwater sources. This report covers the schemes in the case study catchments operated by public water supply companies but not those managed by the Environment Agency.

**Hands Off Flow (HOF) or Hands Off Level (HOL) conditions**
Many abstraction licences contain conditions where the licence holder has to reduce or stop abstracting water once the river has dropped to a certain water level or flow. These are known as Hands Off Flow (HOF) or Hands Off Level (HOL) conditions and protect other river users and the environment. The HOF or HOL is the flow or level below which an abstraction licence holder cannot abstract water from a watercourse or a borehole.

**Headroom**
Headroom is the term used to refer to the margin between supply and demand. The target headroom is the minimum buffer that a prudent water company should allow between supply (including raw water imports and excluding raw water exports) and demand to cater for specified uncertainties (except for those due to outages) in the overall supply/demand balance.
**Target headroom**
Company target for the difference between Distribution Input (demand) and WAFU (supply).

**Levels of service**
Specific measures of services to consumers with regards to water supply these are issues related to low pressure, supply interruptions and restrictions on water use.

**Licensed versus actual abstraction**
The licensed abstraction is the maximum amount of water that can be abstracted, within various constraints, from licences within a CAMS area. The actual abstraction is the actual quantity of water abstracted. This is equal to or generally less than the licensed abstraction quantity. Most individual abstraction records are reported to the Environment Agency or Natural Resources Wales each year.

**Naturalised flow**
The flow that would occur in a watercourse in the absence of abstractions and discharges or the operation of flow regulating reservoirs (i.e. in the absence of any artificial influences). This cannot be known for certain but is usually estimated by adding known abstractions and removing known discharges.

**Normal conditions**
Under normal conditions, each water company aims to meet demand at minimum costs and subject to any licence constraints.

**Reservoirs and natural lakes**
Reservoir is a body of water used for the storage and regulation of water. The water is usually impounded by artificial structure such as dam. A reservoir can have natural or pumped inflows. A natural lake will not have a structure such as a dam or weir artificially maintaining water levels in it.

**Return flows**
Return flows are the part of the water withdrawn for an agricultural, industrial or domestic purpose that returns to the groundwater or surface water in the same catchment as where it was abstracted. This water can potentially be withdrawn and used again. In the case study catchments this water is generally returned to watercourses via sewage treatment works and hence is often referred to as effluent flows.

**Service reservoir**
This is a tank containing drinking water that is usually sited within or near to a water distribution system. It is usually used as a reserve (for example, in cases where the supply from a water treatment works to the distribution system fails). It evens out distribution system demand on the supply.

**Supply/demand balance**
The balance between the volume of water available in an appointed water company’s area and the volume supplied to meet consumer demand. Any imbalance between supply and demand can be met through enhancing existing resources or demand management strategies.

**Water available for use (WAFU)**
A projection of dry year supply. The value calculated by deducting allowable outages and planning allowances from deployable output in a resource zone.
Water Resources Management Plan (WRMP)
Every five years, water companies in England and Wales, in consultation with the Environment Agency and Natural Resources Wales, produce Water Resources Management Plans (WRMPs) where they lay out the actions they will take in order to maintain security of water supply over the next 25 years or more. These WRMPs form an important part of the water companies’ business plan submission to Ofwat for the five yearly Periodic Review.

Water Resource Zone
The largest possible zone in which all water resources, including external transfers, can be shared. Hence, it is the zone in which all customers experience the same probability of supply failure from a resource shortfall.

Terms relating to reform

General terms / current system

Abstraction Market
The buying and selling of authorisations to abstract.

Consumption
The amount of abstracted water that is not returned to the source it is abstracted from, close to the point it was taken from soon after it is abstracted.

Consumptiveness
The difference between the volume of water abstracted and the volume of water discharged, where the discharge is both local and recent to the location and time of abstraction. It is usually expressed as a percentage. One hundred per cent represents an entirely consumptive abstraction. Zero per cent would represent an entirely non-consumptive abstraction where all the water abstracted was returned to the river or stream.

Environmental Improvement Unit Charge (EIUC)
A charge on abstractors to cover the costs of compensating abstractors where the Environment Agency or Natural Resources Wales compulsorily vary or revoke abstraction licences to reduce the risk of environmental damage caused by taking too much water.

Proportionate implementation
A concept whereby the system used to manage abstraction in a catchment would develop over time. Under this approach the basic system would be implemented everywhere and as resources become more stressed, the system would become more sophisticated in response for example, by introducing a trading platform to allow quicker, more frequent trading.

Fully allocated
A catchment is fully allocated if licences have been issued to a total volume equivalent to the water available for abstraction in that catchment.

Loss Factor
A factor used in the existing abstraction charges scheme to express the consumptiveness of different types of abstraction (High, Medium, Low, Very low).

Net Abstraction
The difference between water taken and what’s returned (locally and without significant delay).
One in two out
In England, from January 2013, every new regulation that imposes a new financial burden on firms must be offset by reductions in red tape that will save double those costs. The rule prevents any UK government department introducing new regulation that will impose a direct net cost on business and voluntary organisations - unless the department can find savings by removing or modifying another regulation of twice the equivalent cost.

Review conditions
A set of catchment conditions which, if triggered, would allow the review of regulatory conditions that apply to abstraction in that catchment.

Target Headroom
This is a specific term used in relation to water companies. It is a buffer between the amount of water available for supply and the amount of water in demand from customers. Water companies need to maintain target headroom and in setting the size of the buffer need to balance the costs and risks to customers and the environment of a low headroom allowance against those of a high headroom allowance.

Transition
The process of moving existing abstraction licences into a new system.

Trigger Levels
Water levels or flows at which abstraction is reduced or flexed in relation to water availability. This term could be used under Current System Plus, or Water Shares, but would be applied differently.
In Current System Plus it would be the level/flow at which additional water could be taken or less water was allowed.
In Water Shares, it would be the trigger levels at which the amount of water available gets bigger or smaller.

Unbundling
The concept of separating volumetric abstraction limits from site-specific conditions to reduce the complexity and therefore transaction costs of water trading. This is the term used in Australia – not now used commonly in relation to UK reform and not used in this report – included here for completeness.

Current System Plus (Specific terms)

Bonus Water
When flows are higher than usual, people may be able to abstract more water than they are normally allowed to.

Hands off Period
A period of time during which abstraction conditions cannot be amended.

No Go Below Flow (NGBF)
A flow level established for the purposes of modelling to represent the volume of water needed to avoid environmental deterioration. Should abstraction take flows or levels significantly below this NGBF threshold, the environment may deteriorate and the Water Framework Directive requirements may no longer be met.
**Regulation Minimum Limit**
Many abstraction licences do not currently include a HOF. On transition of these licences into Current System Plus, they would be given HOFs, but these would be set at very low flows.

**Shepherding**
The process of ensuring that, if someone has agreed to trade a volume of water with someone further downstream, the volume of water is protected so that it is still available for the other person to abstract further down the river.

**Site Specific Permit**
A permit including site-specific conditions which is a pre-requisite for abstraction. Conditions could include the requirement for a particular type of fish screen or details relating to the means of abstraction.

**Soft HOF**
A regulatory condition which requires abstraction to gradually reduce before stopping altogether, rather than just stopping abstraction at a single HOF limit.

**Usage Charge**
A charge raised, usually based on meter readings, to reflect the volume of water used.

**Water Shares (Specific Terms)**

**Allocation**
An authorisation to abstract a volume of water for a fixed period of time, for example, two weeks. This volume may be smaller or larger than implied by the size of the entitlement permit to reflect predicted water availability for the duration of the fixed period. The volume will vary with water availability.

**Allocation Period**
The period of time that an allocation covers, for example two weeks.

**Future Period Trades**
Trading future periods within the Tradable Shares Option. This allows abstractors to buy access to other abstractor shares in advance for a 2 week period taking the risk as to the allocations available for that period.

**Share Charge**
A charge raised based on the water shares held.

**Short term trades**
Used to describe temporary trades. Under the existing system, these tend to be defined as less than one year. In Water Shares it refers to trading in allocations. It could be for the next allocation period (e.g. 2 weeks) or people could trade multiple allocations, even if they didn’t know what their actual allocation was going to be.
Trading Platform

Any IT system that will match multiple abstractors who want to buy and sell abstraction authorisations within pre-defined, modelled environmental limits.

Groups of shares

A quantity of water available for abstraction within which each share has the same reliability, often defined and measured at an assessment point. Under the Water Shares option abstractors will be able to hold water shares in a range of different groups to tailor their level of risk to their operational needs.

Water reliability

High reliability water is available for a high percentage of time whereas low reliability water is available only at high flows. Reliability of supply will carry differing levels of importance to different sectors and agents within each sector dependent on the importance of water for their product and the availability of alternatives.

Water Account

An on-line system which tracks who holds which Water Shares and sets out people's allocations for the next allocation period.

Water Share

The long term share of available water that an abstractor is entitled to.

Modelling and data sources

Agent-based modelling

An agent-based model is a class of computational model for simulating the actions and interactions of autonomous agents (both individual and collective entities such as organisations or groups) with a view to assessing their effects on the system as a whole.

Aggregation

The process of scaling up results from case study catchments to country level (England or Wales).

Balance price

The balance price of a market in the modelling is set equal to the price at which the volume of water bid for above that price is the same as the volume of water offered below that price. It is analogous to the market price in the situation where the whole catchment is treated as one market with no constraints on trading between trading units within the catchment.

Base flow

The portion of stream flow that comes from groundwater seepage into a river.

Calibration

The process of adjusting model inputs so that they can produce river flows in the catchment consistent with those observed in real life.

Discovery

Options to increase supply included in Water Company WRMPs tend to include a range of smaller low cost options and larger more expensive capital projects. Initial shortfalls are typically resolved using a combination of the smaller options to produce a solution that is just
big enough. Water companies often find that additional smaller options emerge at each progressive WRMP cycle, and the larger capital projects can get pushed back in time. This process of finding additional smaller options is called discovery.

**CAMS Ledgers**
Spreadsheet tools that contain details of all the abstraction licences (volumes and location and discharges) and are updated every time a new licence is issued, changed or revoked and to inform future licensing decisions.

**Flow duration curve**
A flow duration curve is a graphical representation of a ranking of all the flows in a given period, from the lowest to the highest, where the rank is the percentage of time the flow value is equalled or exceeded.

**Groundwater recharge**
The hydrological process where water moves downward from surface water to groundwater.

**Groundwater response area**

**Flashy zone**
The term ‘flashy’, as applied to stream flow, has no set definition and in general applies to a set of characteristics equated with the rate of change in flow – flashy streams have rapid rates of change and stable streams have slow rates of change.

**Hydrological model**
A simplified, conceptual representation of a part of the water (or hydrological) cycle. They are primarily used for hydrological prediction and for understanding hydrological processes. The hydrological cycle is the continuous movement of water on, above and below the surface of the Earth.

**Lumped model**
A lumped model is one which does not consider any spatial variability across the area being modelled.

**Price takers**
Agents who must accept the market price for their output are price takers.

**Satisficing behaviour**
The targeting of satisfactory profits rather than maximum profits.

**Scenario analysis**
The process of defining a range of possible future scenarios, scoping the full range of possible futures, and then carrying out model runs for each of these scenarios.

**Spot market**
A spot market is one where people put their fixed offers on the table and the cheapest offer wins.

**Top down economic modelling**
Modelling focussed on market and economy-wide feedbacks and interactions.
Trading Unit
A geographic region (based on a river reach or aquifer) within which low risk trading is allowed. Surface water trading units are usually defined as areas between CAMS assessment points. Ground water trading units are usually defined as hydrological linked aquifer units.

Unregulated Contract Water
Water that PWS can sell to farmers and others after they have build additional infrastructure, e.g. water storage, for that purpose and which is not regulated by Ofwat.

Water Resources Geographic Information System (WRGIS)
The Water Resources GIS (WRGIS) is the central system where abstraction, discharge, natural flows and complex impacts information from the CAMSLedgers is uploaded. The WRGIS uses this information to calculate the current resource availability for each water body at four flow percentiles. It incorporates coded calculations based on an integrated surface water / groundwater database of around 1000 water bodies, combined with many other map layers in standardised formats.

Other acronyms and definitions

ABM
Abstractor Behaviour Model

AISC
Average Incremental Social Cost

NPV
Net Present Value

PWS
Public Water Supply

RSA
Restoring Sustainable Abstraction – Under this programme the Environment Agency or Natural Resources Wales investigate the causes of unsustainable abstraction and implement measures to restore sustainable abstraction. This could include changing abstraction licences or other actions to reduce the impact on the environment.

RoC
Habitats Directive Review of Consents – The Habitats Directive and UK Habitats Regulations require authorities to ‘assess the implications for European Sites and European Offshore marine sites’ of their consents, decisions and projects.

SEA
Strategic Environmental Assessment

The Habitats Directive
The Habitats Directive is a European Union directive adopted in 1992 as an EU response to the Berne Convention. It is one of the EU's two directives in relation to wildlife and nature conservation, the other being the Birds Directive.
WFD
Water Framework Directive - The Water Framework Directive is a European Union directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies (including marine waters up to one nautical mile from shore) by 2015. It is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach.