OxCam Integrated Water Management Framework

Phase 1 Report

July 2022

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Environment Agency

OxCam Integrated Water Management Framework

Phase 1 Report

July 2022

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Acronyms

AAD	Annual Average Damages
AMP	Asset Management Plan
APS	Asset Planning System
ABS	Abstraction Sensitivity Bands
BNG	Biodiversity net gain
BRAVA	Baseline Risk and Vulnerability Assessment
BVP	Best value plan
BWR	Blackwater Reuse
CaBA	Catchment Based Approach
CAM	Environment Agency’s Cost of Agricultural Measures
CAMS	Catchment Abstraction Management System
CAS	Common Analytical Scenarios
CBA	Cost benefit analysis/assessment
CCG	Customer Challenge Groups
CP	Catchment permitting
CSEI	Centre for Systems Engineering and Innovation
CSO	Combined sewer overflows
DAPP	Dynamic Adaptive Policy Pathways
DCLG	Department for Communities and Local Government
Defra	Department for the Environment, Food and Rural Affairs
DLUHC	Department for Levelling Up, Homes and Communities
DWF	Dry weather flow
DWI	Drinking Water Inspectorate
DWMP	Drainage and Wastewater Management Plan
EBN	Environmental Benefits from Nature
EBSD	Economic Balance of Supply and Demand
EFI	Environmental Flow Indicator
ELM	Environmental Land Management
FCERM	Flood and Coastal Erosion Risk Management
FRA	Flood risk areas

FRM	Flood Risk Management
FRMP	Flood Risk Management Plans
FRMS	Flood Risk Management Strategies
FZ2	Flood Zone 2
FZ3	Flood Zone 3
GCSPS	Greater Cambridge Shared Planning Service
GiA	Grant in Aid
GWR	Greywater Reuse
HRA	Habitats Regulations Assessments
ICM	Integrated Catchment Modelling
INNS	Invasive Non-Native Species
IRM	Integrated Risk Model
IWM	Integrated water management
IWMF	OxCam IWM Framework
LA	Local authorities
LLFA	Lead local flood authority
LNCP	Local Natural Capital Plan
LP	Local Plans
LPA	Local planning authority
LTIS	Long Term Investment Scenarios
NPPF	National Planning Policy Framework
MCA	Multi-criteria analysis/appraisal
MO RDM	Multi-criteria Robust Decision Making
N2K	Natura 2000
NBS	Nature based solutions
NFM	Natural Flood Management
NFWR	National Framework for Water Resources
NPPF	National Planning Policy Framework
NRFA	National River Flow Archive
NRN	Nature Recovery Network
NWEBS	National Water Environment Benefit Survey

OxCam Arc	Oxford-Cambridge Arc
PCC	Per capita consumption
PWS	Public Water Supply
RAPID	Regulators' Alliance for Progressing Infrastructure Development
RBMP	River Basin Management Plan
RDM	Robust decision-making
RFCC	Regional Flood and Coastal Committees
RMA	Risk management authorities
RoSWf	Risk of surface water flooding
RWH	Rainwater Harvesting
SAC	Special Areas of Conservation
SCP	Systematic Conservation Planning
SDB	Supply demand balance
SEA	Strategic Environmental Assessment
SEOP	Storm Overflow Evidence Project
SFRA	Strategic Flood Risk Assessments
SPA	Special Protected Areas
SPZ	Source protection zone
SRO	Strategic Resource Options
SRP	Soluble Reactive Phosphate
SSSI	Sites of Special Scientific Interest
SuDS	Sustainable drainage systems
SWMP	Surface Water Management Plans
TAL	Technically achievable limit
TAG	Transport Appraisal Guidance
TN	Total nitrogen
UGF	Urban Greening Factor
UKTAG	UK Technical Advisory Group
UWWTD	Urban Wastewater Treatment Directive
VWSF	Volume weighted spill frequencies
WCS	Water Cycle Studies

WFD	Water Framework Directive
WINEP	Water Industry National Environment Programme
WRE	Water Resources East
WRMP	Water Resource Management Plan
WRPG	Water Resources Planning Guidelines
WRSE	Water Resources South East
WRZ	Water resource zones
WSIMOD	Water Systems Integration model
WwTW	Wastewater treatment works

Glossary

AMP7	Asset Management Period for the UK water sector between 2020-2025
AMP8	Asset Management Period for the UK water sector between 2025-2030
BOD	Biochemical oxygen demand is defined as the amount of oxygen needed by aerobic biological organisms to break down organic matter present in the medium.
EFI	Ecologically acceptable deviation from natural flow at various points in the flow curve, grouped according to the deemed sensitivity of the river
Nutrient neutrality	Limiting additional net nutrient loading from development as required in order to avoid deterioration in status of any designated site or water body, irrespective of site or water body location
Offsetting	Investing in schemes that save water in the local region such as retrofitting existing buildings with water efficient devices or water reuse systems, where the water saved through these schemes is equal to the residual mains water usage of the new development
Operational Catchment	As defined by the WFD, Operational catchments are a way of grouping WFD waterbodies together for the purposes of economic appraisal. Every waterbody has been assigned to an Operational catchment. They are not always hydrologically correct catchments as the river waterbodies may have been grouped based on pressures and measures than hydrology
QMED	Median of the annual maxima of river flows during the simulation period
Q95	The flow rate which is exceeded for 95% of the historical record
R-B	Index for variability (flashiness) of river flows
RCP4.5	Carbon emissions peak in 2040 due to aggressive adoption of renewables

RCP8.5	Carbon emissions at business as usual
TAL	The lowest nutrient concentration that can be reliably achieved by existing wastewater treatment technologies
Water Body	As defined by the WFD, these are lakes and parts of rivers, estuaries, coastal waters and groundwater. They include artificial water bodies, such as canals, and heavily modified water bodies, such as deepened and straightened rivers. Environmental objectives are set for each water body.
WRMP19	Water resources management plans produced by UK water companies published in 2019 which set out maintaining the balance between water supply and demand
WRMP24	Water resources management plans produced by UK water companies to be published in 2024 which set out maintaining the balance between water supply and demand

Executive summary

Overview

The Oxford-Cambridge Arc (OxCam Arc) is one of the most water stressed areas of the country, with high levels of unsustainable abstraction making water resilience key to future planning. Flood risk across the region is high and growing, and the natural environment has significantly declined in quality. Integrated water management (IWM) will be critical in supporting this long-term ambition to develop a resilient water environment.

This project establishes an innovative framework for integrated water IWM across water resources, wastewater, flood risk and the water environment for the OxCam Arc. Information from this project will help inform future decision making and strategic (and development level) planning to ensure the intended development is sustainable, legal/policy compliant and that it achieves the best outcome for the water environment across the OxCam Arc.

The OxCam IWM Framework (IWMF) is to be delivered in a number of phases. The emphasis of this current phase of the project (Phase 1) is on the development of the baseline and system understanding and identifying which questions/issues the framework should address. These will set the basis for options appraisal and prioritisation of interventions.

We propose two main ways in which the water system in the OxCam Arc can be influenced to deliver better outcomes for the environment and society:

1. More integrated multi-criteria appraisal (MCA) of solutions across the four core water sub-systems (water resources, wastewater, flood risk and water environment), integrated with local growth planning to inform or prescribe spatial planning, not just respond to it.
2. Improved/tailored IWM standards at all scales: individual development project planning, local planning authority (LPA) strategic planning (i.e. Local Plans), catchment planning and regional water planning (e.g. Water Resource Management Plan (WRMP), Drainage and Wastewater Management Plan (DWMP), Flood Risk Management, and River Basin Management Plan (RBMP)).

We started by gathering evidence relevant to the IWMF to specify a baseline across core water systems. We undertook systems mapping to specify the interconnected nature of the systems under consideration, categorise options and benefits relevant to integrated appraisal, identify appraisal criteria and create insights and participant buy-in. We then outlined metrics for MCA criteria, and set out an approach to integrated solutions appraisal, including pilot modelling using a dynamic catchment model and a high-level MCA of generic option types. We reviewed water and nutrient neutrality as potential to improve IWM standards, set out policy considerations for IWM and finally refined an approach to future phases of the IWMF development.

Baseline capacity assessment

We present key baseline evidence across water resources, wastewater, flood risk and the water environment, and relevant geospatial data in a GIS platform. We also present an initial hotspot assessment to illustrate the whole water system in terms of the following elements: Water Framework Directive (WFD) water body status (current and objective); wastewater treatment capacity; nutrient offsetting potential; flood risk, locally, in the wider operational catchment and under climate change; environmental flow deficits; water resources supply/demand balance; and soil health. The hotspot analysis does not attempt to show exactly where new development would be more or less appropriate, but instead provides a starting point for weighting criteria in different catchments for catchment modelling and MCA.

The OxCam Arc is facing significant water resource challenges related to ambitions to restore the natural environment through reduced groundwater abstraction, increase drought resilience for households, and mitigate climate change. Additional demand will cause significant local challenges in the short to medium term if water resource impacts are not adequately addressed. For OxCam growth, the primary issues are regarding timing: if new resources and/or supply network infrastructure cannot be delivered rapidly enough to keep up with growing demand, then level of service may not be met, and/or environmental damage may result. The Environment Agency has responded to the emerging regional plans and has identified the need to reduce abstraction in the short term to prevent deterioration. This will further reduce the available headroom in companies' networks to meet the needs of growth in the short to medium term.

Systems assessment

We used a Participatory System Mapping method to map interactions and dependencies across environmental systems (water quality and rivers, flooding, water resources), water utilities (water supply and wastewater treatment), spatial planning, development and agricultural systems. Framing the development of the IWMF as a systems process has been beneficial. As a result, we have been able to:

- Identify how different aspects of water and flooding are related and the factors that influence these
- Set out options and benefits for all aspects of water that can be planned
- Select a wide range of criteria to evaluate the different aspects of water, covering the key functions of the core systems and relevant wider co-benefits (e.g. health and wellbeing).
- Identify the potential for integration at the water planning level so that synergies are achieved across items such as urban planning, flood control and water quality.
- Create insights and stakeholder buy-in, to foster improved collaboration and participation

The maps act as repository of knowledge categorising options and benefits. These categories are likely to evolve as the IWMF develops and the maps should be considered live documents to be updated in subsequent phases.

Integrated solutions appraisal (MCA)

Planning processes such as WRMP, DWMP, Flood Risk Management, and RBMP are developed over different timeframes. While there are interdependencies between these processes, planning assumptions differ creating a significant impediment to integrated planning. We set forth a method in which options with multiple benefits can be included in more than one planning framework. This integrated approach would enable cost sharing of multi-benefit options making more options cost-effective. Since cost effectiveness is a common constraint on flooding and environmental outcomes, efficient cost sharing could increase the implementation and achievement of flood and environmental planning. It could enhance the cost effectiveness of water resource options bringing savings for customers. In order to achieve an integrated approach the following steps are needed in order to make planning processes comparable:

- A common set of metrics.
- A common set of planning assumptions.
- A common set of scenarios.
- A consistent set of management targets and performance thresholds.
- A consistent categorisation of option categories.

In this report we present a set of metrics relevant across the planning frameworks.

We demonstrate how integrated catchment modelling would enhance the capability of IWMF to coordinate the integration of water resource, wastewater, flooding and environmental planning. A pilot study modelling the Rhee, Cam and Granta showed the interconnected impacts of different catchment interventions. The Integrated Catchment Model evaluates water resources and water quality and provides indicative results of flow variability for flood impacts. The study provides proof of concept for integrated modelling in support of integrated planning. Water quality, environmental flow and water resource objectives can be quantified directly through mass-balance models, such that their integrated MCA criteria can be appraised in integrated modelling directly. Flood risk appraisal requires geospatial modelling to determine performance, which is best undertaken within planning frameworks. However, integrated modelling could be applied to deliver integrated MCA if flood risks are specified as performance thresholds, represented by high flow proxies in the integrated model, which could also be used to identify in-combination risks and synergies across planning frameworks.

By providing a centralised and high-level approach to modelling, an IWMF coordinating office could enable the integration of planning frameworks but does not seek to take on the detailed analysis that is better handled within dedicated system-specific planning frameworks.

IWM standards

In relation to improved IWM standards for LPA local plans, the current impacts, costs and opportunities of water resources and wastewater impacts are not fully accounted for in planning development decisions. For wastewater, existing permits and WINEP interventions must be adhered to, but there is no clear mechanism for water impacts to influence development decisions (i.e. determination of planning applications), and local plans traditionally do not address these issues in any depth. Often the impacts occur beyond planning boundaries.

We review the potential for improved IWM standards at all scales of the water system in the OxCam Arc to deliver better outcomes for the environment and society. We identify a range of policy measures that could be used to protect and enhance the water environment in OxCam, across design standards, planning policy and beyond. The close relationship between growth and environmental capacity would be best addressed with a catchment-based approach to IWM. Flooding, environment and water quality systems operate, to a high degree, within catchment boundaries. Water resource systems operate regionally as water is transferred at this scale.

Urban planning decisions do not currently take account of the full costs of development on water sub-systems. The IWMF should account for the full costs of development on water sub-systems when deciding where development is located. The IWM standards for compliance by developers and local government will be important in determining the ambition for the Arc and creating opportunities for developers to find innovative solutions to the achievement of that ambition at the local level.

Water and nutrient neutrality should be understood as being tools within the development of the IWM standards, rather than standards themselves – as relying on neutrality alone will not create the environmental enhancement to which the OxCam Arc is committed. A key concern, that requires further analysis, is the scale over which water and nutrient neutrality would be deployed as a planning tool.

To comply with the 2017 WFD Regulations and Habitats Regulations, water companies must not cause a deterioration in status of any water body or statutory protected site. There are several water bodies in the OxCam Arc where an increase in water abstraction or increase in pollutant loading would cause deterioration in status. In these cases, the abstraction of additional water for new development would cause water companies to be non-compliant with statutory legislation without intervention. Intervention could involve water neutrality measures to prevent increase in abstraction from relevant water sources, and/or nutrient neutrality measures to prevent any increased loading of nutrients to sensitive water bodies or protected sites. Any offsetting measures must take account of seasonal and spatial risks to ensure no damage or deterioration anywhere at any time.

We note that growth in water demand is not driven by housing development alone. Household occupancy is equally important, and may be driven upwards by growth in employment opportunities, forcing more people into the existing housing stock. Temporary increases in demand associated with daily or seasonal migration to/from the Arc for work or leisure may also be important contributors to demand, especially at critical demand periods. Strategic planning should take account of these effects, when deciding whether economic growth plans are likely to drive migration into a catchment whose water body status could be deteriorated by additional abstraction irrespective of plans to build new homes.

In some cases, avoiding damage or deterioration may not be feasible with local off-setting and the only way of mitigating increased demand for water or wastewater services would be through the delivery of major new infrastructure. In these cases, no new housing development or growth in work space should be permitted until this infrastructure is fully operational, which may take a number of years. Identifying these locations within the Arc requires detailed local hydrological and water quality modelling, which has not been undertaken in Phase 1 of this work. In water bodies at risk of deterioration, the precautionary principle should be followed: evidence should be provided to show how no increase in abstraction from sensitive sources will be achieved, and/or no increase in nutrient concentrations at any sensitive water feature above safe limits. This should be done in consultation with water companies, the Environment Agency and Natural England.

Concluding remarks

The regional water resource planning processes created under the Environment Agency's National Framework for Water Resources has achieved a major development in coordinated planning. It has addressed water resources and to some degree environmental planning objectives. The development of these plans continues to be a complex and demanding activity. In comparison, the ambition of the OxCam Arc which aims to integrate a larger number of planning frameworks is greater still. Our assessment is that a coordinated and centralised high-level approach to modelling options would enable the efficiencies of co-developed, multi-benefit options to be realised at scale. This approach would identify the cross-system synergies and provide the unified perspective on where effort is needed to realise these opportunities.

We propose that it would be more efficient to develop this high level-overarching view of the synergies than to rely on each planning framework to develop its own approach to interacting with all of the other system frameworks – an approach that would be more onerous and lack the consistency of a unified overview. The interaction between planning frameworks and integrated modelling proposed in this project provides building blocks for how that overarching coordination could be achieved.

1 Introduction

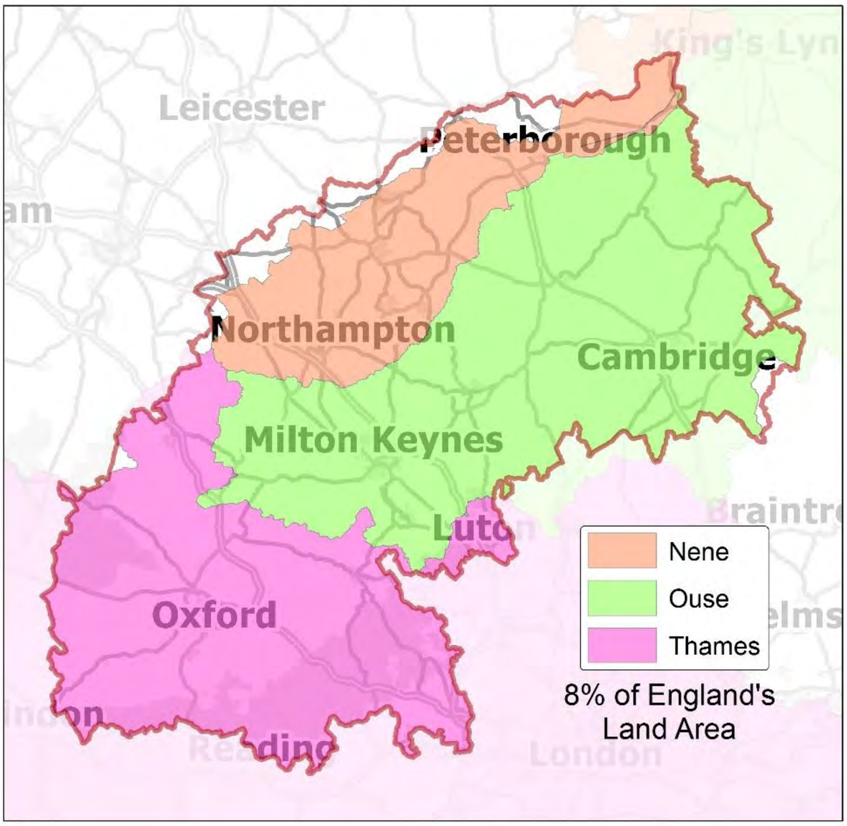
An integrated water management framework (IWMF), developed in a phased approach, is proposed for the OxCam Arc to inform future decision making, policy and strategic planning, both locally and nationally (via design standards, design codes, planning policy amendment and evolution, and future water regulation). Water management in the OxCam Arc is influenced by a wide range of policy, regulation and guidance. The starting aims for IWMF are to integrate existing water planning processes and improve urban planning policy and standards, in order to ensure the intended development is sustainable, legal/policy compliant, and maximises environmental gain in the Arc through identifying and enabling co-benefits of interventions across the key water sub-systems.

1.1 Background

The Oxford-Cambridge Arc (OxCam Arc) is one of the most water stressed areas of the country, with high levels of unsustainable abstraction making water resilience key to future planning. Flood risk across the region is high and growing, and the natural environment has significantly declined in quality. A map of the Arc is shown in Figure 1.1.

Sustainable water management will be critical to help realise the ambition of sustainable economic growth in the OxCam Arc. It requires an understanding of the current water landscape across the Arc, where investment is planned and whether it would be beneficial for Government to intervene with policy or water management initiatives. Information from this project will help inform future decision making and strategic (and development level) planning to ensure the best outcome for the water environment across the Arc.

Figure 1.1: Map of the OxCam Arc and key water catchments



1.2 Purpose

This project looks to establish an innovative framework for integrated water management (IWM) across water resources, water quality and flood risk for the OxCam Arc. The aim is to achieve the best outcomes for the water environment in the OxCam Arc, taking account of the needs for development, to provide safe and secure water supplies, and to address flood risk. Information from this project will help inform future decision making and urban planning, at both strategic and development levels.

The OxCam IWMF is to be delivered in a number of phases as shown in Figure 1.2 below, to provide opportunity to review the approach and reach wider agreement on decisions at key points to gain buy-in from stakeholders. The emphasis for this Phase 1 of the project is on the development of the baseline, system understanding and framework. These set the basis for options appraisal and prioritisation of interventions, following initial "light appraisal" of options. This light appraisal provides proof of concept for the baseline, data handling and framework developed in the project and will enable a more substantial appraisal to be undertaken subsequently. Phase 1a will pilot the approach to detailed Multi-Criteria Analysis (MCA) across the OxCam Arc using dynamic catchment modelling. Phases 2 and 3 will design the framework and recommend delivery mechanisms.

Figure 1.2: IWMF phases of work

The purpose of this report is to describe the outcomes of Phase 1 for consultation. It draws together the series of technical notes issued throughout the project, reflecting considerable feedback from the project Technical Group comprising subject matter experts from various sectors relevant to the water system, including water companies, regional water resource groups, the Environment Agency, Natural England, the Department for the Environment, Food and Rural Affairs (Defra), the Department for Levelling Up, Homes and Communities (DLUHC) and Homes England. A list of the Technical Group members is presented in Annex A. We note that membership of the technical group does not imply endorsement of any/all of this report or its content. The OxCam Arc IMWF's overarching objectives are shown below in Figure 1.3.

Figure 1.3: OxCam Arc overarching objectives

2 Current planning frameworks

2.1 Introduction

Delivery of integrated water management for the OxCam Arc will require co-ordination of the planning processes of four core water sub-systems: water resources, wastewater, flooding and environment. This will enable the OxCam Integrated Water Management Framework (IWMF) to deliver the aspirational goals of the 25 Year Environment Plan through overseeing integration and promoting co-benefit options across the following planning processes:

- Environment – Water Framework Directive (WFD), River Basin Management Plans (RBMPs) and Water Industry National Environment Programme (WINEP)
- Water resources – National Framework for Water Resources (NFWR), Water Resource Management Plans (WRMPs),
- Wastewater – Drainage and Wastewater Management Plans (DWMPs),
- Flooding – Flood and Coastal Erosion Risk Management (FCERM) and Flood Risk Management Plans (FRMPs),

The benefits of interventions in one sub-system may depend on those in other subsystems. For example, an improvement in ecological or overall status of a water body may require both restoration of natural flows and improvement of water quality. In this case, the role of the IWMF would be to align water quality interventions in the WINEP with water resource interventions included in a WRMP (the abstraction licensing strategy).

An important objective will be to identify options for co-funding multi-benefit options. For example, if a flooding scheme has a water resource benefit, then the IWMF will enable the water resource element of that option to be reflected in water resource planning in a consistent manner allowing co-development and co-funding of the option.

This section sets out the planning interfaces that need to be managed in order to implement the IWMF. An overview of the timelines and existing planning processes is provided, followed by analysis of the timelines and implications for the design of the OxCam IWMF, as well as outlining challenges which will need to be addressed.

Further detail on the legal and policy background can be found in Annex B, including a number of ways in which wider policy and/or regulation could be enhanced to support delivery of the environmental ambitions within the OxCam Arc.

We note that the forthcoming Environmental Land Management schemes will need to be integrated into this framework as practice develops in addition to the water industry planning frameworks listed above. Similarly local government planning cycles need to be integrated.

2.2 Planning framework summary

The IWMF would aim to maximise opportunities for improvement in the management of water resources, water quality, flood risk and the water environment. These four core sub-systems are currently appraised separately, and whilst benefits against multiple criteria are accounted for within each planning process through MCA, the current water planning frameworks do not allow for core system benefits to be recognised across sub-systems. If a flooding option offers benefits in terms of water resources, this is not necessarily translated across for appraisal in water resource planning. Furthermore, there may well be synergies and feedbacks resulting from option interaction, such that two options appraised in different planning processes could deliver a net benefit greater than the sum of their individual benefits, which will also be missed by appraising them separately.

A key challenge for an OxCam IWMF (and nationally) is that these four aspects of water planning are currently appraised at very different spatial scales and through very different approaches and differing timescales/planning cycles.

In water resources management, abstraction limits to maintain sufficient water for the needs of the water environment are identified first through RBMP and WINEP. Public water supply options appraisal is then undertaken by water companies on the basis that the volume of water available for use for public supply under specified drought conditions must balance the total demand for public water, given specified drought restrictions. The drought level of service is specified nationally by regulation. Options are selected on a best value for money basis, but the objective of supply-demand balance is an absolute requirement, not evaluated for value. Given the spatially distributed and large-scale nature of water resource options, appraisal must now be done at a regional level, with reconciliation at a national level, in line with the National Framework for Water Resources; and taking a long-term view. Planning requirements are applied via Local Plans and the National Planning Policy Framework (NPPF) (Paragraphs 20 and 153) for new developments through the LPA development management system to ensure their impact on water supply is addressed.

In contrast, for flood risk options appraisal, the use of targets such as return period is complicated by the fact that it may not be cost effective to aim for a uniform level of protection. Therefore, there is no absolute minimum requirement to meet. Instead cost/benefit assessment is used to appraise flood defence for existing properties, and planning requirements are applied via Local Plans and the NPPF for new developments through the LPA development management system to mitigate their impact on flood risk. The NPPF states, “Strategic policies should set out an overall strategy for the pattern, scale and design quality of places, and make sufficient provision for infrastructure for transport, telecommunications, security, waste management, water supply, wastewater, flood risk and coastal change management.”

Historically, the ratio of financialised benefits to costs had to exceed some value; typically a ratio as high as 8 to 1. This is no longer the case where partnership funding is available. Because options have historically been local and relatively small-scale, with relatively low lead times, Flood Risk Management (FRM) Plans are short-term (six years) and updated annually. There is likely no feasible over-delivery in terms of risk reduction, though potentially a risk that the best value cost/benefit ratio is set incorrectly high or low. FRM schemes can be unpopular in the communities they are designed to protect, if deemed to be unsightly, or where households do not consider themselves to be at risk. Local opposition can prevent scheme delivery even where funding is available.

For wastewater, the conventional approach has been to determine investment to maintain or improve environmental status by meeting discharge permit limits on wastewater quantity and quality. Therefore, plans have had to maintain the collection, transfer and treatment capacity to meet discharge consents, which has been done locally and viewed mainly as part of capital investment plans. The introduction of DWMPs is now encouraging a more strategic view of wastewater capacities, but primarily still framed around the need to meet discharge consent limits, which may often not take account of wider system interactions. Planning requirements are applied via Local Plans and the NPPF (Paragraphs 20) for new developments through the LPA development management system to ensure their impact on wastewater capacity is addressed.

2.3 Existing planning timelines

The following figures are presented to show the existing inter-dependencies between planning frameworks.

- A high-level view of interdependencies in planning frameworks is shown in Figure 2.1.
- A high-level view of planning timelines is shown in Figure 2.2.
- Information from these first two figures is combined to show the framework interdependencies between 2021 and 2025 in Figure 2.3.

Figure 2.1: High level view of interdependencies in water management planning frameworks

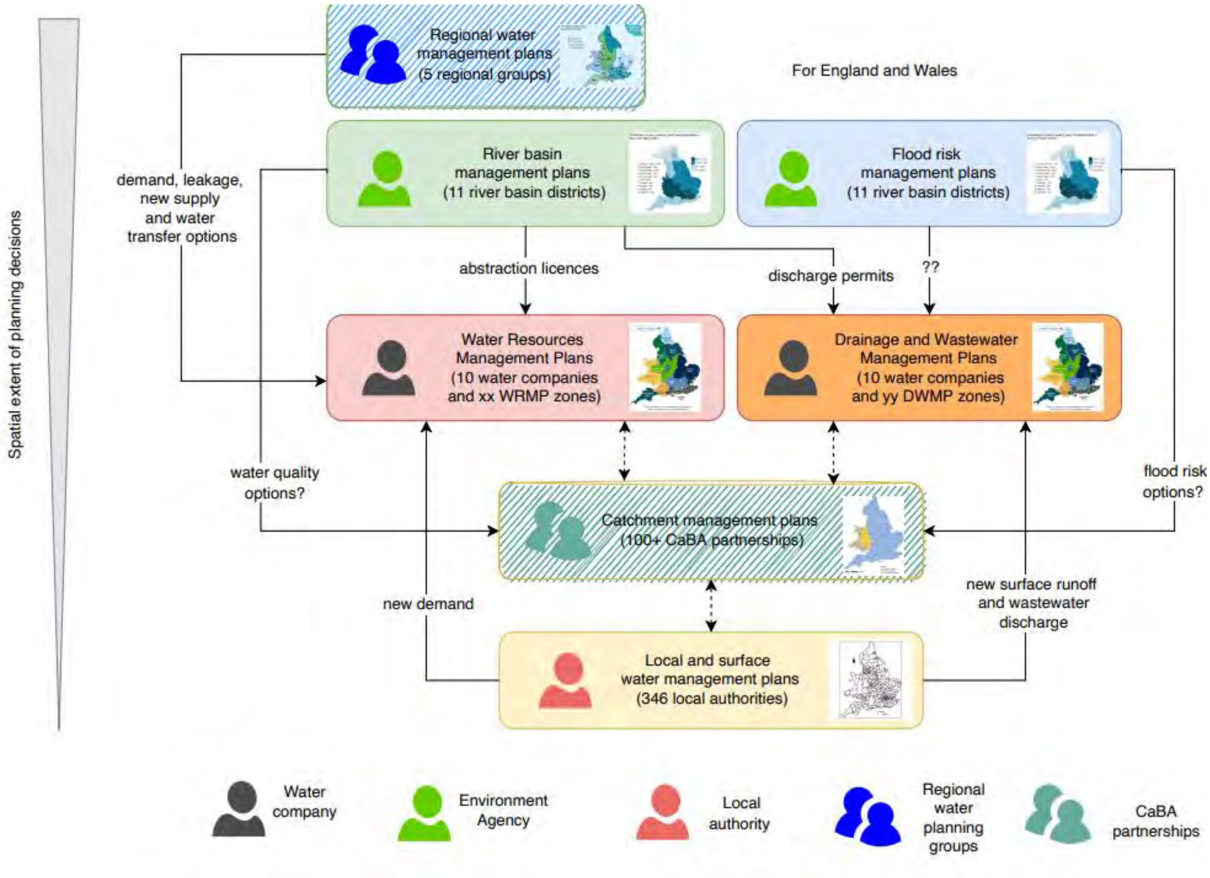


Figure 2.2: Planning framework timelines – high level view

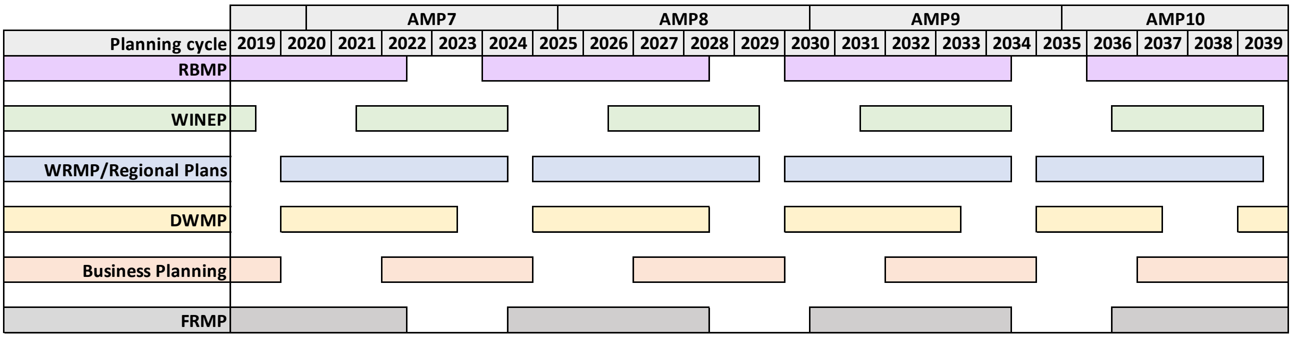
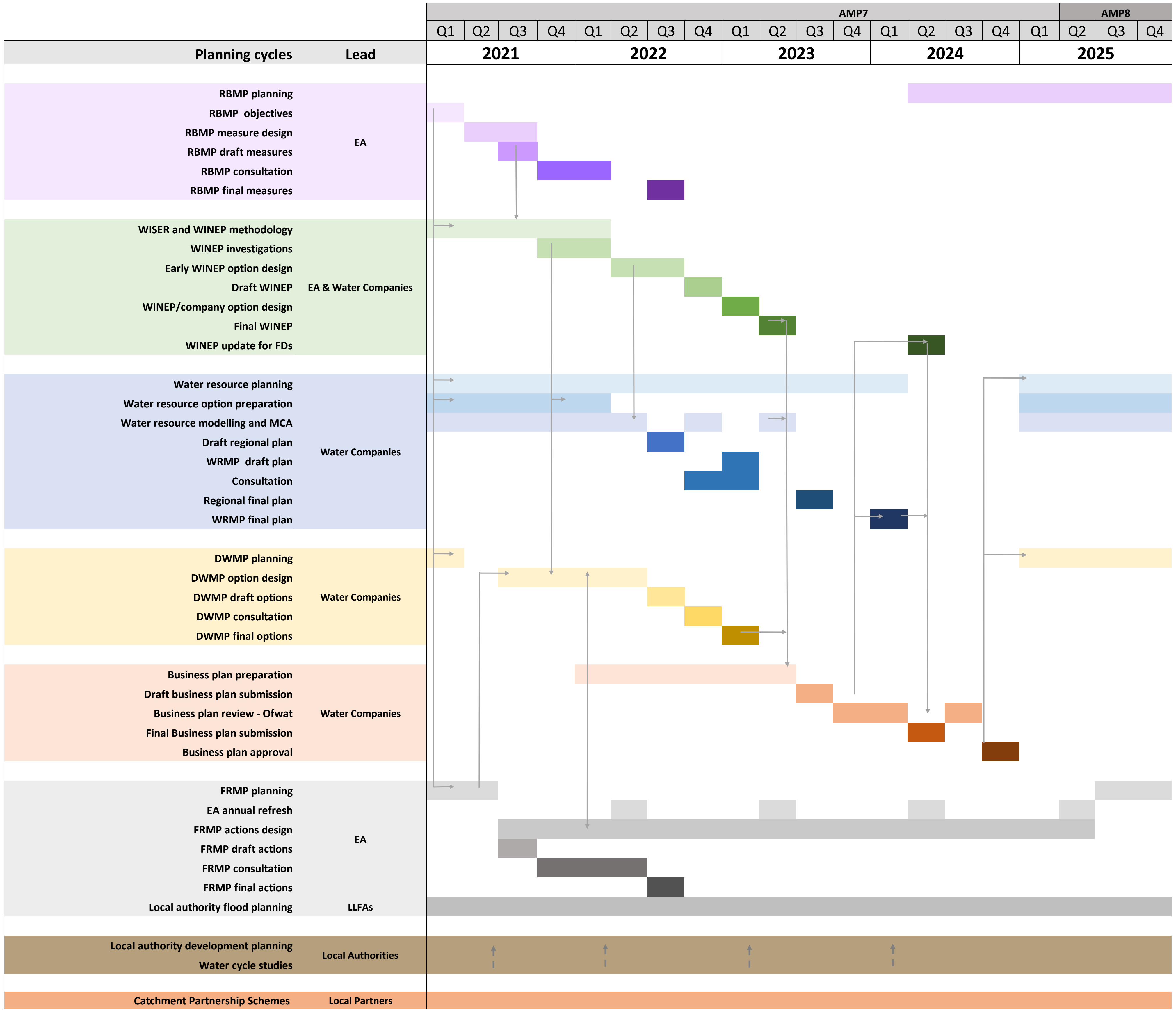


Figure 2.3: Planning timelines for water resources, wastewater, flooding and environment



2.3.1 Water environment planning

2.3.1.1 Relevant planning frameworks

The overarching environmental framework for catchments is the Water Environment (Water Framework Directive) (England & Wales) Regulations 2017 (referred to as the WFD Regulations). Under the WFD Regulations, a River Basin Management Plan (RBMP) must be prepared by the Environment Agency for each river basin district. The environmental objectives of the RBMP inform the Water Industry National Environment Programme (WINEP).

RBMPs establish an integrated approach for the protection and sustainable use of the water environment and focus on improving the ecological status of water bodies. RBMPs set out the statutory environmental objectives for water bodies including those for International, European and National protected areas for nature conservation and landscape such as Ramsar sites, Special Protection Areas, Special Areas of Conservation, National Parks and Sites of Special Scientific Interest (SSSIs). These environmental objectives are specified through cost benefit analysis (CBA), along with the high-level programme of measures required to meet them. Defra and the Environment Agency undertake cost benefit analysis through an economic appraisal, identifying the monetary valuation of the major benefits for achieving these objectives and comparing these with the cost of the high-level programme of measures.

Within WINEP, water companies appraise technically feasible options in detail, and determine the costs of delivering these schemes for inclusion within their business plans. WINEP comprises:

- investigations to provide evidence to inform WRMP and DWMP
- the programme of measures for the following Asset Management Plan period (AMP)
- the delivery programme of the measures

2.3.1.2 Planning interfaces

As the key strategic plan for the water environment, the specified environmental objectives within the RBMP drive the need for many interventions across all subsystems e.g.:

- WRMP: abstraction licence reductions (up to 2500 Ml/d across the East and Southeast of England specified in Water Resources East (WRE) and Water Resources South East (WRSE) emerging regional plans (2022))
- DWMP: the progressive reduction in the adverse impacts of discharges from storm overflows; and new or enhanced discharge consent limits,
- WINEP[1] investigations and measures

As public bodies, Local Authorities (LAs) are required to ‘have regard’ to the RBMPs in exercising their functions.

2.3.2 Water resources planning

2.3.2.1 Relevant planning frameworks

Water Resources planning requirements are set out in the Environment Agency’s National Framework for Water Resources (NFWR)[2] and statutory legislation for Water Resource Management Plans (WRMPs). Regional Water Resource Plans require the creation of strategic Best Value Plans (BVP) to provide a resilient, multi-sector, water management framework for each region of England. WRMPs are a statutory

[1] Actions included in a water company’s WINEP reflect the company’s obligations arising from environmental legislation such as Urban Wastewater Treatment Regulations, Water Environment (Water Framework Directive) Regulations, Bathing Waters Regulations, and Conservation of Habitats and Species Regulations. The WINEP may also contain non-statutory actions.

[2] Summary of the NFWR

requirement in which water companies set out an investment plan for the following 5 year AMP to meet public water supply needs within the wider strategic plan set out for the region with a 25 year horizon or longer.

The Regulators' Alliance for Progressing Infrastructure Development (RAPID) is a collaboration between Ofwat, the Environment Agency and the Drinking Water Inspectorate (DWI) that has been set up to progress water resource infrastructure projects of national significance known as Strategic Resource Options (SROs).

2.3.2.2 Planning interface

WRMPs are statutory plans created under a broader umbrella of the regional plans. WRMP planning is also influenced by environmental objectives such as abstraction licence changes which are confirmed under WINEP. The Water Abstraction Plan 2017[3] sets out how water abstraction management will reform over the coming years. It states how this will protect the environment and improve access to water in line with the RBMPs. The plan has 3 main parts to: address unsustainable abstraction; develop a stronger catchment focus; modernise regulation.

The Catchment Abstraction Management System (CAMS) translates the RBMPs and the Water Abstraction Plan into the licensing policy, based on Environmental Flow Indicators, set at a level believed to support Good Ecological Status. This licensing policy is a key driver for investment in Water Resources Management.

Strategic Resource Options (SROs) also provide an area of interface with other planning processes such as DWMPs, FRMPs and WINEP to maximise co-benefits for individual schemes. However, SROs are designed primarily to meet water resource requirements, and specifying co-benefits for other water subsystems is encouraged but not consistently defined. There is also no directly equivalent process for delivering large infrastructure for other subsystems.

2.3.3 Wastewater planning

2.3.3.1 Relevant planning frameworks

Wastewater planning is now determined by the DWMP planning process undertaken by water companies. This is a newly introduced process to encourage a more strategic view of drainage and wastewater planning over a minimum 25 year timeframe.

2.3.3.2 Planning interface

The DWMP planning interface is influenced by the following processes:

- Environmental water quality objectives set by RBMPs, which determine permit limits for wastewater treatment works (WwTWs), with changes specified in the WINEP.
- Spatial alignment with FRMP and RBMP planning to plan at river catchment scale rather than WwTW catchments.
- Utilities are also required to follow the Flood and Coastal Erosion Risk Management (FCERM) strategy, ensuring that wastewater management options also account for flood risk.

There is an expectation that DWMP will closely align with WRMP in the next AMP[4].

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[3] https://www.gov.uk/government/publications/water-abstraction-plan-2017/water-abstraction-plan

[4] Guiding principles for drainage and wastewater management plans - GOV.UK (www.gov.uk)

2.3.4 Flood risk management planning

2.3.4.1 Relevant planning frameworks

Flood risk management planning is set out in the FCERM strategy which determines how much flood defence is required nationally. The Long Term Investment Scenarios (LTIS) which provide an economic assessment of the optimum level of investment for FCERM. FRMPs are the key planning process to deliver the FCERM strategy at a national level, with the Environment Agency and lead local flood authority (LLFA) work together to produce and review these plans. Within flood risk management, other relevant planning processes include:

- Surface Water Management Plans (SWMPs) and local Flood Risk Management Strategies (FRMS) produced by LLFAs.
- Strategic Flood Risk Assessments (SFRAs) and Water Cycle Studies (WCS) produced by Local Planning Authorities (LPAs).
- WCS produced by District Councils to assess the constraints and requirements on the water environment that may arise from development in the area. They address likely wastewater compliance issues as well as flood risk issues, and water resource needs at a high level.
- Other planning bodies include the Regional Flood and Coastal Committees (RFCCs) who approve the annual programme of FCERM work in their region and set the local levy that funds FCERM activities within the region that are a local priority.

2.3.4.2 Planning interfaces

Challenges within the flooding interface are as follows:

- Local level plans (such as SFRAs) and WCS') produced by LPAs are timed to inform the development of Local Plans rather than aligning with the FRMP process.
- DWMP guidance specifies coordination between draft RBMPs, FRMPs and DWMP planning. However, SWMP and FRMP co-ordination with DWMPs is not consistent across all local authorities. There is only limited interaction between FRMPs and WRMP. FRMP only takes into account previous WRMP and DWMP when determining flood risks. FRMP outputs feed into DWMP, but the impacts of draft DWMP or WRMP interventions on flooding cannot be taken into account in FRMP due to timing constraints.

2.3.5 Other policy interfaces

2.3.5.1 Agriculture

The introduction of Environmental Land Management (ELM) will also impact on water environment planning processes primarily through the Tier 2 (Local Nature Recovery) and Tier 3 (Landscape Recovery) schemes, although the (Tier 1) Sustainable Farming Incentive will also have an effect.

It is expected this will interface with the following areas:

- RBMPs – through schemes being included as part of environmental measures to meet WFD requirements up to 2027.
- Water company catchment management options – through opportunities for multiple funding streams if options are shown to align with ELM objectives.
- WINEP – potential for future co-ordination and development of catchment management options included within ELM schemes.

Land-use management decisions outside of WINEP are currently based primarily on short-term and long-term profit maximisation taking account of ELM schemes and regulatory requirements. The phasing out of the current Basic Payments approach (with a three year transition period between 2024 – 2027) and then the piloting and roll out of ELM have important implications for land-use planning, which may well interface with WINEP, WRMP and DWMP.

2.3.5.2 Urban planning

Another policy interface which exists but is not shown within the timeline is that of urban planning. Planning processes are governed by the following elements:

- The overarching National Planning Policy Framework (NPPF) which dictates what Local Authorities must include in their plans and is only updated when significant changes take place.
- Local Plans (LPs) which generally follow a 5 year cycle, although they are updated throughout this period and the timings of these cycles would vary significantly between each Local Authority.

The work of LLFAs and localised flood risk management, as well as Water Cycle Studies, are used to inform LPs. WRMPs, DWMPs, and FRMPs also take account of the most recently published LPs in their growth forecasts, i.e. based on planned housing development. WRMPs "should reflect local growth ambitions and plan to meet the additional needs of new businesses and households." These may be used in combination with trend-based forecasts. The guidance for WRMP reference to LPs is shown below.

WRMP Planning Guideline 2021

"Local authorities in England are now required to use local housing need calculations to inform their local plans as they are revised and updated. This assessment may indicate that the number of properties could be higher or lower than the forecasts in current adopted local plans. If there is a significant difference between the local plan and the local housing needs numbers you should contact the relevant authority to discuss the implications of this for future plans.

ONS also produces population projections and household projections. Population projections provide an indication of the future size and age structure of the population based on mid-year population estimates and a set of assumptions of future fertility, mortality and migration.

However, it is worth noting that these projections have limitations as they are based on recent trends in data that can be influenced by recent economic, political and natural situations. Therefore, it is appropriate to test the impact of alternative population and household growth scenarios on your plan. You should consider an adaptive plan where there is a significant difference in projections, particularly where this might affect your investment decisions in the first half of your plan.

You should ensure your plan does not lead to over-investment or constrain planned growth."

2.3.5.3 Water company business plans

Other elements of water industry planning which need to be considered are the overarching AMP7 and AMP8 cycles and water company business plans that are produced for Ofwat's Price Reviews. These plans interface with multiple planning processes as they include a wide range of options proposed within companies' WINEP commitments, WRMPs and DWMPs. However, the Price Review has historically been tailored to maximising the costs incurred by water company customers, whilst ensuring companies can meet their statutory obligations, and specifying market incentives (outperformance payments and underperformance penalties) to deliver specific outputs to an agreed timescale. This has tended to embed and amplify siloed approaches to delivering objectives, inhibiting more integrated and innovative solutions.

Key outputs are as follows:

  – Business plan preparation throughout 2022 and early 2023

– Draft plan submission in Q3 2023
– Final plan submission in Q2 2024
– Ofwat reviews of draft and final plans and final approval in Q4 2024.

This process will be repeated in the following cycle.

The investment plans identified in the WRMP and DWMP that have been signed off by the Environment Agency ultimately need then be signed off by Ofwat. Companies and Ofwat need to balance the investment being driven by environmental requirements, growth and factors such as climate change against customer bills.

2.3.6 Interface gaps and opportunities

Potential synergies exist between all areas of water environment planning, providing the opportunity to enable comprehensive integrated water management. Here we discuss potential gaps and opportunities in interfaces, according to three phases of planning based on the water company AMP planning cycle.

As the current interfaces are heavily interlinked, it is important that the IWM MCA recognises that there is potential to give different types of intervention different selection rules.

Early-planning Phase

- Insufficient integrated planning early in the planning process can mean that options scoring lower on primary benefits exclusively in one water sub-system are discounted, as it is not realised they could provide multiple secondary benefits to other areas.
- It can also be difficult for individual planning frameworks to adequately define feasible innovative solutions, e.g. nature-based solutions, due to lack of available models at an appropriate scale, and/or lack of models that are designed to evaluate the benefits required. This is confounded by limited data on, for example, the impacts of nature-based solutions on groundwater recharge, particularly at scale.

Mid-planning Phase

- One potential issue for WINEP and WRMP is that water companies propose WINEP actions/solutions in AMP Years 1-2, in parallel to WRMP options appraisal and regional plan development. The Environment Agency assesses proposals via cost benefit assessment (CBA) to finalise the WINEP in AMP Years 3 and 4. In reviewing the WRMP, the Environment Agency looks to ensure that where the company has identified a licence change is needed to deliver the environmental outcome (as identified by Water Industry Strategic Environmental Requirements) that these are met within the WRMP, but there is no clear mechanism for the impact of licence changes on WRMP costs to feed into the CBA for WINEP. Furthermore, RBMP WFD water body status objectives were determined through CBA in 2015 using estimated costs, updated with actual PR19 costs in 2019 and checked again in 2022. But it is not clear that the impact of licence changes on WRMP costs are included in this CBA either, and the timing of the RBMP economic Impact Assessment (2015) and National Economic Assessment (2022) would make it difficult to incorporate any updated objectives into water resource planning.
- Another issue for WINEP (under new AMP7 guidance) is that measures to deliver non-statutory objectives should now aspire to at least 20% co-funding (from sources other than water companies). Water companies and the EA may currently lack the tools to demonstrate all the benefits of non-statutory measures to potential co-funders, and the mechanisms to facilitate this funding, making it difficult to deliver non-statutory measures despite potentially considerable opportunities for co-benefits.

Late-planning Phase

After determination of draft plans across water resources, flooding, drainage and wastewater, and WINEP, we also identify a potential gap in reconciliation across the planning processes and with RBMP objectives. For example:

- RBMP objectives may feed through abstraction licence changes and WWTW permit changes through WRMP and DWMP, to drive a new desalination plant and phosphate treatment upgrade at very considerable expense. These cost/benefit implications need feeding back into RBMP objectives to ensure they are cost effective, given other catchment pressures: were objectives set based on certain assumptions over cost of delivery, and have those assumptions been proved correct? Would alternative combinations of measures deliver better value for the environment within the catchment or to a different catchment?
- WRMP, DWMP, FRMP, WINEP and catchment measures in combination may impact water body flows and water quality significantly, but any such effects are not currently appraised. FRMP objectives and measures feed into DWMP, but the impacts of draft DWMP or WRMP interventions on flooding are not taken into account in FRMP.

General Gaps

- The WINEP is currently limited by its short planning timeframe (5 years) and lack of integration with long-term planning and actions emerging from RBMPs, WRMPs and DWMPs. The 5-year timeframe has also led to the promotion of short-term environmental improvements schemes at the expense of more strategic and integrated solutions to achieve a resilient environment. This reduces the incentive to develop more holistic catchment-based solutions which could deliver greater value and additional natural capital benefits.
- Current limitations of the WINEP have led to consultation[5] on how the process can be improved, through review of the current methodology by Ofwat[6] and the Environment Agency[7]. A WINEP taskforce has been developed to produce a draft methodology for the next planning period, with the final methodology and option appraisal guidance currently undergoing consultation and awaiting publication (as of May 2022). This is likely to lead to changes in the way the WINEP operates, including increasing the length of the WINEP from 5 to 10 years.
- RBMP catchment interventions outside WINEP are currently not subject to the same strategic planning as WINEP. For example, this can include measures such as local river restoration through Catchment Based Approach (CaBA) partnerships, reduced agricultural abstraction measures, or measures to mitigate impacts from road run-off by Highways England. These may be led by local interest, rather than environmental need, which can result in sub-optimal investment plans from an environmental point of view.
- Land-use change may be more cost effective than hard infrastructure solutions, but investment is currently biased towards hard infrastructure due to difficulties with quantifying catchment benefits and lack of regulated control of catchments (as compared to water company activities).

Urban Planning

- Urban planning decisions do not currently take account of the full costs of development on water sub-systems, or the potential impacts on water companies in terms of meeting their legal obligations under environmental legislation such as the Habitats Directive. Water companies have a statutory duty to supply water and waste water to their customers, and small increases in demand can trigger the need for expensive infrastructure to store, treat and deliver water to or from customers, potentially some way away.
- The timing of Local Plans is not currently specified consistently, and the timing of some Plans can already make interfacing with WRMP, WINEP, FRMP and DWMP difficult. Some potential impacts on protected sites are only being identified at planning application stage, with requirements for water and nutrient neutrality in some areas currently the only way in which development may go ahead. However as

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[5] Review of the water industry national environment programme (WINEP): summary of consultation responses - GOV.UK (www.gov.uk)

[6] WINEP review discussion paper (ofwat.gov.uk)

[7] Review of the water industry national environment programme consultation document.pdf (environment-agency.gov.uk)

described in our Phase 1 report, there are several issues with both water and nutrient neutrality, in terms of effectiveness and implementation. At the very least, how to meet environmental legal obligations needs addressing at Local Plan stage, and this requires better interfaces between urban and water planning processes.

- Water Cycle Studies are intended to assess the constraints and requirements on the water environment that may arise from development in the area, but there is no clear mechanism to ensure that complete water system impacts are accounted for fully in development decisions, and any residual impacts are mitigated in full.

2.3.7 Challenges

For successful interfacing with the IWMF, interventions from each planning process must be aligned, as described in Section 5. Additional areas of planning and interface which will need greater consideration are:

- **Flood risk performance indicators** – for the IWMF MCA, it is likely the approach will involve specifying performance thresholds or management targets for integrated catchment modelling (ICM) indicators, based on detailed modelling within each planning framework. It should be possible to specify these performance thresholds for environmental flows, drought resilience and water quality, because the relationships between the indicators and objectives are closely aligned, and can be modelled on a mass balance basis. However, for flood risk:
  - The relationship between flow indicators and flood impact is more complex, and may be highly non-linear depending on catchment topography, and property spatial distribution within the catchment.
  - There are more flow variables which could represent flood risk performance, such as QMED, R-B index.
  - Flood impact can be mitigated without altering flows (through building flood defence barriers), such that the flow performance indicator may vary significantly between FRMP portfolios.
- **Incorporation of surface water and local flood risk management options -** Beneath the high level FCERM and Environment Agency-led FRMPs, there are also multiple other local authorities and RMAs responsible for managing flood risk. It is less clear how the IWMF could incorporate flood planning at a local level where timelines align with urban planning instead. Much of this planning is ad hoc in nature with no clearly defined timescales, which may prevent full integration into the IWMF. However, it is hoped that incorporation of the FRMP process will cascade through to local flood planning as well.
- **Existing interface between regional plans and WRMPs -** The IWMF may need to interface differently with regional plans and WRMPs. For example, for draft WRE simulation, only options above 10 Ml/d were included meaning that smaller options within company WRMPs are assessed separately through Economic Balance of Supply and Demand (EBSD) modelling (see Annex K). Therefore, final options input into the OxCam IWMF MCA would likely need to come from WRMPs to ensure that all levels of options which may provide multiple benefits to other sectors are included. Depending on the point within the IWMF cycle, it may be necessary to provide information to regional planning at the outset and then receive it later on in the process from companies.
- **Changes to the WINEP –** the changes under the consultation described in Section 2.3.1, such as increasing programme length from 5 to 10 years, may have implications for the interface of WINEP with the OxCam IWMF. A full appraisal of these changes must await final publication after consultation.
- **Interface with urban planning** – maximising environmental improvements and minimising negative impacts of development may in part depend on the inclusion of new design standards (e.g. nutrient or water neutrality) within the NPPF and any regulations specified as part of OxCam spatial planning, to provide a legal basis for inclusion of these standards within Local Plans. Some degree of strategic planning for water associated with new development, including transport infrastructure, is likely to be required. This could involve closer collaboration between the IWMF and Local Authorities. Depending on the scale at which ICM is carried out, the timing of some Local Plan activities (including consultation), may require specifying consistently at a regional level to manage development impacts effectively.

3 Water systems baseline

In this section we collate relevant data and information from key readily available datasets to create a consolidated 'evidence base' across four sub-systems: water environment; wastewater; water resources; and flood risk. We evaluate key capacity constraints for water resources and wastewater, and present metrics that could be used to inform the IWMF development and subsequent IWMF policy.

A full list of evidence sources used to define the baseline is presented in Annex C.

3.1 Environment

3.1.1 WFD water body status

The Environment Agency catchment data explorer provides information on waterbodies across England, including waterbody status, pressures, and activities. Waterbody information for the OxCam Arc is summarised in the tables below.

The OxCam Arc comprises 346 water bodies, 41 operational catchments distributed over 19 management catchments and 3 river districts. Table 3.1 provides a summary of the current overall, ecological, and chemical status for all water bodies in the Arc. Table 3.2 provides a summary of pressures on waterbodies in the Arc contributing to non-good status, and the activities responsible for those pressures. The spatial distribution of WFD status, current and target objectives, is shown in Figure 3.1. Spatial distributions in WFD pressure certainties by activity for phosphorous, abstraction, irrigation, drinking water and hydrology, sediment, morphology and physical modification are shown in Figure 3.2, Figure 3.3, Figure 3.4 and Figure 3.5.

Table 3.1: Overall, chemical, and ecological status classification for waterbodies in the OxCam Arc

	Number of waterbodies				
WFD Water body status type	**Good**	**Moderate**	**Poor**	**Bad**	**Fail**
Overall Status	26	216	92	12	N/A
Ecological Status	26	216	92	12	N/A
Chemical Status	343	N/A	N/A	N/A	3

Table 3.2: Summary of pressures on waterbodies arising from activities in the OxCam Arc as identified in WFD catchment challenges: number and % of water bodies impacted

Pressure	Activity	Number of water bodies impacted	% Water bodies impacted
Abstraction and flow	Drought	14	4%
	Groundwater abstraction	33	10%
Ammonia	Sewage discharge (continuous)	18	6%
Chemicals	Not applicable	14	4%
Dissolved oxygen	Sewage discharge (continuous)	14	4%
	Drought	23	7%
	Low Flow (not drought)	13	4%
	Not applicable	24	7%
	Poor nutrient management	17	5%
	Sewage discharge (continuous)	39	12%

Pressure	Activity	Number of water bodies impacted	% Water bodies impacted
Fine sediment	Poor nutrient management	14	4%
	Poor soil management	25	8%
Flood protection	Other (not in list, must add details in comments)	45	14%
Hydrology	Drought	13	4%
	Groundwater abstraction	20	6%
Invasive non-native species	North American signal crayfish	47	14%
Land drainage	Other (not in list, must add details in comments)	40	12%
Morphology	Barriers - ecological discontinuity	38	12%
	Land drainage	49	15%
	Land drainage - operational management	54	17%
	Urbanisation - urban development	25	8%
Nutrients	Poor Livestock Management	46	14%
	Poor nutrient management	81	25%
	Sewage discharge (continuous)	120	37%
Other	Not applicable	13	4%
Other (not in list)	Not applicable	13	4%
Phosphorous	Not applicable	17	5%
	Poor Livestock Management	103	31%
	Poor nutrient management	152	46%
	Sewage discharge (continuous)	213	65%
	Sewage discharge (intermittent)	25	8%
	Trade/Industry discharge	19	6%
	Transport Drainage	17	5%
	Urbanisation - urban development	33	10%
Physical modification	Barriers - ecological discontinuity	38	12%
	Land drainage	49	15%
	Land drainage - operational management	54	17%
	Other (not in list, must add details in comments)	75	23%
	Urbanisation - urban development	25	8%
Recreation	Other (not in list, must add details in comments)	16	5%
Sediment	Poor nutrient management	14	4%
	Poor soil management	25	8%
Urbanisation	Other (not in list, must add details in comments)	25	8%

Of the pressures listed in Table 3.2, the most significant pressure is phosphorous, with nutrients, physical modification, morphology also highly significant. Sediment, dissolved oxygen, abstraction and flow, hydrology, and invasive species are also significant pressures.

In addition to the above:

- Sewage is a confirmed activity challenge in much of the Anglian River Basin, though somewhat less so in the Nene catchment, and a suspected or probable challenge in much of Thames, other than the Colne and much of the Chilterns.
- Groundwater abstraction is designated a challenge mainly for the southern edge of the Arc, particularly the Cam, Rhee and Granta, the Bedford Ouse, the Upper Lee, the Colne and South Chilterns, also affecting the Cherwell to the west.
- Drought is a challenge only in pockets such as the Lower Great Ouse, suspected in the Cherwell and Ray, the Thame and the southwest Chilterns.
- Arable diffuse pollution is a challenge for much of the Arc, though less prevalent in areas with a groundwater abstraction challenge.
- Livestock is a confirmed challenge along a corridor north of Cambridge, Bedford and Milton Keynes and a probable challenge for much of the Nene catchment and the southwest of the Bedford Ouse.
- Invasive Species are a confirmed challenge in parts of the Nene catchment, and suspected in parts of Cherwell.
- Morphology is confirmed as a challenge for parts of the Cam and Upper Ouse, the Ouzel, the Upper Lee, and the Misbourne and it is probable or suspected in much of the Thames basin.
- Transport and urbanisation affect many of the more urban areas around Northampton, Kettering, Milton Keynes, Cambridge, Oxford, Peterborough and elsewhere.

We note that as development in OxCam may trigger additional abstraction or discharge to neighbouring water bodies, it will be important to take account of all possible impacts in the design of the IWMF.

Figure 3.1: Overall WFD water body status: current classification and objective (target) classification

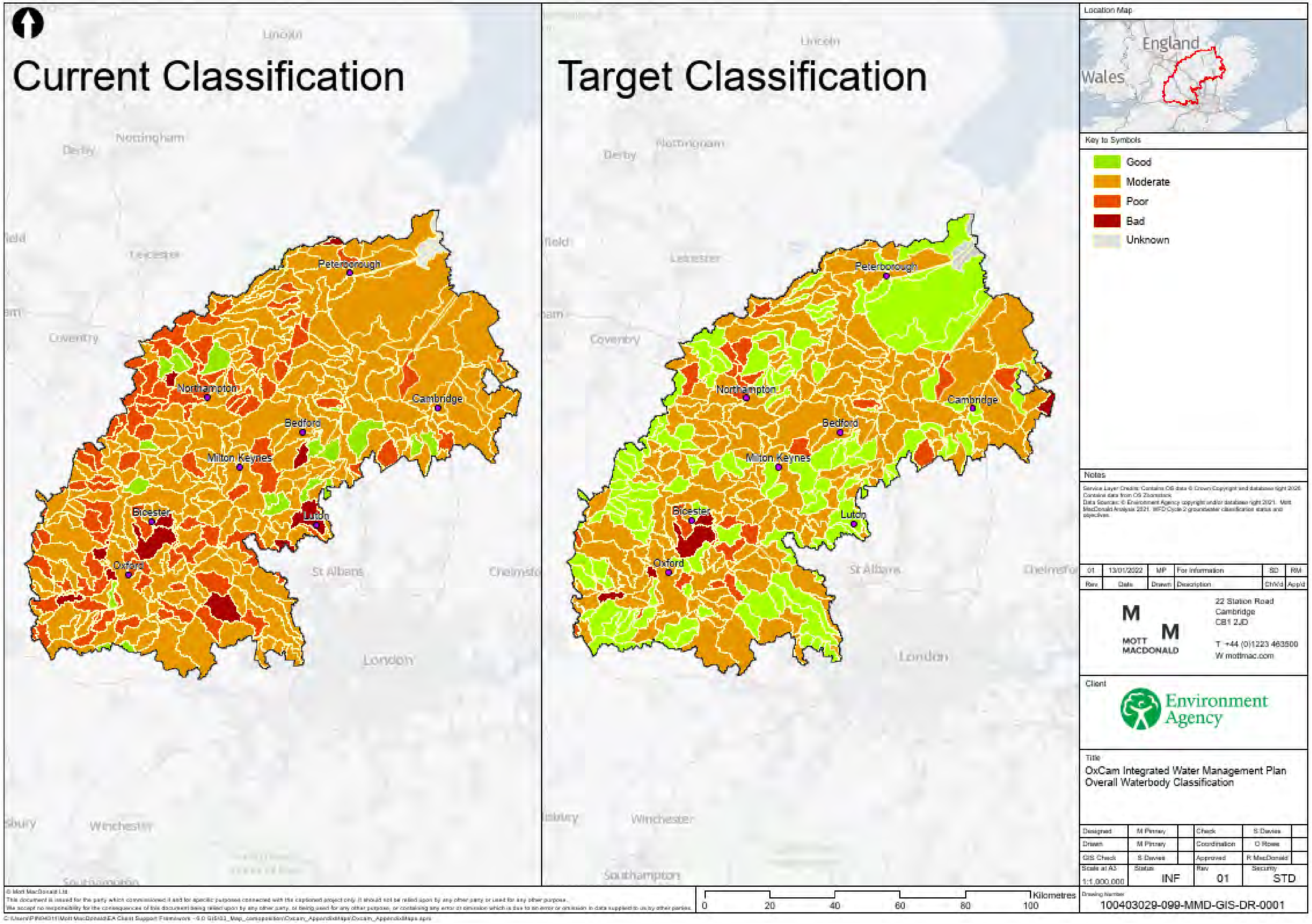


Figure 3.2: WFD phosphorous pressure certainty by key activities

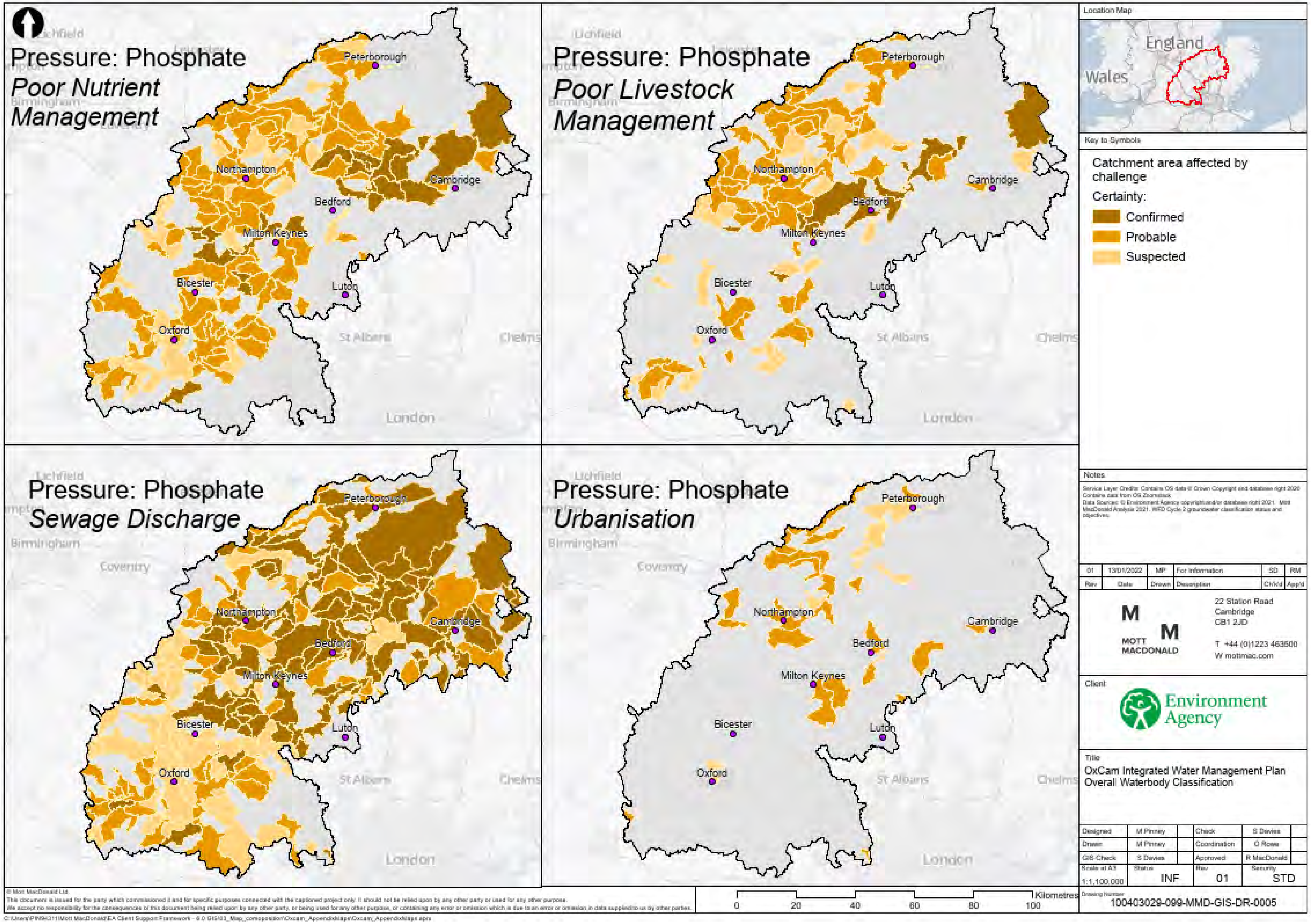


Figure 3.3: WFD abstraction, irrigation, drinking water and hydrology pressure certainty by key activities

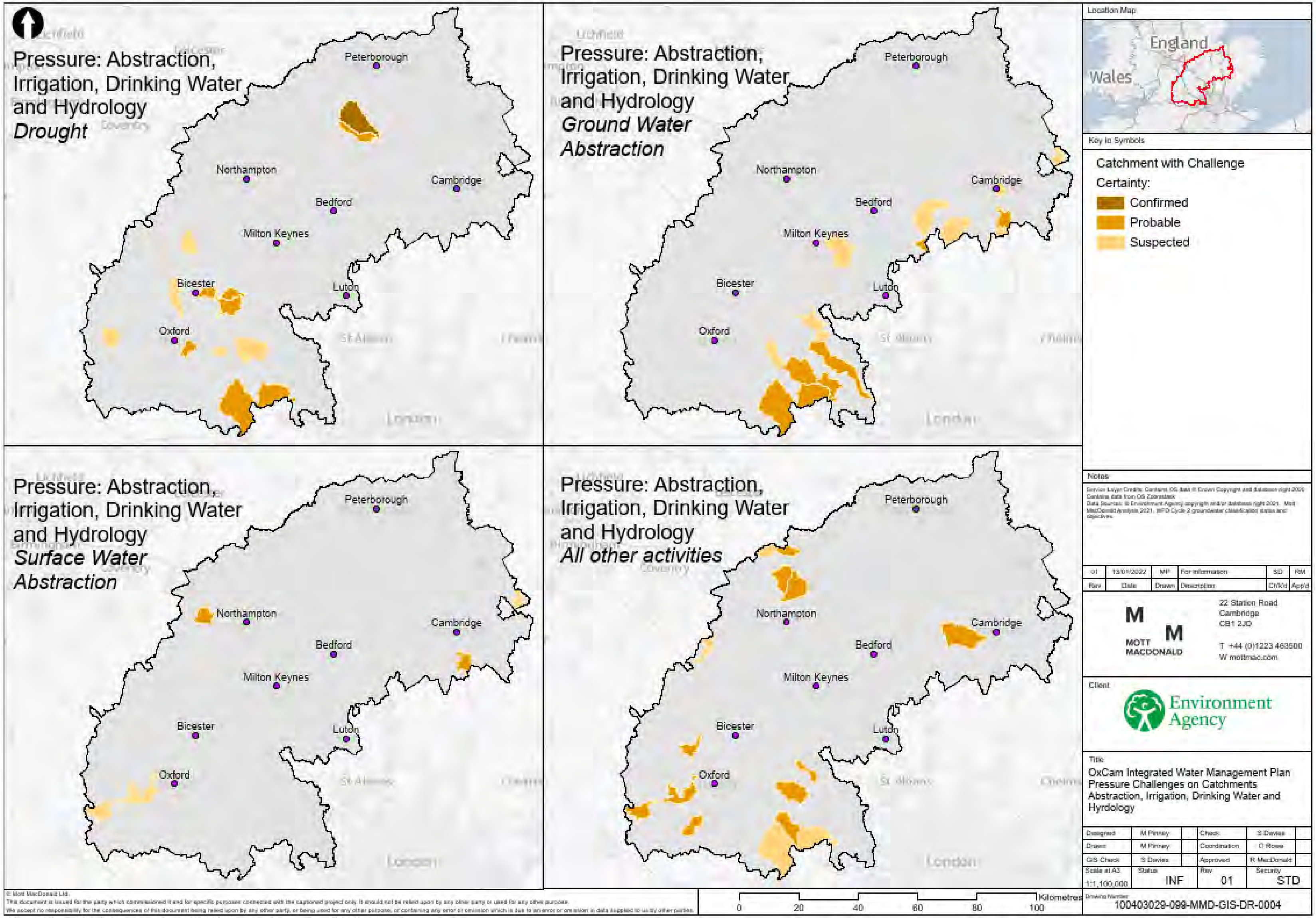


Figure 3.4: WFD sediment pressure certainty by key activities

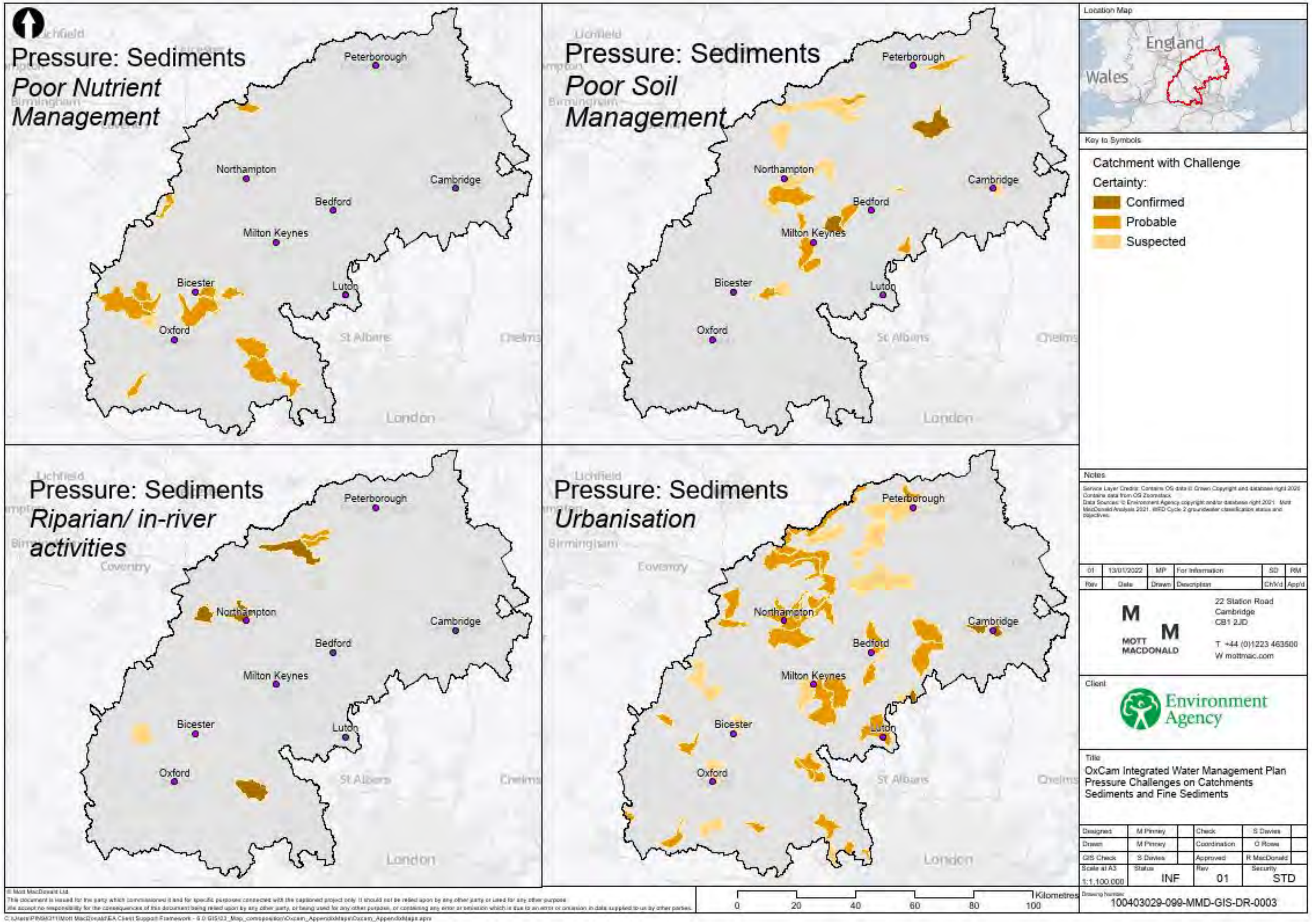
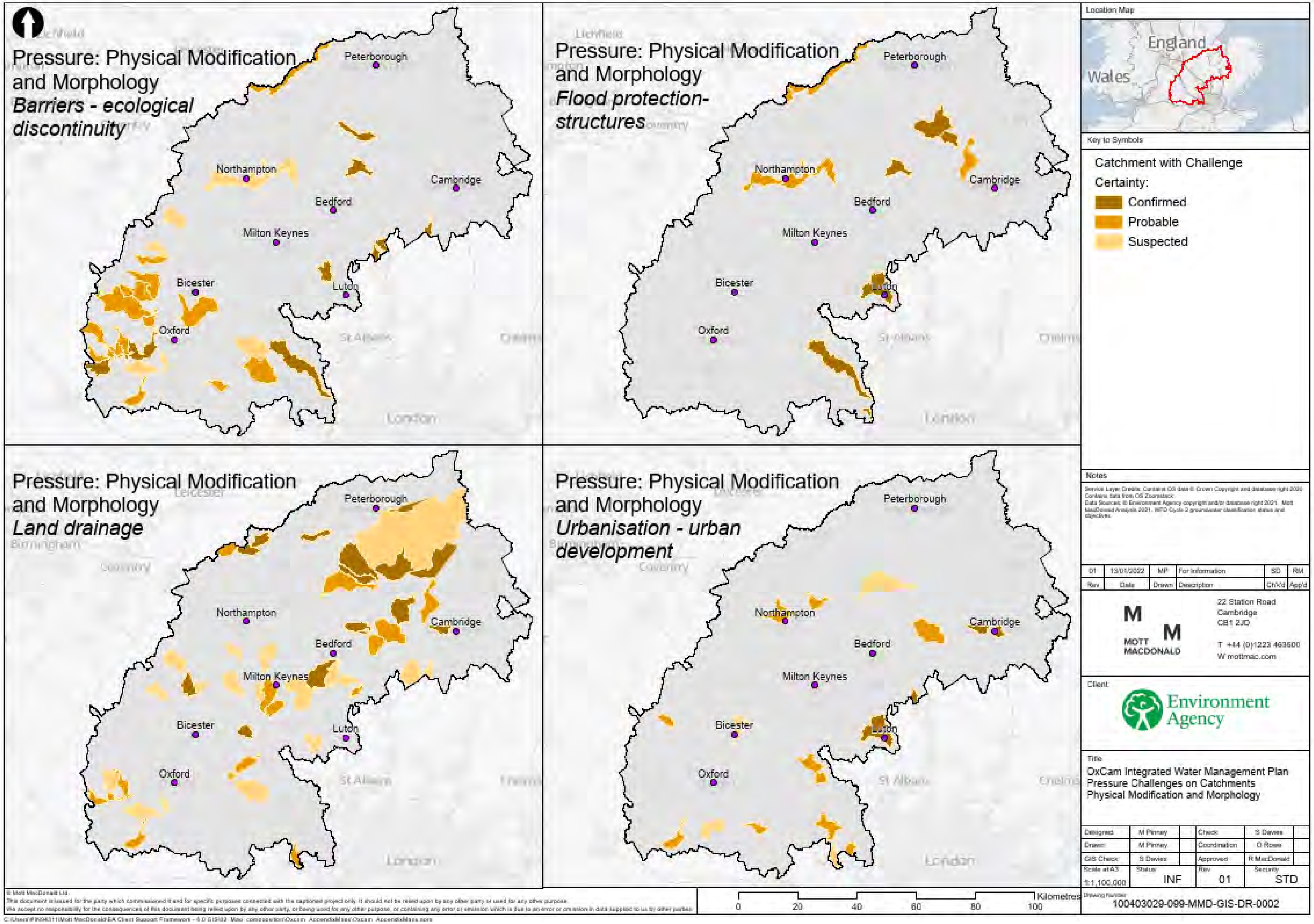


Figure 3.5: WFD morphology and physical modification pressure certainty by key activities



3.2 Wastewater

3.2.1 Wastewater contribution to dry weather flow

Permitted dry weather flow (DWF) as a percentage of very low flows (95th percentile) (Q95) in the receiving water bodies was calculated for both the operational and management catchments in the OxCam region. This metric has been applied to illustrate where baseflow in a river is heavily supported by artificial influences including sewage discharges.

The results by surface water management catchment are shown in Table 3.3 below. Consented dry weather flows make a significant contribution to low flows for most catchments, though with significant variation, between 9.5% for Maidenhead and Sunbury and 893% for the Upper Lee.

Table 3.3: Consented dry weather flow compared to total Q95 low flow for OxCam management catchments

Surface Water Management Catchment	Consented DWF Ml/d	Historical Q95 Flow Ml/d	Consented DWF as % of Historical Q95
Avon Warwickshire	725.0	324.1	224
Cam and Ely Ouse	339.7	158.0	215
Cherwell and Ray	92.2	69.5	133
Colne	342.1	159.8	214
Combined Essex	590.5	98.8	598
Cotswolds	64.4	107.1	60
Gloucestershire and the Vale	288.4	285.1	101
Kennet and tributaries	64.7	329.2	20
Maidenhead and Sunbury	124.6	1,318.5	9
Nene	591.6	346.6	171
North West Norfolk	25.7	53.1	48
Thames and South Chilterns	166.3	501.5	33
Upper and Bedford Ouse	791.0	190.1	416
Upper Lee	420.7	47.1	893
Old Bedford and Middle Level	42.0	135.1	31
Welland	91.6	77.9	118

The overall proportion of flows by effluent type are shown in Table 3.4. Water company final/treated sewage discharges account for just over half of consented discharges, with storm overflow/storm tank consents accounting for 42% and water company pumping stations 4.4%.

Table 3.4: Overall dry weather flow contribution by different effluent types in the OxCam Arc

Discharge Consent Type	Total Dry Weather Flow	% of Total Consented
Sewage Discharges - Final/Treated Effluent - Water Company	2,420,663	51.3
Sewage Discharges - WwTw Storm Overflow/Storm Tank - Water Company	1,987,377	42.1
Sewage Discharges - Pumping Station - Water Company	205,453	4.4
Sewage Discharges - Sewer Storm Overflow - Water Company	55,414	1.2

Discharge Consent Type	Total Dry Weather Flow	% of Total Consented
Sewage Discharges - Final/Treated Effluent - Not Water Company	10,584	0.2
Trade Discharges - Process Effluent - Water Company (WwTW)	8,736	0.2
Trade Discharges - Mineral Workings	7,855	0.2
Agriculture - Fish Farming - Not Water Company	6,822	0.1
Trade Discharges - Cooling Water	5,368	0.1
Other	15,501	0.3
Total	**4,723,773**	**100**

3.2.2 Wastewater capacity: low flows

DWF headroom on discharge consents for 2021 were provided by Anglian Water. The total DWF across Anglian Water Wastewater Treatment Works (WwTWs) is 1,692 Ml/d. Overall dry weather (Q90) discharge from the works is 79% of the permitted DWF (Q80 discharge is 83%). 135 WwTWs record actual Q80 flow exceeding permitted DWF, and are at risk of breaching consented dry weather flow in the future.

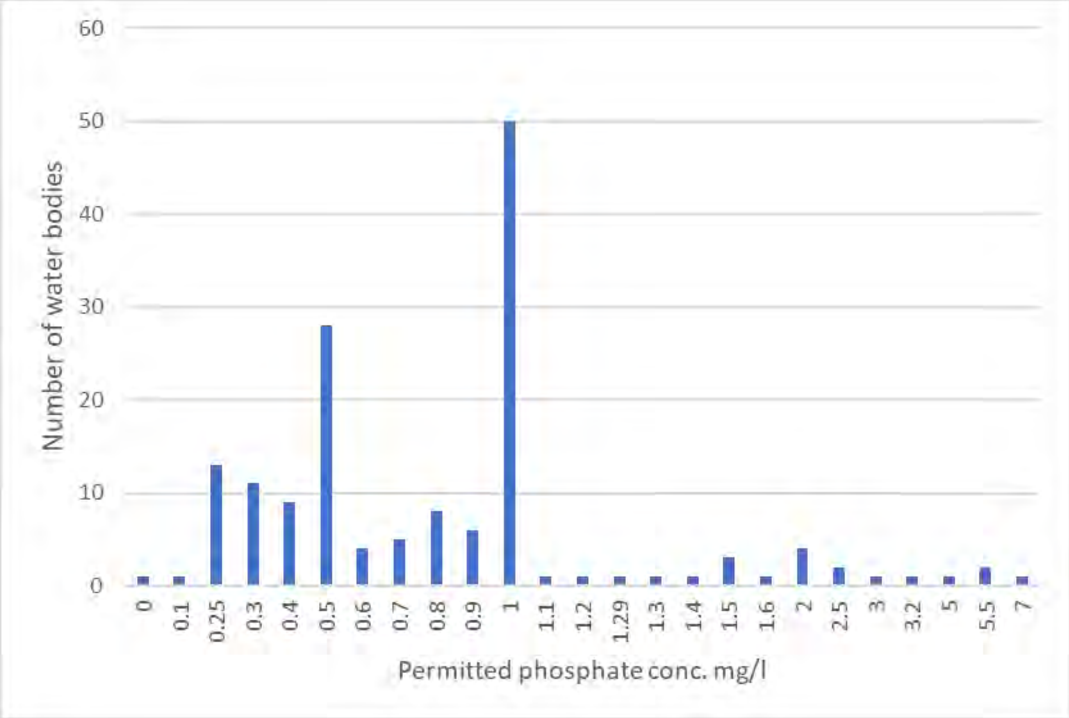
Some discharge consents specify a maximum allowed concentration of specific determinands in the final effluent. This permitted concentration is determined based on the degree to which the determinand is causing a problem in the catchment, and the degree to which the consented discharge is responsible for the problem. The lower the permitted concentration, the greater the problem and the more the discharge is responsible. Phosphorous is selected as the most relevant determinand, due to the significance of the challenge associated with it, and the large number of water bodies where phosphorous pressure resulting from sewage activity is a confirmed or probable challenge, more than any other pressure/activity combination.

In order to specify the permitted phosphorous concentration value for a given WwTW, data from both existing discharge consents and WINEP was compiled. WINEP specifies where reductions in permitted concentrations are needed in order to meet water body status objectives. The lowest value was identified from WINEP and existing consents for a given WwTW, and the results are presented in Figure 3.6 below. Anglian Water specify a technically achievable limit (TAL), the minimum phosphorous concentration that can be delivered with existing treatment technology, of 0.25mg/l. It is unclear why limits below 0.25mg/l are specified.

We propose to use proximity to TAL as one indicator in the water body hotspot mapping. If any effluent volume increases above the currently specified DWF, then a corresponding reduction in permitted concentrations would normally be required to enable an increase in the DWF on a new discharge consent. Once the permitted concentration is at the TAL, no further increase in permitted DWF will be allowable. In this case, for development to proceed, either:

a. wastewater will need to be transferred to another water body where consented phosphorous concentration is above the TAL, or
b. local discharge consent DWF is increased with phosphorous concentration held at the TAL and determinand load must be reduced from other sources (e.g. agriculture), with a reduction in permitted concentration on the corresponding consent.

Figure 3.6: Number of water bodies specified for each permitted phosphorous concentration value



Source: Consented Discharges to Controlled Waters with Conditions; WINEP.

3.2.3 Wastewater capacity: high flows

High flow capacity is dependent primarily on the capacity of wastewater networks and storage to avoid triggering combined sewer overflows (CSOs), which can result in untreated effluent entering the fluvial system. Storm overflow data for 2020 in the OxCam Arc was obtained from the Defra data services platform. The total number of overflows are shown below in Table 3.5, with statistical data in Table 3.6.

Table 3.5 Total number and duration of storm overflow events by management catchment in the OxCam Arc during 2020

Management Catchment	Total Duration (hours)	Total Number	Average duration per event (hours)
Cam and Ely Ouse	7,470	773	9.7
Nene	12,550	1768	7.1
Old Bedford and Middle Level	1,511	122	12.4
Ouse Upper and Bedford	18,967	1293	14.7
Welland	22	7	3.1
Avon Warwickshire	2,578	276	9.3
Cherwell and Ray	17,779	1560	11.4
Colne	2,808	211	13.3
Cotswolds	18,518	1192	15.5
Gloucestershire and the Vale	10,642	778	13.7
Lee Upper	28	14	2.0
Maidenhead and Sunbury	4	5	0.9

Management Catchment	Total Duration (hours)	Total Number	Average duration per event (hours)
Thames and Chilterns South	21,493	1490	14.4
Grand Total	**114,370**	**9489**	12.1

Table 3.6 2020 storm overflow statistics

	Mean	Max	Min	Mean per week	Median per week
Number of storm overflows	32	185	0	0.6	0.33
Hours of storm overflows	390	4193	0	7.5	1.5

The minimum number of storm overflow events was zero, with 52 CSO sites across Anglian Water, Thames Water and Severn Trent Water achieving this. The maximum storm overflow number was 185 at Odell WwTW. By WwTW, the average event duration varied between 0.1 and 24 hours. On average across all sites in 2020, there were 32 overflow events per year, for 390 hours on average at each site, equivalent to 7.5 hours per week at each site on average. The average of the mean duration of each WwTW was 6.6 hours. Averaged across all events, the mean duration was 12.1 hours. Combined storm overflow event data 2020 by total duration and number of events is shown in Figure 3.7.

The Storm Overflow Evidence Project[8] (SOEP) recently published indicators for storm overflow impacts on river health, public health and social impact. These are based on volume weighted spill frequencies (VWSF). For river health, the SOEP uses a dilution ratio estimate for each water body as a means of assigning an Equivalent Ecological Status to the water body as a consequence of the operation of storm overflows alone, using dilution as a proxy for in-river 99 percentile BOD (and 99 percentile BOD as a proxy for ecological status); i.e. the status the water body would achieve if the only pressure on it was storm overflows. For public health, water bodies are classified as swimmable or not swimmable based on whether VWSF is greater than or less than 5 (assumed equivalent to one spill per bathing season). VWSF itself is used as a proxy for social impact of storm overflows. Maps of SOEP water body metrics for the impact of storm overflows on river health, public health and social impact are presented in Figure 3.8.

[8] Storm overflows evidence project (publishing.service.gov.uk)

Figure 3.7: Combined storm overflow event data 2020 by total duration and number of events

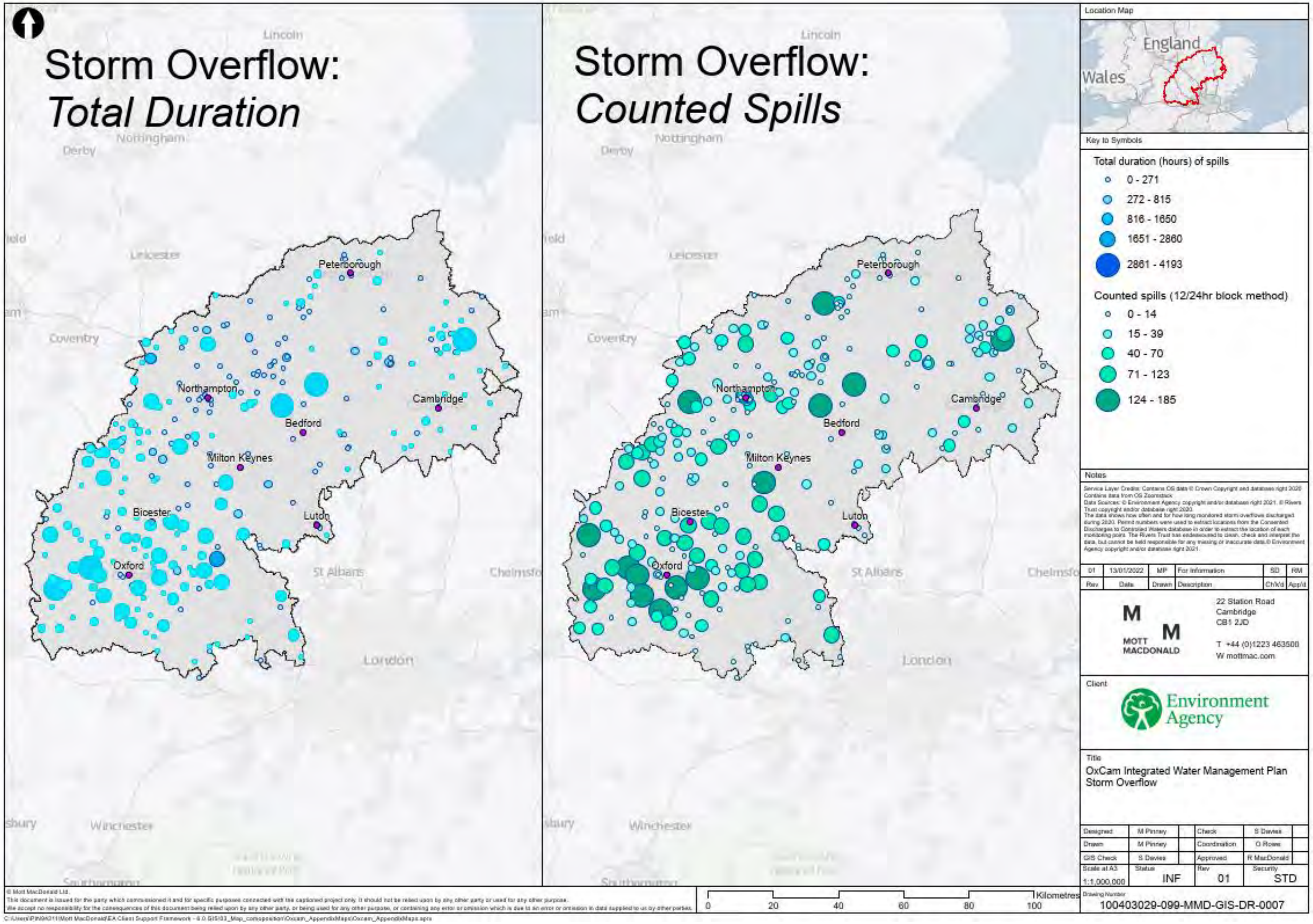
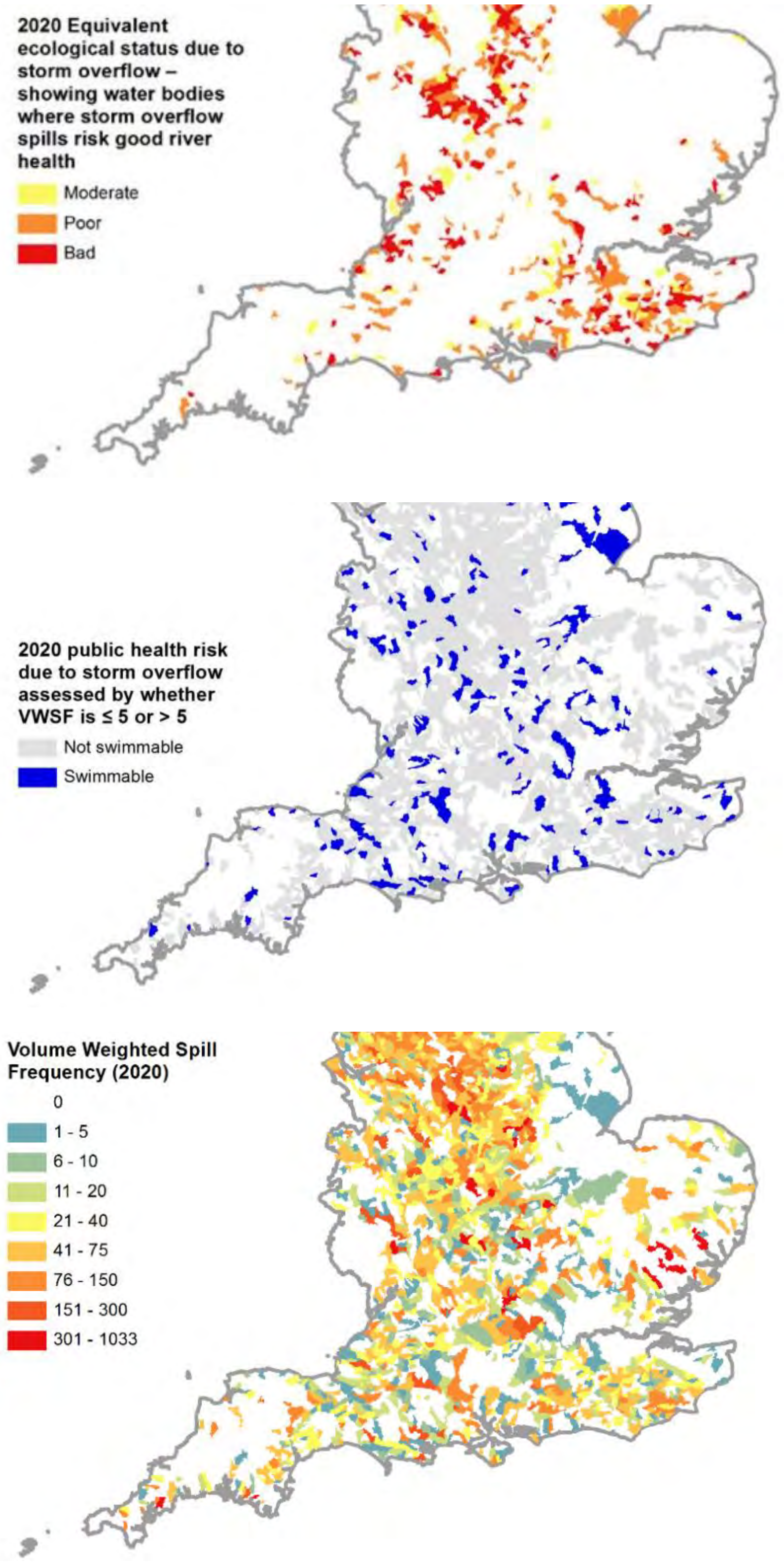


Figure 3.8: Storm Overflows Evidence Project Measures of Storm Overflow Impacts on River Health (top), Public Health (middle) and Social Impact (bottom)



Source: Storm overflows evidence project (publishing.service.gov.uk)

3.3 Water resources

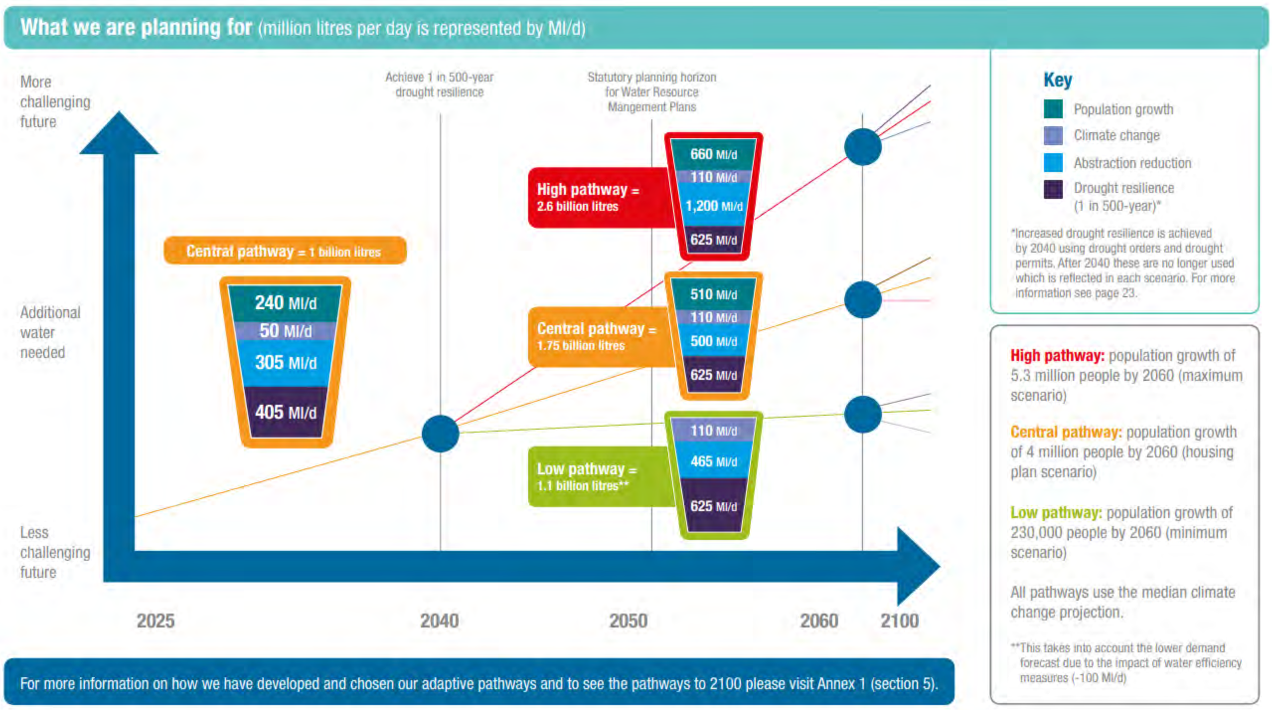
3.3.1 Water quantity

At WRMP19, the net deficit of all water resource zones making up the OxCam Arc was forecast to be 42Ml/d by 2025-26, 62Ml/d by 2029-30 and 139Ml/d by 2044-45. This deficit was overcome by selecting an equivalent range of supply options at appropriate times in the planning period.

The Environment Agency's WRGIS Surplus Deficit data suggests a maximum total baseline deficit across the OxCam Arc of 1350 Ml/d. To avoid skewing the results, this excludes the Thames Reading to Cookham water body, whose enhanced fully licensed deficit of 854Ml/d must relate primarily to abstractions outside of the OxCam Arc, supplying households outside of the Arc.

WRMP24 supply demand balance (SDB) data is not yet available, as draft WRMP24 plans are yet to be published. There is significantly greater uncertainty in SDB deficits as a result of the National Framework for water resources specifying potentially more ambitious environmental destinations than at WRMP19. However, the Water Resources South East regional planning group (WRSE) emerging regional plan gives the first indication of the scale of the WRMP24 challenge, and shows initial projected supply demand scenarios (Figure 3.9) and draft WRMP24 supply option information was provided by WRSE.

Figure 3.9: WRSE Emerging Regional Plan supply/demand balance scenarios



Source: https://wrse.uk.engagementhq.com/the-proposed-solution

Table 3.7 shows the timing and Ml/d benefit of Thames Water and Affinity Water draft WRMP24 supply options selected under different WRSE scenarios. Note that this information applies to the whole of the two water companies' supply areas, not just the OxCam Arc. More than 600Ml/d of new resource is required to meet deficits under all scenarios by 2050, and therefore would not be available to meet any additional demand beyond the baseline forecast. A further 233Ml/d is required under some scenarios of environmental ambition, climate change or demand by 2050. Beyond 2050, up to 377Ml/d additional supply benefit is required under different scenarios.

Table 3.7: Draft WRMP24 selection status and Ml/d benefit of Thames Water and Affinity Water supply options.

Selected under which WRSE scenario	Timing	Ml/d benefit
All scenarios	Pre-2050	665.89
Some scenarios	Pre-2050	233.15
All Scenarios	Post-2050	21.37
Some Scenarios	Post-2050	304.99
All Scenarios	Post 2070	42.74
Some Scenarios	Post 2070	8.10
Not selected	N/a	1220.10
Total New Resource		2496.33

Based on certain assumptions around demand management, the data shows that whilst significant new water resources are required early in the WRMP24 planning period, including more than one strategic regional option, considerable additional water resource remains available from Thames Water and Affinity Water.

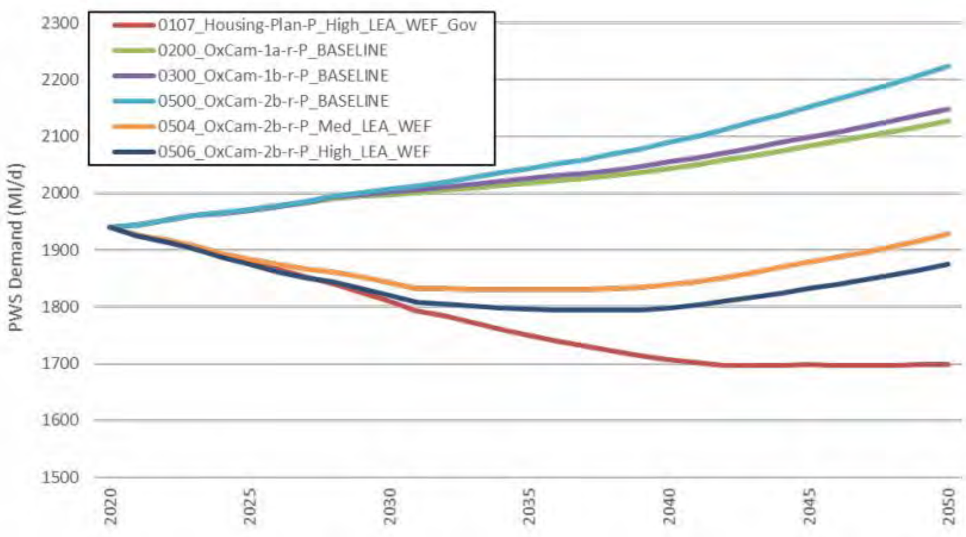
For Water Resources East regional planning group (WRE), six demand scenarios for public water supply are shown in Figure 3.10, including varying degrees of demand management through leakage reduction and water efficiency measures. This shows that at a regional level, ambitious demand management may be sufficient to offset all additional population growth in WRE, with or without OxCam. However, there is considerable uncertainty regarding the success of this demand management, growth in demand may occur locally, and Figure 3.11 shows that significant water resource challenges remain, driven primarily by sustainability reductions to overcome baseline abstraction-related impacts on the environment.

This data shows the potential for growth in the region to be an opportunity if managed well and timed to align with water resource infrastructure. If the gross value added from growth is put towards addressing baseline challenges/net gain, then this could potentially offset additional impacts. However, given the lead times required for major infrastructure, and the significant other drivers of water resource deficits (climate change, improved level of service and environmental ambition), it may be that any further housing development in the region must be delayed by some time to avoid non-compliance with statutory requirements.

The Environment Agency has responded to both emerging regional plans and has raised the need to reduce abstraction in the short term to prevent deterioration. This will further reduce the available headroom in companies' networks to meet the needs of growth in the short to medium term.

Figure 3.12 shows the total deployable output from possible feasible new supply options in WRE's emerging plan. The 1820Ml/d total is not sufficient to meet the worst-case deficit of 2267Ml/d, such that further demand management, imports from neighbouring water resource zones (WRZs) and/or additional water resource options could be required by 2050. Looking at WRE and WRSE combined, the overall challenge could be c. 4,500Ml/d by mid-century without demand management. This compares to 4,300Ml/d of total feasible supply options identified to date.

Figure 3.10: WRE Emerging Plan demand scenarios for public water supply to 2050



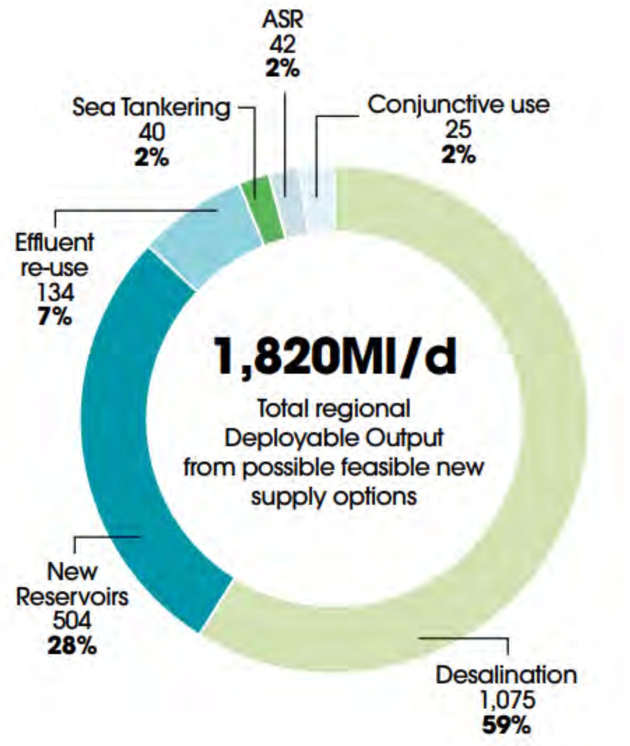
Source: https://wre.org.uk/wp-content/uploads/2022/01/WRE-Emerging-Plan.pdf

Figure 3.11: WRE Emerging Plan breakdown of water resource supply/demand balance drivers by 2050

Sector	Pressure	Dry year annual average estimated impact (Ml/d)		Comment
		Lower	Upper	
Public water supply	Climate change	54	180	Includes range of possible high/low climate change impacts mostly on reservoir yields.
	Sustainability reductions	790	1,325	Includes cross-sector abstraction licence reductions resulting from a range of environmental destination scenarios outlined by the EA. The lower limit represents the business as usual (BAU) scenario, with the upper limit accounting for the enhanced scenario. Current values apply to all existing licences except the energy sector. Further refinement will be made through discussion with the EA and Natural England.
	Growth (population)	-250	273	Upper limit accounts for growth targets in local plans and some consideration of strategic growth and limited progress with planned demand management measures. Lower end represents lower population forecasts and high uptake of water efficiency measures.
	Drought resilience	88	88	Methodological uncertainties subject to work in progress
	Regional exports	0	0	Not considered at this stage, although 100 Ml/d export to WRSE is currently assumed for the South Lincolnshire Reservoir SRO development.
Energy	Decarbonisation	-38	181	Updated forecast based on research commissioned by the Joint Environmental Programme, Energy UK[9] on a baseline of 61Ml/d.
Agriculture	Growth (irrigation)	59	220	Updated forecast based on uplift factors from research commissioned by WRE[10] on a baseline of 190Ml/d.
Total		**703**	**2,267**	

Source: https://wre.org.uk/wp-content/uploads/2022/01/WRE-Emerging-Plan.pdf

Figure 3.12: WRE Emerging Regional Plan total deployable output from possible feasible new supply options



Source: https://wre.org.uk/wp-content/uploads/2022/01/WRE-Emerging-Plan.pdf

3.3.2 Water quality

New development in the OxCam Arc has the potential to impact the water quality of abstractions for public or private water supply, for example through infiltration of contaminants to groundwater. To evaluate the risk to groundwater, we consider source protection zone (SPZ) information. The percentage land area of OxCam classified against each SPZ is show in Table 3.8 below.

Table 3.8 Source protection zone summary area for the OxCam Arc.

Source Protection Zone	SPZ Area (Hectares)	Percentage of Arc
Bespoke	2,435	0.21%
SPZ1	1,310	0.11%
SPZ2	13,494	1.17%
SPZ2 (default for a new SgZ)	2,252	0.19%
SPZ3	658	0.05%
Grand Total	20,151	1.75%

Source: https://www.gov.uk/guidance/groundwater-source-protection-zones-spzs#technical-guidance

A relatively small area of OxCam Arc, 1.75%, is classified as any SPZ category. It should be possible to minimise risk of groundwater contamination from new development as a result, and existing regulation exists to do so.

Surface water abstraction contamination risks are harder to quantify, as potentially any part of the catchment could result in contamination of a source. However, dilution for most sources is significant, and it is unlikely that direct pollution from contaminants such as tyre dust or microplastics would be sufficient to result in a reduction in wholesomeness. Increased wastewater effluent could also potentially cause problems for abstraction water quality at times of low flow. Most major pollutants, such as nitrogen and phosphorous can be treated effectively and it should be possible to mitigate additional loads from any increase in effluent at most WwTW through additional treatment of abstracted water. However, there may be some minor pollutants where monitoring and/or treatment is not reliable or possible under current operational practice. This is a potential gap in data, which could warrant further investigation. See Annex F for more discussion on emerging contaminants.

The primary area where new standards may be required to account for water quality impacts on water resources is to address novel contaminants. This will be addressed further in subsequent phases of work.

3.4 Flooding

Statistics for the area and number of buildings in Flood Zone 2, Flood Zone 3 and in Areas Benefitting from Defences are shown in Table 3.9 below. These statistics were calculated using Flood Zone shapefiles[9]. The number of buildings in each category was calculated by intersecting the Flood Zone shapefiles with OS OpenMap data[10]. Figure 3.13 shows buildings at risk of flooding from 1 in 30 year surface water flooding and fluvial flooding (flood zones 2 and 3).

Table 3.10 shows the number of properties at risk of a 1 in 100 year flood risk event (fluvial, surface water and tidal combined) modelled by the Environment Agency for OxCam water bodies under different scenarios of climate change. This shows that the number of properties at risk could almost double over 90 years.

Table 3.9: Area of land and number of buildings in Flood Zones and benefitting from defences across OxCam Arc

	Area of land (km^2)	Percentage of land in the OxCam Arc (%)	Number of buildings
Flood Zone 2	1,907	16.62	49,672
Flood Zone 3	1,687	14.70	31,321
Area benefitting from defences	750	6.54	12,429
Risk of surface water flooding (3.3% AEP)	275	2.40	3,647
Risk of surface water flooding (1% AEP)	487	4.25	7,327

Table 3.10: Number of properties at modelled 100-year risk of flooding (fluvial, surface water and tidal combined) under different climate change scenarios: year 0 and year 90

Scenario	Year 0	Year 90	Percentage Increase (%)
Baseline	41,373	41,373	0
Central	41,373	69,312	67
Upper End	41,373	79,062	91

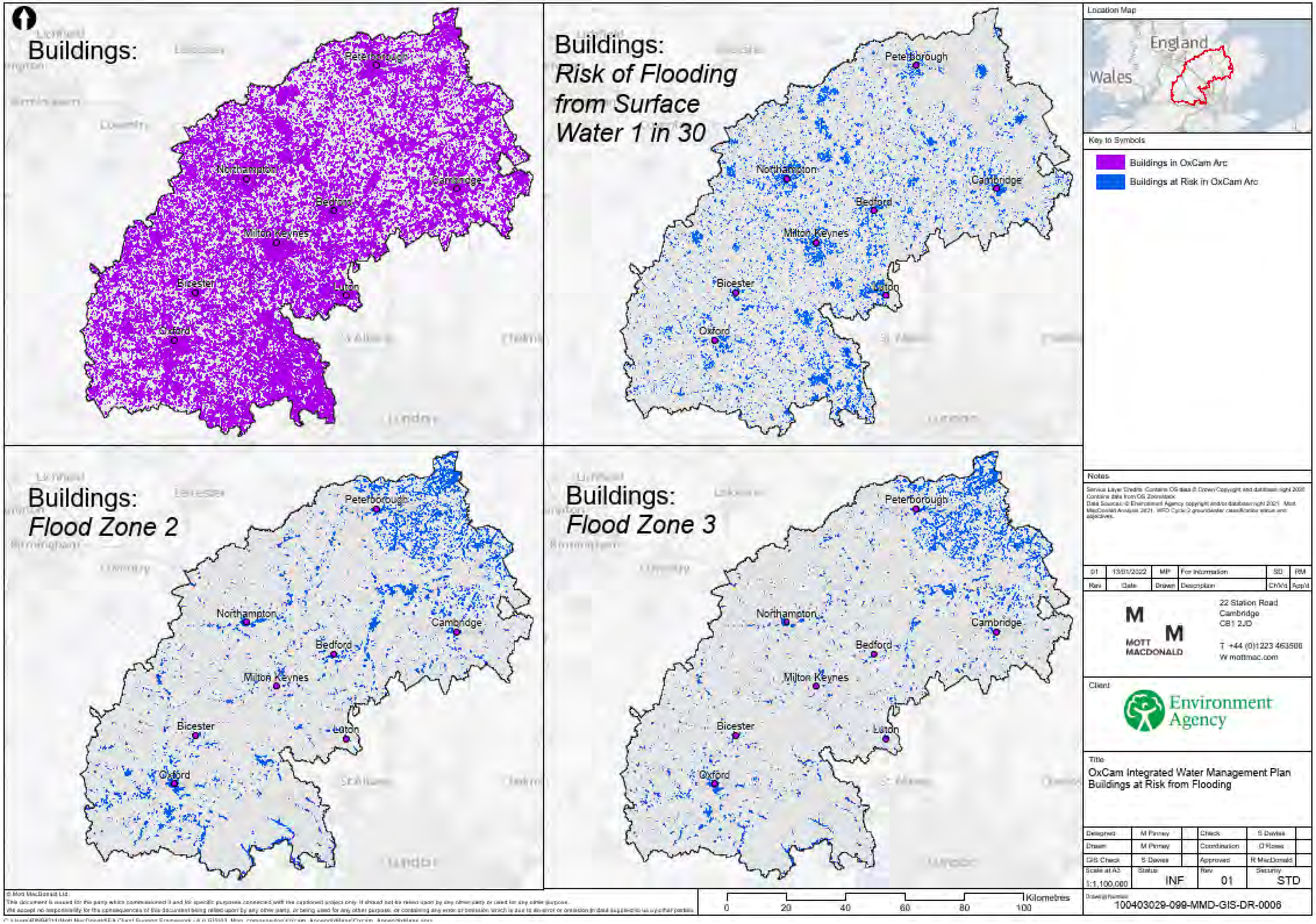
[9] Risk of Flooding from Surface Water Extent: 3.3 percent annual chance - data.gov.uk
[10] OpenMap

Flood defences provide protection for 39% of the land area of Flood Zone 2, 45% of the land area of Flood Zone 3, 25% of buildings within Flood Zone 2 and 40% of buildings within Flood Zone 3. Statistics for the area of land and the number of buildings impacted by surface water flooding were calculated using the Environment Agency map of surface water flooding with a 3.3% chance of happening in a given year.

Note that the flood risks datasets are indicative and provide an estimate of the area and number of buildings at risk of flooding: there is particular uncertainty in modelling of surface water flooding. 46 wetspots, areas with a high risk of surface water flooding, were identified in the SWMPs.

There are 109 additional flood risk management schemes identified in FRMPs, SWMPs and in the list of flood schemes planned by the Environment Agency and other lead local flood authorities over the next six years. Calculation of the area and number of buildings impacted by these schemes was not possible with available data.

Figure 3.13: Buildings at risk of flooding from 1 in 30 year surface water flooding and fluvial flooding (flood zones 2 and 3)



3.5 Soil health

We include soil health as a criteria for high level MCA. Our proposed five metrics to compile for soil health assessment include:

- Soil cover
- Soil bulk density
- Organic carbon content
- Soil erosion vulnerability
- Soil nitrogen concentration

"Maximum Slope" data may be an appropriate proxy for soil vulnerability erosion vulnerability. For data on soil type, including soil property data and agro-climatological data, LandIS by Cranfield University is the largest comprehensive soil dataset system for the UK. NatMap as a data set within LandIS could be useful to provide soilscape data that can be downloaded and analysed alongside soil texture and soil carbon content.

SciMap data could also be valuable to indicate the erosion risk and connectivity risk contributing to diffuse pollution through soil run off events. This data compiles land use, slope and source pressures including sediment, nutrient, microbial pollution and flood hazard generation. Such maps could be used to target mitigation actions at the landscape scale. Both LandIS and SciMap are not open-source data and require licensing agreement.

As the aim of this study is to exclude non-open-source data, we present an approach to defining a soil health metric based only on soil cover, bulk density, carbon and nitrogen content in Section D.1.8.

3.6 Baseline capacity summary

We present a high-level assessment of the capacity for the OxCam Arc to accommodate growth in housing and population from the point of view of water resources and wastewater.

3.6.1 Water resources: quantity

- The additional water resource demand from OxCam Arc development above and beyond baseline growth is forecast to be between 157 and 166Ml/d, assuming PCC of 125l/h/d.
- The Environment Agency's WRGIS Surplus Deficit data suggests a maximum total baseline deficit across the OxCam Arc of 1,350Ml/d. We note that growth in water demand within the OxCam Arc may drive changes in abstraction outside of the Arc, and therefore assessment of the impacts of increased demand, any strategic planning or policies on neutrality, etc, must take account of environmental deficits across a wider area, wherever the impacts of growth on abstraction would occur.
- Emerging WRMP24 regional planning suggests between 666 and 900Ml/d of new supply-side water resources will be required by Thames Water and Affinity Water by 2040 to address: reductions in abstraction associated with existing environmental deficits; potential losses in supply from climate change; improved level of service to provide resilience to 1:500 year drought; and population growth.
- Up to a further 377Ml/d supply-side resource is identified as potentially required by 2100. A further 1200Ml/d of Affinity Water and Thames Water feasible new resource options are not selected under any draft WRSE scenarios for WRMP24 by 2100.
- For WRE, the emerging regional plan identifies 1,820Ml/d total feasible new deployable output compared to a worst case deficit of 2,267Ml/d by 2050, such that further demand management, imports from neighbouring WRZs and/or additional water resource options could be required.
- Looking at WRE and WRSE combined, the overall challenge could be c. 4,500Ml/d by mid-century without demand management. This compares to 4,300Ml/d of total feasible supply options identified to date.
- Seen in this context, the maximum additional OxCam growth of c.166Ml/d is unlikely to significantly impact the long-term water resource challenge for the region, especially as some of this growth is likely to result from population movement within the combined WRE/WRSE region. That said,

additional demand will cause significant local challenges in the short to medium term, if water resource impacts are not adequately addressed.

- The primary issues are regarding timing: if new resources and/or supply network infrastructure cannot be delivered rapidly enough to keep up with growing demand, then level of service may not be met, and/or environmental damage may result in the short-medium term.
- The Environment Agency has responded to both emerging regional plans and has raised the need to reduce abstraction in the short term to prevent deterioration. This will further reduce the available headroom in companies' networks to meet the needs of growth in the short to medium term.
- For some locations, these issues could limit the rate of growth and/or add significant costs to development if not properly accounted for. They could prevent any development from happening entirely for a number of years, until such time as new large-scale water resources can be brought online.

3.6.2 Water resources: quality

- 1.75% of the OxCam Arc area is classified as a source protection zone of one level or another. Therefore, it should be possible to minimise groundwater abstraction contamination risks by limiting development to the other 98.25%.
- Surface water contamination risks are harder to evaluate, but for most surface water abstractions, dilution is likely to minimise the risk of diffuse contamination. There are few direct river abstractions in the Arc area where dilution could be less effective. A detailed surface water risk assessment is beyond the scope of this study, but could be worthwhile to identify any locations where development should not occur to overcome any risks.
- Emerging contaminants are a risk under certain situations, for example where wastewater effluent makes a significant contribution to abstracted water at times of low flow.

3.6.3 Wastewater

- Wastewater treatment constraints do exist at certain WwTWs: where treatment technology is close to technically achievable limit and there is limited headroom in terms of dry weather flows, where nutrient offsetting would be required.
- As for water resources, wastewater is unlikely to present a constraint to growth for the Arc as a whole, although in some cases offsetting would not be possible, such that transfers of wastewater to alternative catchments or no further growth in housing would be possible.
- For some locations, these requirements could limit the rate of growth and/or add significant costs to development if properly accounted for.

3.6.4 Flood risk

In total, 16% of the OxCam Arc surface area is classified as flood zone 2, containing 46,000 properties, 14% of which is also flood zone 3, containing 29,000 properties, and 2.4% is at risk of surface water flooding, with 3600 properties at risk. 11,700 properties benefit from some form of flood protection. The number of properties at risk of flooding is forecast to increase by up to 91% over the next 90 years as a result of climate change.

Key Conclusion: On the basis of the evidence used by this study, it is not possible to define a schedule of shortlisted IWM options in an OxCam IWM Plan due to the different scales over which water resources, wastewater, flooding and environmental interventions must be appraised.

- Water resources must be appraised regionally because of the scale of the challenge in environmental ambition and therefore the scale of resources required. Regional appraisal also enables best value plans to be developed, taking account of the cost of transferring water, given water may be available at significantly lower cost considerable distances from the point of demand.

Implication: An OxCam IWM Framework should specify improved linkages between existing planning programmes rather than trying to specify detailed schedules of options or replace any existing planning programmes.

3.7 Hotspot mapping

An original aim of Phase 1 was to deliver hotspot maps showing spatial variation in risks of new housing development to the environment. Annex D presents an initial hotspot desk study which was used to develop thinking around the framework. This desk study showed that it is not possible to identify specific locations where housing development would pose a greater risk to the environment without detailed modelling under a range of scenarios: the system interactions are too significant. Therefore “hotspot mapping” has significant limitations in terms of application to the OxCam IWMF. Instead, proposed development plans are best evaluated through system modelling and scenario analysis.

4 Systems mapping

We use a systems-mapping approach to identify interlinkages and interdependencies across water and development systems. This is used as a foundation for new IWM delivery standards, and as a basis for selection of criteria for integrated MCA. The maps were created drawing on expertise within the Environment Agency and project stakeholders and from other projects in similar conditions where system maps have been produced.

4.1 Introduction

There are five purposes of using a systems-mapping approach to inform the development of the Integrated Water Management Framework.

2. To create insights and participant buy-in, to foster improved collaboration and participation
3. To clarify the categorisation of interventions/options and benefits across the different systems.
4. To identify system linkages and potential co-benefits of interventions/options and policy priorities.
5. To validate the selection of criteria for use in the MCA.
6. To enable prioritisation of effort on numerical modelling of the systems in future.

These uses of the system maps are discussed in Section 4.2.

We use the method laid out in Defra's report, "Systems Analysis for Water Resources", which describes a Participatory System Mapping approach. Here we apply a few modifications for efficiency which we describe in Section 4.3.[11]

Mapping was undertaken in the online software platform, Kumu[12]. All of the maps are interlinked to create one overall meta-system map – a "system of systems". Further detail on how the maps were created, and can best be viewed, is provided in Annex E. The overall map has been developed in a way that focusses around four themes:

- Flooding
- Planning and development (showing interconnectivity with flooding and water quality and aquatic ecosystems)
- Public Water Supply (PWS) and wastewater (showing links to water quality and aquatic ecosystems)
- Water quality (also showing agriculture and links with PWS and wastewater)

We take a broad perspective for the system we refer to as water quality, including related issues such as aquatic biodiversity and river condition. The system maps are made of nodes and links (edges). Nodes are all system attributes which can go up or down in value – a node can have a higher or lower (increasing or decreasing) 'notional quantum' (e.g. winter rainfall, fluvial flooding) or they can become better or worse (e.g. river water quality, mental health).

There are three types of link:

- A positive link is shown in green. If node A goes up then node B will go up and if node A goes down, then node B goes down.
- A negative link is shown in red representing influence in the opposite direction. If node A goes up, then node B goes down or if node A goes down then node B goes up.
- A complex link is shown in blue and represents a connection that cannot be categorised reliably as positive or negative. This may be because there is a threshold or other form of complexity in the relationship between the two nodes.

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[11] http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=20286

[12] Systems mapping demonstration OXCAM • Kumu

In this report and on the maps, we capitalise the first word of the name of each node to indicate that we are referring to a node on the map.

4.2 Purpose

4.2.1 Categorisation of interventions/options and benefits

The OxCam Integrated Water Management Framework takes a combined perspective across water resources, wastewater, flooding, water quality, habitats and natural capital. Consequently, the IWM list of generic option types compiled for this work has been developed by reviewing a significant number of different schedules of options (e.g., WRMP, WINEP, flood defences, sustainable drainage systems (SuDS)). Neither the categorisation of these options, nor the categorisation of associated benefits are consistent across the different existing schedules. The system mapping has enabled a comparison and synthesis of option and benefit categories and a single list to be compiled that works across all of the systems of interest to OxCam (flooding, PWS and wastewater, water quality, planning and development).

This purpose relates to validation of the MCA by providing a systemic rationale for the option categories and benefits.

4.2.2 Identification system inter-linkages

The system mapping has enabled system interlinkages to be identified. The system interlinkages come in three main ways:

7. Common elements that are relevant to numerous systems – such as soil health and infiltration, which is relevant to flooding, water quality, water resources and development. These touchpoints between systems identify how complementarity can be brought into the design of developments and the selection of options creating multiple benefits of investment.
8. Option types that are relevant to different systems are identified. For example, wetlands produce benefits to water resources, water quality and flooding systems.
9. Policy interventions that influence more than one system – this may be positive co-benefits of a policy intervention or unintended consequences in one system of an intervention designed to benefit another. The system maps allow investigation of both beneficial and problematic system influences.

This purpose relates to validation of the proposed Integrated Water Management Framework guidelines and the MCA. We will identify where system design may be integrated at the conceptual or the strategic level (such as integrating flood control and water quality management when we are designing catchment scale plans).

4.2.3 Selection of criteria for Multi-criteria analysis

The Multi-criteria analysis is intended to reflect a representative set of benefits across the systems of interest. We have highlighted nodes we consider to be key system outcomes, and these have been used in the MCA. The selection of these nodes was undertaken as an iterative process with the review of option benefits. In this way we show that the full list of options and their corresponding benefits will address all of the key system outcomes.

4.2.4 Framework for future numerical modelling

In a future phase of the work, there is likely to be a need to undertake numerical modelling of some aspects of the systems. The system mapping provides a conceptual model of system causality in the Arc and therefore provides an initial overview of what processes could be modelled, from which a prioritisation of modelling can be made.

4.2.5 Creation of insights and participant buy-in

Participatory system mapping is a stakeholder engagement process as well as being an analytical activity. The mapping provides insights that illustrate the interconnectivity of the systems – such as the potential use of blue-green corridors in urban planning: these can bring flood resilience benefits and allow a network of cycle-paths to be created that could reduce road traffic and the water pollution associated with roads. Communication of this kind of insight in anecdotal form is important in developing a cultural shift towards more integrated thinking and planning.

4.3 Method

We use “Starter maps” from similar projects are used so that valuable participant time is not used in setting up the basic system functions but is directed at adding detail on the map that adds value. The system maps are categorised as either baseline sub-system maps or interventions.

- Baseline sub-system maps represent existing systems such as flooding, agriculture, or public water supply.
- Interventions are maps that overlay the baseline sub-systems and show the influence of different categories of option on the baseline sub-system. In some cases, options are integrated within baseline sub-system maps to reflect a feedback loop where the system function influences the implementation of an option.

The overall approach to mapping undertaken for the Integrated Water Management Framework was as follows:

1. We used “starter maps” for the baseline sub-system and intervention maps as a basis for building the maps. The origins of these starter maps are the various datasets documented in Annex E, with links to source information specified in a data collection register.
2. We modified the maps to provide better connectivity of sub-systems and interventions in a way that is appropriate for the OxCam context, with guidance from our in-house (Mott MacDonald) subject matter experts as required.
3. We undertook two rounds of consultation with the Environment Agency OxCam technical team and wider Technical Group during the development to advise and guide on their construction.
4. We reviewed the option categories and their corresponding benefits along with provisional scoring of options in the high-level MCA. An iterative process was used so that the system maps informed the scoring and the scoring provided feedback on the system maps. The maps thereby enabled the clarification of option categories for use in this project.

The baseline subsystem maps informed the selection of criteria for development of multi-criteria analysis described in Section 5, with the use of mapping demonstrated in Annex H. There have been subsequent changes made to the selection of criteria as a result of the pilot modelling and an assessment of data availability.

The intervention maps informed our categorisation of option types in Annex I.

4.4 Maps

4.4.1 Flooding

The Flood and Coastal Erosion Risk Management (FCERM) strategy has four categories of flood resilience: protection, response, recovery and placemaking.[13] The development of the system maps centred around analysis of these themes and how they influence different parts of the flooding system. Interventions (options) that provide these forms of resilience are shown on the flooding system maps. The Sustainable Drainage System (SuDS) and Natural Flood Management (NFM) option types are also shown. An example of a baseline systems map, for flooding, is provided in Figure 4.1. The principal system outcomes for the flooding systems are:

- Annual flood damage

[13] Environment Agency – National Flood and Coastal Erosion Risk Management Strategy for England (publishing.service.gov.uk)

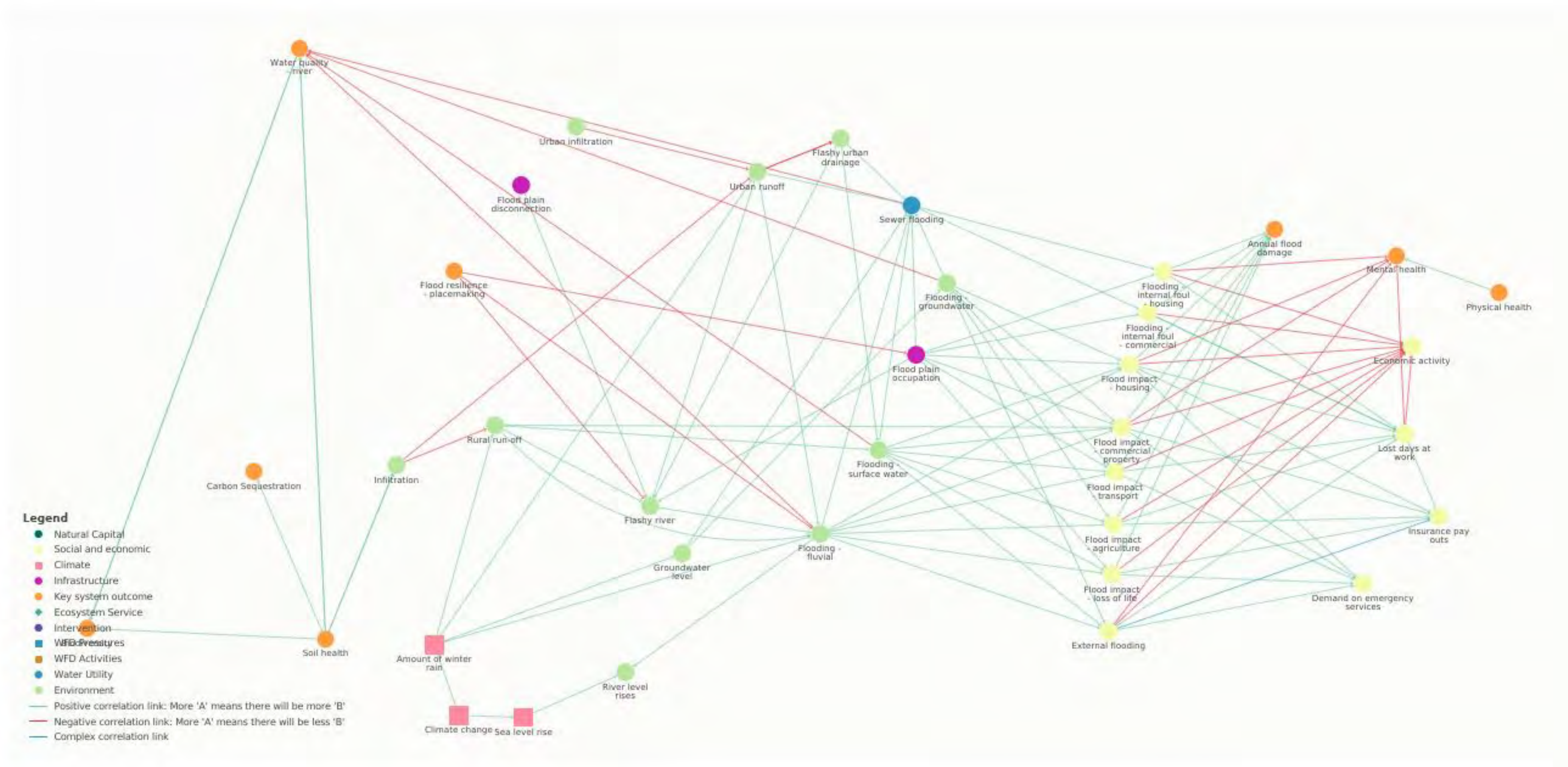
- Flood resilience – placemaking

These outcomes are selected because the Annual flood damage is relevant to flood Protection. We have not, at this stage, included options relevant to flood response and recovery in the MCA. This selection therefore addresses both protection and placemaking which are relevant to options and to planning guidance in the Integrated Water Management Framework.

Additional system outcomes include:

- Mental health (and by extension, physical health).
- Water quality – river, which numerous SuDS and NFM interventions contribute to.
- Biodiversity, Carbon Sequestration, and Q95: Low flows avoided – summer/autumn (linked to the NFM map), which some SuDS and NFM interventions contribute to.
- Soil health is a key system outcome that influences flooding processes.

Figure 4.1: B02 – Baseline flooding map



4.4.2 Planning and development

Good urban form is a key node that influences the planning and development system. Good urban form relates to a mix of land uses that makes urban areas good living spaces. The ideas of a 20-minute neighbourhood[14], in which there are good opportunities to use local amenities all within 20 minutes of any home via high frequency transport links, also influence this system in positive ways.

This system has some important outcomes such as Mental Health and Physical Health, Water Quality – River, and Flood resilience - placemaking. Biodiversity and Carbon sequestration are also influenced by these systems. Soil Health is influenced by Brownfield remediation which in turn has benefits to water quality and other outcomes, including flooding.

An important set of insights from the map are indicated by the links from Blue green corridors (conveyance), which reflect Good urban form. They have an immediate impact on Flood resilience – placemaking. They also create space for cycle paths, that can reduce public car traffic and consequently reduce urban pollution, improving Water Quality – river. Blue green corridors also increase Trees / parkland – local green spaces which bring numerous additional benefits including Cooling and shading, Aesthetic value and Sense of place, Interaction with nature and hence Mental health, as well as Carbon sequestration. Following these links provides a useful way into this map.

This system has important additional links to other systems. For example, the planning and development maps have important links with flooding. An important connection is made from Roads and Railways via Transport Earthworks to Flood storage and Engineered high ground; it was suggested that large-scale earthworks for transport might open opportunities for large scale flood mitigation and other benefits. These links are shown as complex because they are not necessarily positive; they need to be created through effective engineering design coordination and planning. There are two important feedbacks from flood impacts to the planning and development map – negative links to Mental health and to Economic activity.

4.4.3 Water quality

The water quality sub-system map was started from Water Framework Directive (WFD) activities and pressures across the OxCam Arc. We consolidated the number of pressures and activities included by reviewing how many water bodies within OxCam were affected by each one, in order to make the maps legible and not overly complex. The WFD map includes the following Key system outcomes relating to water quality and river health: Dissolved Oxygen, Sediment, Nutrients, Organic Pollution, Natural morphology, Biodiversity, Invasive and non-native species and an aggregated outcome for Water Quality – River. The mapping also identifies how:

- benefits of NFM to Water Quality are realised via nutrients and sediment; and via Q95: River low flows avoided – summer / autumn.
- ELMs benefits are realised through influence on WFD pressures, which are highlighted as key system outcomes. The ELMs submap highlights the importance of Farming financial resilience / profit as a driver for “On farm decision making towards sustainability”, which drive implementation of ELM options.
- the wastewater system links in to the corresponding WFD activities.
- SuDS impact on WFD pressures / key system outcomes at the top of the map.

“On farm decisions towards sustainability” is the central node on the Agricultural system map. It determines the extent to which ELMs and NFM interventions are undertaken and negative WFD activities are avoided. Farm financial resilience/profit is a key influence on “On farm decision making towards sustainability”. Other important influences are shown by clusters around the following nodes:

- Perception of future financial uncertainty

[14] https://www.tcpa.org.uk/the-20-minute-neighbourhood

- Diversity of farm revenues
- Farmer willingness to change
- Farming regulation
- Multi-benefit ecosystem service schemes

The system map also shows that numerous key system outcomes are all within two steps of the "On farm decision towards sustainability". This highlights the significance of farmer behaviour (rural land use) on integrated water management in the OxCam Arc and draws attention to the need to engage with the complex influences on farmer decision making as listed above.

Seasonality is important in the analysis of farming water. The system shows an interaction between agricultural decision making, environmental factors and system outcomes that varies from one season to another. An interesting example is highlighted by selecting both Climate change and Bare soil (winter) and selecting a two-step focus. Bare soil (winter) is an important cause of nutrients and sediments in water courses and has a direct link to winter water quality.

- Climate change drives Hotter drier summers, increasing the likelihood of a late harvest and planting of Spring crops creating Bare soil over the winter.
- Climate change also drives Higher winter rainfall, increasing Waterlogging, delayed planting of Spring crops and Bare soil (winter).

Mitigating actions include planting of cover crops, which reduces the bare soil, and improved Soil health which improves Winter water quality. The addition of the PWS shows how the seasonal factors contribute to a Resilient water resource which is a key node. There is an important loop back to the agricultural and water quality system via the node, Water companies engage with farmers.

4.4.4 PWS & wastewater

The PWS map has two clusters of nodes and two principal key system outcomes. The higher of the two clusters on the screen relates to water resources and focusses on the Resilient water resource node. The lower of the two clusters on the screen is focussed on the Supply demand balance – engineered Water Available for Use benefit. The Supply demand balance is dependent on the Resilient water resource, but this dependency is mediated by engineering infrastructure, management, and customer behaviour. The influence of the WFD system on the PWS system comes via river Water quality. Low flows influence both the WFD and the PWS systems.

There are a cluster of option types that influence Resilient engineering operation – PWS, Resilient engineering infrastructure – PWS and Resilient water supply to customers. A second cluster enhances the Resilient water resource, and a third cluster influences WFD pressures, such as Nutrients.

WINEP options principally influence Water quality – river, and consequently Resilient water resource.

The wastewater system influences the WFD system via the sewage-related WFD activities and influences the PWS system via Water quality – river and then Resilient water resource. There are important linkages coming from the flooding system to the wastewater system.

SuDS options influence: the wastewater system via Flashy urban drainage and Urban runoff; the WFD map via Sediment and Nutrients; and the PWS map via Water quality – river.

DWMP options reduce Wastewater pollution and enhance Resilient Engineering infrastructure and operation.

4.5 Systems mapping summary

We used a participatory system mapping method to map interactions and dependencies across environmental systems (water quality and rivers, flooding, water resources), water utilities, planning and development and agricultural systems.

- The system maps provided the basis for categorising option types and benefits from planning processes across these systems. This list of option benefits defined the list of criteria used in the MCA. The maps act as repository of knowledge categorising options and benefits. These categories are likely to evolve as the project progresses. The system maps record the rationale for the option and benefit categorisation and any subsequent changes.
- The maps also identified the potential for integration at the spatial planning level so that synergies are achieved across items such as urban planning, flood control and water quality. For example, an urban planning strategy could include creation of blue-green corridors that create benefits across flood resilience, transport (with cycle routes) and benefits from urban-tree planting such as well-being, temperature regulation, biodiversity and carbon sequestration.

The maps are designed to be a live document to support ongoing analysis and implementation of the OxCam Integrated Water Management Framework, with the expectation and hope that they are owned by appropriate stakeholders. At this stage we believe more work is required to take a consistent approach to the impacts of climate change across all of the systems and to add additional analysis of links between water quality and development.

Future use of the maps would include:

- The system maps inform the design of numerical modelling of the Arc water system as they provide a wide scoping perspective on system links and functions. From this wide perspective a selection of which interactions need numerical modelling can be made.
- The system maps will enable identification of new options as stakeholders collaborate to address challenges in the OxCam Arc.
- The system maps provide a basis for analysis of attribution of benefits to different actions in the Arc. As such they provide a platform both to mobilise blended finance for options and a platform for the design of an evaluation framework for collaborative management of the arc.
- The system maps provide insights that allow for a more strategic integration of system design in the Arc (such as designing transport earthworks to contribute to flood management).
- The system maps will continue to provide a tool for stakeholder engagement – recording insight from stakeholders in a way that builds a holistic and detailed picture on system function. This engagement also has the benefit of creating insights useful to participants in the mapping programme that provide anecdotal material that can nudge organisations towards cultural change that embraces holistic perspectives and bridging of disciplinary siloes.

Key Learning

- Better value will be achieved if there is greater strategic integration of the planning processes. System mapping identifies opportunities for integrating development of the Arc and the strategic level.
- New development can affect the water environment in complex ways due to interactions between sub-system elements
  - System mapping shows numerous positive and negative interactions between water sub-system elements
- Systems mapping contributed to the selection of the MCA criteria requirements and identifies a comprehensive set of criteria for IWM.

Implications

- Some degree of strategic planning for water is likely to be necessary to determine optimal spatial plans, as well as to specify optimal portfolios of interventions to mitigate development

5 Integrated solutions appraisal

We present a schedule of metrics for the multi-criteria analysis (MCA) that have been made as a result of our system mapping, the modelling pilot study and our assessment of data availability. We provide a discussion and conclusions, proposing how the modelling and metrics could be used to further the objectives of the OxCam IWMF.

Understanding from the evidence base and system mapping has been used to develop more integrated multi-criteria appraisal of solutions across the four core water sub-systems (water resources, wastewater, flood risk and water environment), integrated with local growth planning to inform or prescribe spatial planning. This approach has also been informed by our review of MCA and appraisal practice (Annex K) across strategic planning frameworks within the water sector.

Many of the existing water sub-system option appraisal processes include some element of MCA. The analysis in the different planning processes is not comparable because they are undertaken with different planning assumptions, using different categories and are assessed against different objectives. By creating some alignment of planning processes, it would be possible for the processes to be aligned and thereby create the opportunity for integrated planning. The following items need alignment:

- A common set of metrics.
- A common set of planning assumptions.
- A common set of scenarios.
- A consistent set of management targets and performance thresholds.
- A consistent categorisation of option categories.

Common planning assumptions would include items such as design horizon, costs, carbon pricing, and optimism bias. Consistent scenarios would have to address growth and climate assumptions. Consistent management targets and performance thresholds would allow the level of ambition and service provision to be comparable across the planning frameworks.

To inform the approach to solutions appraisal for Phases 2 and 3 of the IWMF, we identified a set of 186 option categories across all planning frameworks and scored these against the starting list of IWM MCA criteria. This high level MCA enabled us to identify option types with the highest potential for offering co-benefits and any which if selected in one framework could present risks to the delivery of objectives in other frameworks. The results of this are presented this in Annex I.

Should the planning frameworks be aligned with the common approaches above, then it would be possible to integrate the planning frameworks by summing the benefits across the scenarios and negotiating a revised portfolio that reflected a more effective, efficient and synergistic set of options. We set out an approach to integrating planning frameworks in Section 5.2.

We have undertaken a pilot modelling exercise summarised in Section 5.3. The pilot modelling allowed refinement of the schedule of metrics which had initially been based on the system mapping (Section 3.7).

5.1 Criteria definition and rationale

We used the following attributes to guide our selection of metrics:

- Strategic: assessing the value of options in terms of IWM priorities
- Outcome focused: valuing the ends, not ways and means
- Independent: can be assessed one at a time, the assessment of one does not depend on another
- Measurable: allowing a level of value to be represented

- Absent of Redundancy: criteria do not mean the same thing, or overlap
- Unambiguous: clear and concise
- Addressable: can be impacted by decisions taken within the IWM framework

In Annex H, we present a provisional set of criteria and metrics for use in a multi-criteria analysis following our work on system mapping, a pilot study on integrated modelling (Section 5.3) and a review of current practice across subsystem planning frameworks. We have indicated where Integrated Catchment Modelling (ICM) could provide data for metrics and where the data would need to come from the planning frameworks. Not all of this data is currently available: we propose them as them as a schedule for adoption in future planning cycles. We have not included property connections and networks for water supply or wastewater as metrics for optimisation but propose they are treated as fixed planning requirements.

Table 5.1: Proposed criteria and metrics

Criteria	Subsystem Metric Data	IWM Metric Data	IWM Data source
Water Resources	Dry year supply demand balance benefit (Ml/d)	Dry year supply demand balance benefit (Ml/d)	ICM modelling
Water Quality	WFD metrics Protected Site Status	Phosphorous, Nitrate, Ammonia Concentration Suspended Solids	ICM modelling
High flow water quality	99 percentile BOD		
Environmental flow	WRGIS deficit (Ml/d)	Q10, Q5 flow	ICM modelling
Flood Protection	Property flood risk band numbers Others under development	Q5 QMED flow R-B Index	ICM modelling for indicative metrics Planning frameworks for flood impact
Flood Placemaking			
Invasive Non-Native Species	INNS WFD pressure status		Planning frameworks
Carbon Sequestration	Tonnes carbon equivalent		Planning frameworks
Embodied Carbon	Tonnes carbon equivalent		Planning frameworks
Biodiversity	Biodiversity net gain		Planning frameworks
Soil Health	No consistent metrics	Soil health and erosion risk metrics	Planning frameworks
Mental health		Weighted score based on increased access to green/blue space for recreation	Planning frameworks
Physical health			Planning frameworks
Social connectivity and networks		Local connectivity impacts and stakeholder networks	Planning frameworks

The review of subsystem planning frameworks is presented in Annex G, with tables of key criteria included in each framework, and a view on whether they should be included in the Integrated Water Management (IWM) MCA. The following observations are made about subsystem criteria and metrics following Phase 1a analysis.

5.1.1 Water resources

Impacts on Supply Demand Balance can be modelled directly in regional ICM by determining the change in abstraction required to maintain number of days drought failure constant at a baseline value. Therefore, supply demand balance can be included in regional MCA directly, either as a target threshold to be met, or as a value-based metric based on marginal value of water resource in the region.

Water network constraints cannot be modelled easily in a regional level integrated model, due to model complexity constraints. We suggest that this criteria is excluded from regional modelling.

5.1.2 Water quality

Water quality is of critical importance to the ecological status of water bodies, and the status of designated sites. In the evidence gathering and analysis phase of work, we used the Environment Agency Catchment Challenges data on pressures and activities for not achieving good status against River Basin Management Plan objectives as the starting point for identifying water quality and other environmental criteria. To constrain the list of pressures and identify those that should be included as criteria, we started by excluding pressure/activity combinations that affect few water bodies and reviewed the spatial coherence of pressures and activities as shown in Annex H.3.2. We have updated this table to show any conclusions resulting from Phase 1a pilot modelling.

5.1.3 High-flow water quality

It was not possible to test biological oxygen demand in pilot modelling. However, water quality values for phosphorous, sediment, nitrate and ammonia can be output at any flow duration curve value. Pilot modelling suggested reasonable coherence in these parameters at Q5 flow across the options tested, though with some notable differences. We propose to include all quality metrics at Q5 flow initially in any IWM regional modelling, and potentially exclude some metrics upon review of results.

5.1.4 Environmental flows

A dynamic ICM would be capable of outputting flow values at any point on the flow duration curve for each water body, or at finer spatial resolution with appropriate model refinement locally. Environmental flows can therefore be modelled directly.

5.1.5 Flooding

The FCERM guidance [15]identifies four categories of option relating to flooding: protection, placemaking, recover and respond.

Flood annual average damage or property risk banding cannot be determined directly in the integrated modelling tested in Phase 1a because flood impact also requires a geospatial assessment. Options that provide benefits of protection and placemaking can be modelled with proxy indicators of impact such as Q10 and Q5 flows and the R-B index. The flood planning frameworks (FRMP) would have data relating to numbers of properties in flood risk bands, which cannot easily be recreated by integrated models.

Options that provide benefits of protection and placemaking can be modelled with proxy indicators of impact such as Q10 and Q5 flows and the R-B index. The FRMP would have data relating to numbers of properties in flood risk bands, which cannot easily be recreated by integrated models.

We understand that metrics for flood resilience are under development by others and these should be reviewed for applicability in subsequent work.

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15 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/920944/023_15482_Environment_agency_digitalAW_Strategy.pdf

5.1.6 Best value metrics

5.1.6.1 Invasive Non-Native Species

Invasive Non-Native Species (INNS) affect 50 water bodies in OxCam and are distinct from all other pressures. We did not test modelling INNS in the pilot modelling, but they could be included in IWM MCA as a best value metric based on option type.

5.1.6.2 Soil health

We derived a metric for soil health as a criterion for high level MCA in the earlier part of Phase 1, based on freely available open-source data on bulk density, organic matter content and total nitrogen concentration. "Maximum slope" data could be added as an appropriate proxy for soil vulnerability erosion vulnerability.

No further analysis has been undertaken in Phase 1a.

5.1.6.3 Carbon impacts

We propose to consider two criteria relating to greenhouse gases: one for carbon sequestration and one for embodied carbon. Whilst arguably a tonne of carbon is of equal importance no matter whether it is emitted or sequestered, as we progress towards net zero, embodied carbon may well reduce as better materials become available, whereas sequestered carbon should remain of consistent value. It is therefore useful to understand how options contribute to both.

This would be a weighted maximisation criterion, based on carbon pricing, as there is no objective means of specifying a target ambition, and reducing carbon is not a primary goal of the IWM.

5.1.6.4 Biodiversity / ecology

WFD status captures most aspects of water body biodiversity and ecology, with ecological status being a key metric in WFD appraisal. However, water system interventions may well affect other aspects of biodiversity and ecology, e.g. terrestrial habitat creation as part of catchment management or nature-based solutions. These benefits require their own criterion, with maximisation metrics TBC. Biodiversity net gain is likely to be the most appropriate metric for this.

Natural Capital was considered as a potential criterion, and both ENCA and Natural England metrics were reviewed. We propose not to specify it as a criterion, because it is insufficiently independent of other more strategic criteria, some of which are themselves natural capital sub-criteria. Optimising against other criteria will implicitly increase natural capital significantly. Overall natural capital should be applied separately, e.g. through the OxCam Local Natural Capital Plan.

5.1.6.5 Wellbeing

Review of best practice identifies considerable overlaps between mental & physical health and social capital. Social Capital could be specified as the overarching theme, with three sub-criteria as follows:

1. Access to recreational opportunities and amenity benefits for users of the new infrastructure
2. Local connectivity impacts, for example active travel opportunities and/or impacts as a result of the location of the new infrastructure
3. Stakeholder relationships and partnerships that form as a result of construction and operation of the infrastructure

Each of these contribute to physical and mental health.

5.2 Summation of benefits

Having adopted a common set of metrics and planning assumptions, it would be possible to select options that work together for increased benefits across the planning frameworks. Figure 5.1 shows a method for the summation of benefits across four planning frameworks leading to the creation of a combined portfolio of options. The diagram shows how benefits from the four planning frameworks could be summed and then a combined portfolio negotiated and agreed.

The primary benefits in each system are coloured bold and co-benefits are coloured faintly. Water resource benefits are blue, wastewater yellow, environment green and flooding pink. Rows 1-4 show the benefits and co-benefits of the options selected within each framework. Columns A to D show the benefits to each of the four planning frameworks. Columns E to J show co-benefits that represent additional value ("Best Value" to use the terminology of WRMPs) such as social benefits, carbon sequestration etc. Row 5 shows the sum benefits of all of these portfolios. Row 6, at the bottom of the page shows how a revised set of options could be negotiated to create a portfolio that reflects the efficiencies and potentially enhanced delivery of an integrated approach. The Best Value benefits in purple represent additional value from synergistic effects and investment.

As an example, using this method, a SuDS flood management project with a secondary benefit to water resources would appear in both the flooding portfolio in Row 4 and summation of benefits in Row 5. A review would then be made to assess whether it should be included in the combined portfolio Row 6. This option could displace a more costly water resource option and create a more cost effective water resource portfolio. If another similar project exists that does not meet the cost benefit threshold for flood schemes when considered in isolation, then identifying a cost share with another portfolio may mean that it becomes viable for inclusion in the flood portfolio too, entering the diagram in Row 6. Performance targets are shown as horizontal lines. A solid line is a planning constraint - this objective must be met. A dashed line is a soft target - it is aspirational and may be subject to a cost benefit threshold).

Note that the magnitude of benefits attributed to each planning framework are entirely arbitrary in this diagram and in no way indicate likely scale of benefits derived in reality.

Figure 5.1 Combining benefits and co-benefits in the MCA

5.3 Pilot modelling

5.3.1 Modelling summary

Pilot modelling has been undertaken by The Centre for Systems Engineering and Innovation (CSEI) at Imperial College using their Water Systems Integration model (WSIMOD). Their report is provided in Annex L of this report. A summary of the modelling method and outputs is provided below.

The Integrated Catchment Modelling pilot provided a mass balance model indicating water resource, water quality and flood behaviour across 27 water bodies in the Cam, Granta and Rhee catchments, as shown in Figure 5.2. The conceptual arrangement of the model is show in Figure 5.3. The resolution of the model is the water body (i.e. the calculations indicated in Figure 5.3 are calculated at each of the water bodies shown in Figure 5.2). The red lines on Figure 5.2 indicate the catchments of interest in the pilot study, meaning that the modelling results discussed in this document refer to the starred locations which are the downstream points in each of the three catchments.

Figure 5.2: Area of the pilot modelling

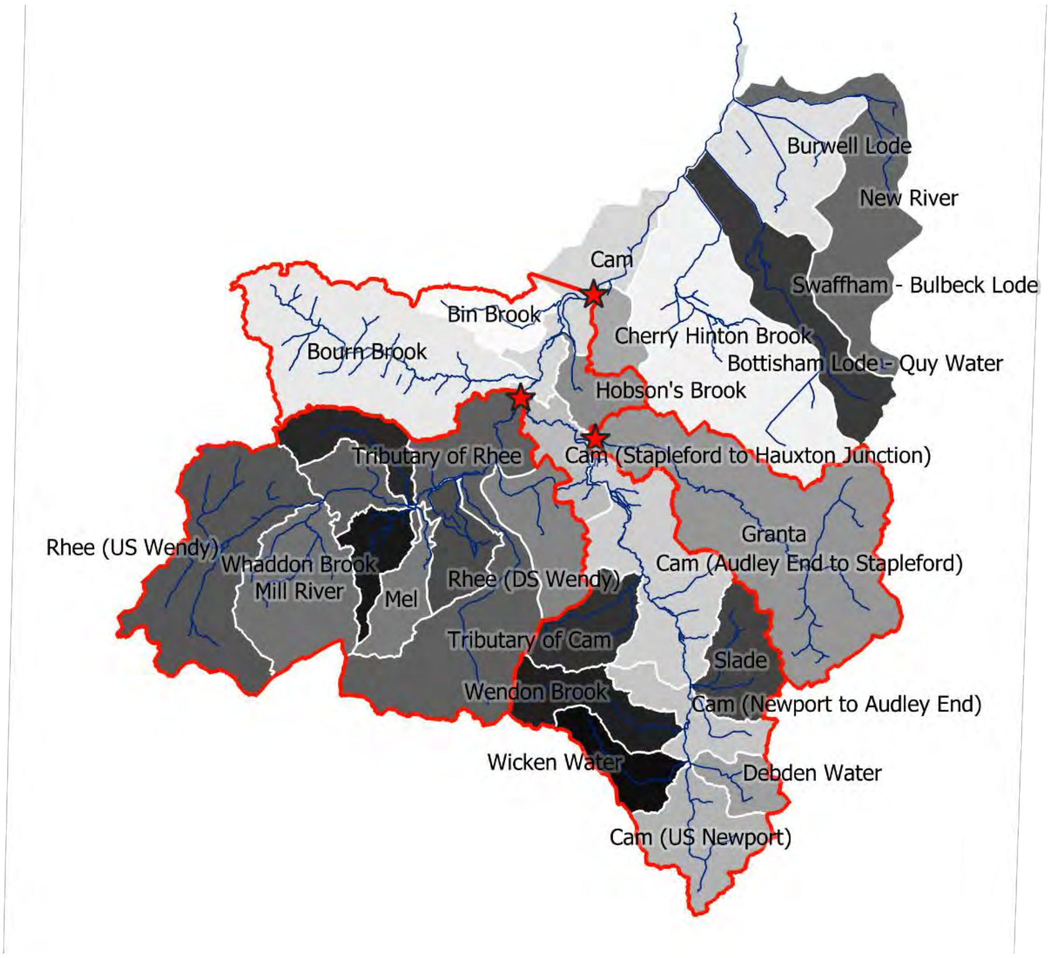
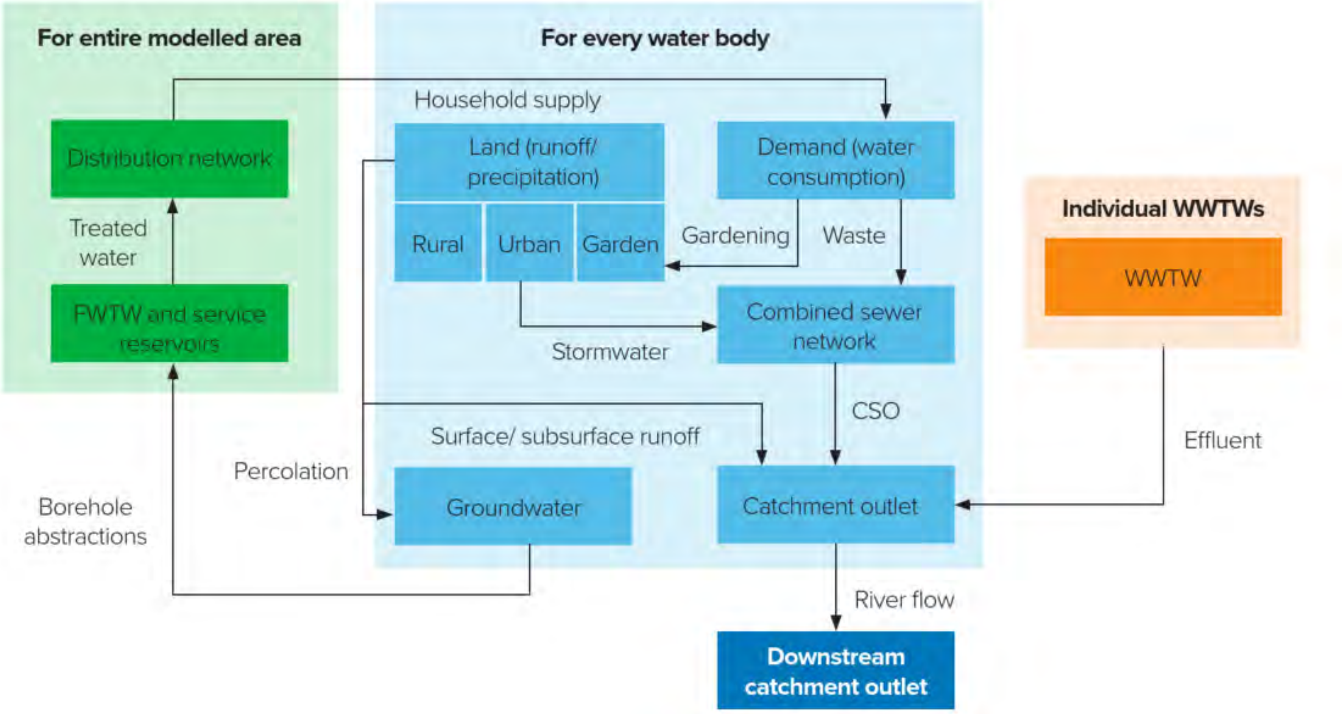


Figure 5.3: WSIMOD conceptual model



Water availability data was extracted to give the following metrics:

- Dry year supply demand balance expressed as Ml/D change in demand required to maintain constant number of days when drought measures are required
- Q90 and Q70 flow

Water quality was represented with the following parameters:

- Ammonia
- Soluble reactive phosphate
- Inorganic nitrogen
- Inorganic suspended solids

Flooding behaviour was indicated by the

- R-B Index for variability (flashiness) of river flows
- QMED (median of the annual maxima of river flows during the simulation period)
- Q10 and Q5 flow

The following intervention options were modelled:

- Reservoirs
- Wetlands
- Tree planting
- Per capita consumption reduction
- Urban water attenuation measures
- Wastewater treatment and storm tank capacity

- Sewer capacity (high level rather than individual sewer modifications)
- Regenerative farming

Population growth scenarios were modelled as follows:

- No change
- New settlements – 23,000 growth in population
- New settlements – 30,000 growth in population
- Expansion of existing settlements – 23,000 growth in population
- Expansion of existing settlements – 30,000 growth in population

Climate and scenarios were modelled as follows:

- RCP4.5 (carbon emissions peak in 2040 due to aggressive adoption of renewables)
- RCP8.5 (business as usual)

Imperial College provided the following summary of the results of the modelling:

Water availability. Climate change together with increased groundwater abstractions decrease groundwater storage in all catchments, while both climate change and population growth will significantly increase freshwater treatment deficit, which endangers future water security. Reservoir operation slightly decreases groundwater storage in Granta and Rhee catchments, with potential negative impacts on dry periods baseflow; however, new reservoir decreases freshwater treatment deficit under all scenarios, adding to water security in the region. Wetland in Granta contributes to groundwater recharge, leading to increased baseflow to rivers in dry period and attenuation of river flow peaks in wet period. Tree planting in Granta increases evapotranspiration, resulting in a decrease in groundwater storage, lower low flows, and the slight increase in water deficit. Less per capita demand has positive impact on groundwater storage, however, causing less wastewater effluent to be discharged into rivers during the low-flow period, potentially impacting downstream dilution capacity of rivers.

Water quality. We see effects of both climate and population scenarios, with negative impact on rivers dilution capacity during drier climates and increase in wastewater effluent discharge into rivers due to population growth. A new reservoir generally increases river pollutants concentration, especially nitrate and to a lesser extent phosphate. Wetland affects water quality through increased baseflow providing more dilution, which will decrease ammonia and soluble reactive phosphate (SRP) concentration in Granta. Through storing rural runoffs, wetland will also sediment solids and enhance denitrification that removes nitrates. Per capita reduction reduces urban pollutants (ammonia and phosphate) but nitrate and solids concentrations are increased because the reduction in effluent causes reduced dilution of these pollutants.

Flood behaviour. Population growth has very little effect on high flows and flashiness of flows, which is because the flashiness of large rivers is dominated by contributions from rural runoff. Neither of the two climate change scenarios modelled has a significant impact on high flows or flashiness of flows, but the scenarios selected are not representative of the full range of climate change. The new reservoir seems to have minimal effects on flood behaviour because it is only impacting river flows at lower flows, and not changing the generation of runoff. Wetland significantly reduces flood peaks by storing surface runoffs on site in Granta. The trees significantly reduce flooding metrics, due to less surface runoffs that are the major cause of hydrograph peaks in rivers, while per capita reduction has minor effects.

5.3.2 The potential to integrate modelling

The integrated catchment modelling is an important new development for regional planning. It combines water resource and water quality modelling and provides a useful indication of potential flood impacts.

- Water resource and water quality modelling can usefully be combined because they are both based upon mass-balance.

- Flood impacts cannot easily be combined with this modelling because determining flood impact also requires a geospatial aspect to the modelling.
- Some aspects of the wastewater system, such as treatment capacity, can be modelled where the principal influence is on water quality. Hydraulic modelling of sewer networks is not achieved, but this modelling would be less appropriate at the regional level since it is unlikely to identify multi-benefit system linkages that are the core aim of this higher-level modelling.

The ICM piloted here does not directly provide impacts in terms of Water Framework Directive (WFD) objective status (for flow or water quality parameters), nor does it provide impacts in terms of flood impact (annual average damage, change in property flood risk band or equivalent). The impact on WFD status could be derived if the relationship between water quality concentration and status is known for a given water body.

Strengths and weaknesses

Table 5.2 provides a summary of the strengths and weaknesses of ICM when compared with current practice on modelling the component systems in their respective planning frameworks.

Table 5.2: Relative strengths and weaknesses of ICM at the regional level with a resolution at the water body when compared with current industry practice of modelling sub-systems separately

	Integrated Catchment Model		Current practice in sub-system modelling	
	Strength	**Weakness**	**Strength**	**Weakness**
Water resources	Provides integration of water quality water resources. Potential to optimise across water resource and quality.	Water networks not modelled	Mass balance models provide similar functionality to the ICM model used here. Groundwater and rainfall-runoff models provide detailed geospatial analysis.	Not integrated with water quality modelling
Water quality			A range of models provide water quality and ecology analysis	Not integrated with water resource modelling
Flooding	Provides indicative results on flooding, integrated with water resources and water quality.	Does not provide flood impact results due to lack of geospatial analysis (Provides indicative results only)	Provides flood impact results	Not integrated with water resource or water quality modelling
Wastewater	Provides water quality related results	Does not provide hydraulic analysis of networks	Sewer models provide hydraulic results needed for sewer design	Not integrated with water resource modelling.

Table 5.2 indicates that the advantages of using ICM are that it provides an integrated perspective across water resources and water quality and an indicative output on flood impacts. The weaknesses of the ICM are that it does not provide detailed results on flood impact, and it does not provide detail on hydraulic performance of sewers or water distribution networks. Our assessment is that these weaknesses do not create a difficulty for use of the model at the regional level where a higher-level perspective is appropriate. We have listed the main modelling methods used in each planning framework in Annex J for comparison. The list indicates that a wide range of modelling is undertaken, and we do not believe it would be appropriate or feasible to replicate this modelling at the regional scale. By contrast, we recommend that a high-level integration of water resource and water quality modelling is an appropriate level of integration at the regional scale.

Optimising the performance of the system, drawing on the potential to design sets of options that work in combination, means that the modelling has potential to create a significant enhancement to catchment outcomes.

Limitations identified in the pilot modelling

Calibration and asset owner liaison has not been undertaken for this pilot exercise. By engaging with asset owners, it will be possible to improve on some of the assumptions made in this pilot. Improving the understanding of treated and raw water transfers between water bodies would enhance the analysis. Similarly allowing for a calibration exercise will enhance the analysis.

Integrated modelling and the widespread adoption of nature-based solutions are important emerging areas of work. As such there is limited availability of ground-truthing evaluative studies of NBS implemented at scale by which the impact of different NBS options can be calibrated. This is significant for complex interventions such as regenerative agriculture and tree-planting for which the intervention has numerous physical impacts on the water system, and these are context specific. In the absence of major studies, there is a risk of optimism bias given the intuitive attractiveness of nature-based solutions.

5.3.3 Value of modelling

The key question about the value added by this regional modelling is influenced by the way it is used in relation to the system-specific modelling undertaken in the existing planning frameworks.

- By combining water resource and water quality modelling, this modelling provides ability to integrate development of options for regional water resource plans, WRMP, DWMP, WINEP, RBMP and related catchment planning processes. This has real potential to create efficiencies and enhance benefits.
- The fact that flood modelling cannot be achieved in detail means that flood benefits of options need to be identified with bespoke flood modelling. The water resource and water quality co-benefits of those options may be identified in the integrated modelling. Conversely the integrated modelling will identify where water resource and wastewater projects have potential flooding benefits.
- The model could be used to test the impacts of options in combination, or alternative option portfolios, on flood risk: assuming management targets can be derived for flood flow conditions (see “Role of Modelling within the IWMF” for more discussion on this).

We have identified the following benefits of modelling at different planning stages:

- Early phase - Building on outputs from Phase 1 of the IWMF such as the system mapping to quantify potential benefits of options being put forward at a high level, for detailed appraisal in non-flooding workstreams where appropriate.
- Mid-planning phase - When required by individual planning frameworks to support identification of wider co-benefits, risks and opportunities. The impacts of specific draft options could be tested against wider system performance thresholds.
- Late-planning phase – Through testing in-combination effects of all plans, identifying alternative measures that could achieve similar benefits at lower cost, or better overall benefits across multiple objectives, or for the river basin overall. This would require involvement with, for example, RBMP teams, Water Abstraction planners and the UK Technical Advisory Group to translate changes in flow and quality into effects on water body status.
- Urban planning - Without ICM, improved integration could provide benefit by assessing draft Local Plan alternative development scenarios in draft WRMP, which could then feed back into Local Plan decision-making. However, use of ICM could play a further role in addressing some of these issues, by showing what impacts new development will have across flow and water quality at an appropriate scale for each location, and testing options to mitigate these impacts and achieve environmental ambitions across all key indicators. This could be used to identify any capacity constraints to development, inform the most appropriate locations for development and specify planning conditions for development to go ahead.

5.3.4 Scale and resolution of the modelling

We use the term scale to refer to the overall geographical coverage of the modelling. We use the term resolution to refer to the component area for each calculation within the model. We set out strengths and weaknesses of working at different scales and resolutions in Table 5.3 and Table 5.4. The pilot modelling uses WFD water body as the resolution. The scale of the modelling is 27 water bodies with results reported at 3 sub-catchments. The scale can be varied according to requirements. We discuss the resolution on the assumption that the regional scale of the OxCam Arc is required.

We consider the water body to be an appropriate resolution for integrated planning, with the caveat that this be varied where more or less focus is required. Some water bodies may have a large area and need to be broken down; other water bodies are small and if there are few system risks, a coarser resolution may be appropriate. By using the water body as our standard resolution, the entire Arc could be modelled with reasonable computing capacity and effort, notwithstanding the need to model a range of climate and growth scenarios.

The water body scale is appropriate because water resource systems operate at regional level with water moved between catchments to manage droughts (although that has not been modelled in this case). Water quality and flooding systems function at the catchment level and therefore this modelling provides appropriate resolution showing how the different water bodies within a catchment interact. Water body resolution is also suitable for a regional perspective on wastewater as it provides an analysis relevant to system synergies, but not for more detailed localised system-specific design concerns, which are best appraised locally. For environmental flows, sub-water body resolution would be necessary in places, e.g. the upper reaches of chalk catchments: this can be achieved locally in the model with reasonable effort.

Table 5.3: Relative strengths and weaknesses of ICM at different spatial scale

	Regional scale		Catchment Scale	
	Strength	**Weakness**	**Strength**	**Weakness**
Water resources	Water resources are operated at a regional level so an appropriate scale to model them.			Does not reflect regional water resource transfers ie inter-catchment transfers.
Water quality	A consistent approach across numerous catchments which is the key scale for water quality		Water quality functions at the catchment scale	
Flooding	A consistent approach across numerous catchments which is the key scale for flooding		Flooding functions at the catchment scale	
Wastewater	Comprises numerous catchments – so suitable for water quality issues		Suitable for water quality impacts, Generally suitable for hydraulic modelling.	

Table 5.4: Relative strengths and weaknesses of ICM at different spatial resolution

	Catchment resolution		Water body resolution		Smaller than water body	
	Strength	**Weakness**	**Strength**	**Weakness**	**Strength**	**Weakness**
Water resources	A high-level view, uses lower computational power	Lacks resolution as the catchment may be a large area			Detailed perspective	Requires greater computational effort

	Catchment resolution		**Water body resolution**		**Smaller than water body**	
	Strength	**Weakness**	**Strength**	**Weakness**	**Strength**	**Weakness**
Water quality	A high-level view, uses lower computational power	Lacks resolution as the catchment may be a large area			Detailed perspective	Requires greater computational effort
Flooding		Only basic generic indicative outputs	Suitable level for indicative outputs			Higher effort with limited benefit due to lack of specific results on flood impact
Wastewater		Lacking resolution as the catchment may be a large area. Hydraulic issues not addressed.	Suitable, for water quality impacts	Hydraulic issues not addressed.		May not align with sewer networks. Requires greater computational effort.

One challenge in establishing an IWMF for an inland regional such as the OxCam Arc is that there are likely to be benefits of options in the catchment that are downstream of the planning area. This challenge can be addressed by extending the modelling beyond the regional planning area and undertaking a sensitivity analysis to assess the distance downstream from the Arc that benefits would be realised. This sensitivity analysis should be undertaken in Phase 2 of the study.

5.4 Integrated MCA summary

We present a provisional set of criteria and metrics for use in a multi-criteria analysis following our work on system mapping, a pilot study on integrated modelling and a review of current practice across subsystem planning frameworks. We have indicated where Integrated Catchment Modelling (ICM) can provide data for metrics and where the data would need to come from the planning frameworks. Not all of this data is currently available: we propose metrics as a schedule for adoption in future planning cycles. We have not included property connections and networks for water supply or wastewater as metrics for optimisation but propose they are treated as fixed planning requirements. We then present an approach to how benefits from the four planning frameworks could be summed and then a combined portfolio negotiated and agreed.

We undertook an Integrated Catchment Modelling pilot study using Imperial College's WSIMOD mass balance model to investigate water resource, water quality and flood behaviour across 27 water bodies in the Cam and Rhee catchments, across four population growth scenarios and two climate change scenarios. River flow, ammonia, soluble reactive phosphate, inorganic nitrogen and inorganic suspended solids were modelled at a water body resolution under each scenario, and 8 intervention types were tested to investigate effects on the integrated system. The results showed significant system interaction and potential for various risks and opportunities to the delivery of outcomes across planning frameworks as a result of this interaction.

Key Learning

- Existing core system planning “best value” MCA criteria do not capture whole water-system benefits. As a starting point, 14 criteria would sufficiently capture the whole water system requirements, against which interventions should be measured.
  - Systems mapping combined with a first-principles review of MCA criteria requirements identifies a comprehensive set of criteria for IWM.
  - Best value criteria in emerging regional water resource plans do not account for flood risk or water quality benefits which may be significant for some option types, e.g. storage and nature-based blue/green solutions.
- Generic option types appraised in every water sub-system have the potential to provide significant secondary benefits across at least one other water sub-system
- There is significant potential for nature-based solutions (NBS) to contribute major benefits to all water systems. A lack of large-scale interventions delivered to date makes modelling large-scale NBS difficult, with significant uncertainty for planning.
- Water resource and water quality modelling can usefully be combined because they are both based upon mass-balance.
- Flood impacts cannot easily be combined with this modelling because determining flood impact also requires a geospatial aspect to the modelling.
- Some aspects of the wastewater system, such as treatment capacity, can be modelled where the principal influence is on water quality. Hydraulic modelling of sewer networks is not achieved, but this modelling would be less appropriate at the regional level since it is unlikely to identify multi-benefit system linkages that are the core aim of this higher-level modelling.

Implications

- Better value could be realised if more feedback is established between core system planning processes
- Options appraisal requires consistent MCA criteria across different sub-system planning processes
- Applying integrated catchment modelling to subsequent phases of the IWMF would add considerable value to decision-making both for the delivery of large infrastructure and for spatial planning of new housing development.

6 IWM requirements

We review the potential for improved IWM standards at all scales of the water system in the Arc to deliver better outcomes for the environment and society.

Water and nutrient neutrality are policy objectives proposed to ensure that development does not prevent water-related legal obligations from being met, and to further delivery of environmental ambitions. Here we summarise the background to neutrality in terms of recent development issues, and undertake analysis to demonstrate the potential high-level feasibility of water and nutrient neutrality for new development in the OxCam Arc. We discuss various potential issues to be addressed for neutrality to be effective in preventing damage and furthering environmental ambition.

6.1 Improved IWM standards

The current impacts and costs of water and wastewater resources are not fully accounted for in planning development decisions. Developers pay a contribution for water under the Water Industry Act 1991, but this is limited to connection costs and the costs of "other water mains". All new homes must meet a design standard of 125 l/h/d PCC, and this can be lowered to 110 l/h/d by LPAs where there is compelling need. For wastewater, existing permits and WINEP interventions must be adhered to, but there is no clear mechanism for water impacts to influence development.

Water and nutrient neutrality are concepts designed to ensure development:

4. Meets its legal obligations to protect Natura 2000 sites (Special Protected Areas and Special Areas of Conservation)
5. Meets the statutory WFD obligation not to cause deterioration of any water body
6. Delivers aspirational goals of the 25 Year Environment Plan to leave the environment in a better state than it is now

Under the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (as amended 2019) the Environment Agency must set objectives for each water body in relation to: preventing deterioration; achieving a particular status class (as defined in accordance with the criteria for classification set out in the directions on classification); protected area objectives, where relevant. Any new development which risks preventing the delivery of any of these objectives could result in non-compliance with the Water Environment regulations.

The 25 Year Environment Plan sets out goals for improving the environment within a generation and leaving it in a better state than we found it. It aims to achieve clean and plentiful water by improving at least three quarters of water bodies to be close to their natural state as soon as is practicable by reaching or exceeding objectives for rivers, lakes, coastal and groundwaters that are specially protected, whether for biodiversity or drinking water as per our River Basin Management Plans. Nutrient neutrality could contribute to these goals through offsetting if the means of offsetting results in net gain for the environment.

Sixteen of the nineteen management catchments across the OxCam arc region are identified as geographically intersecting with, or hydrologically connected to, an internationally designated site and therefore could be classed as affected areas if these habitats were found to be in unfavourable conditions, or at risk of deterioration, as a result of new development. A total of 207 of the 346 waterbody catchments within the OxCam arc region also intersect internationally designated sites, this equates to 60% of the total waterbody catchments which could be classed as affected areas. The North West Norfolk Coast Management Catchment in the northeast of the region is the only management catchment which does not intersect an international designated site, though runoff from here is likely to impact the Wash

SAC/SPA/Ramsar sites. Currently Natural England has not issued guidance to any councils in the OxCam region; therefore, regulatory requirements may not be present.

We note that "flood risk neutrality" is already effectively implicit within national and local planning policy and national government regulation; government guidance already specifies that all new developments greater than 1 hectare in size, or in an area with critical drainage problems, must produce plans to show they will cause no increase in the volume of surface water and rate of surface water runoff.

Biodiversity is another area of legislation and government policy concerning 'asset neutrality', where development must deliver certain goals relative to a baseline position, in this case going beyond neutrality to a position of biodiversity net gain (BNG). Paragraphs 174(d), 179(b) and 180(d) of the NPPF refer to this policy requirement and the Environment Act 2021 will introduce in 2023 a statutory requirement of 10% biodiversity net gain (BNG) for most development under the Town and Country Planning Association 1990.

We look to define what level of water & nutrient neutrality is achievable and what policy and other delivery mechanisms are needed to embed it for the Arc. We note that only certain aspects of neutrality are currently under the control of developers, e.g. water efficient devices, rainwater harvesting and greywater reuse. Most offsetting measures, and direct nutrient wastewater treatment measures, are outside of the control of developers and local planning authorities, under current legislation. The delivery of offsetting is therefore a key consideration of any policy recommendations.

6.2 Water neutrality

6.2.1 Background

Water neutrality is a concept that has been suggested as a means of ensuring that development does not add to impacts on Ramsar sites or European Special Areas of Conservation (SACs)/ Special Protected Areas (SPAs), where it cannot be concluded that existing abstraction is not having an adverse impact. It has been articulated in a position statement[16] from Natural England on the mitigation of water usage in the Sussex North Water Resource Zone (WRZ), setting out concerns that development in Horsham District, parts of Chichester District and Crawley Borough are increasing the demand for water, which is thought to be harming internationally protected species in the Arun Valley SAC, with the potential threat of extinction of some species. The Position Statement currently relates to one WRZ in Southern Water's area (Sussex North WRZ). The statement means that development must not cause the abstraction to increase, thereby seeking to reduce water stress in the WRZ.

Whilst water neutrality is currently confined to a discrete number of councils in the Southeast at present, the issue of water availability due to unsustainable abstraction, and thereby curtailing housebuilding, is relevant to all parts of England, especially the East. The issue is of concern in the development and planning sectors, given the importance of the underlying legal issues and the key role of Natural England and the Environment Agency as statutory consultees in planning. As the protection of Natura 2000 sites is a legal obligation, and water body non-deterioration is a statutory requirement, if a site or water body is at risk anywhere, water neutrality may be the only means of demonstrating adherence with these legal requirements.

All new homes have to meet the mandatory national standard set out in the Building Regulations (of 125 litres/person/day (l/h/d)). Where there is a clear local need, local planning authorities can set out Local Plan policies requiring new dwellings to meet the tighter Building Regulations optional requirement of 110 l/h/d.[17]

Waterwise state that, "Definitions of water neutrality have varied depending on the context in which they are applied. The definition that appears frequently in literature is: "For every new development, total water use in the region after the development must be equal to or less than total water use in the region before the new

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[16] https://www.horsham.gov.uk/__data/assets/pdf_file/0019/106552/Natural-Englands-Position-Statement-for-Applications-within-the-Sussex-North-Water-Supply-Zone-September-2021.pdf

[17] Housing: optional technical standards - GOV.UK (www.gov.uk)

development”.[18] This (definition is still used widely by bodies such as Natural England), but in 2009 the Environment Agency changed it slightly to include mention of offsetting. Their revised definition became: “For every new development, the predicted increase in total water demand in the region due to the development should be offset by reducing demand in the existing community”.

This is not a new concept in the UK, and there were a number of papers published between 2008 and 2010 notably in relation to large scale development across the Thames Gateway, but in practice there has not been a great deal of action. More recently, Waterwise has published a review[19] and Natural England has issued position statements related to housing developments in Sussex[20].

Some concern has been raised recently that the new water neutrality advice from Natural England may severely impede the delivery of housebuilding in some parts of the country. In the south of England, some Sussex district councils have had to delay planning decision-making as a result.

The September 2021 Natural England Position Statement to Horsham, Crawley and Chichester district councils set out concerns about the adverse impact that current levels of water abstraction are having on protected sites in the region. Natural England advised that any new housing developments requiring a public water supply (in this case from Southern Water) must not add to this impact. Further guidance was issued by Horsham DC in the form of questions and answers in December 2021.[21]. This guidance deals with water neutrality and planning policy and notes that two approaches will be needed to ensure that the Horsham Local Plan is water neutral. Firstly, all new development will need to be as water efficient as possible. This can be achieved by installing water efficiency measures such as low flush toilets, rainwater harvesting and greywater recycling. This requirement will be set out in planning policies within the Local Plan. However, all new development will still require some additional water. This additional water demand will need to be offset by reducing the demand for water in existing development. This might include fixing leaks or retrofitting existing buildings with more water efficient technology. The overall solution for water offsetting will be set out in a wider ‘mitigation strategy’ jointly prepared by all the Local Authorities affected by water neutrality.

The advice from Natural England is to resolve the matter in partnership with local authorities through Local Plans across the affected authorities, and to secure water neutrality collectively through a water neutrality strategy. Pending this strategy, Natural England advised that planning decisions be paused, and that any application that is deemed critical for approval before the strategy is ready must be able to demonstrate water neutrality. In February 2022, Natural England published an Advice Note[22] for the Sussex North WRZ to expand upon and clarify the Position Statement issued of September 2021. The Advice Note observes that water neutrality is not currently defined in legislation, but is drawn from the Gatwick Sub regional Water Cycle Study (2020) thus, “*for every new development, total water use in the Sussex North Water Supply Zone after the development must be equal to or less than the total water-use in the region before the new development.”* The Advice Note adds that:

“In summary, the amount of water from new developments using public water supply in the Sussex North Water Supply Zone will be calculated on an individual or cumulative basis to produce a predicted “demand” for water from growth. Once this per-capita calculation has been made, each new qualifying development will need to demonstrate how that development will achieve no net increase in water consumption. This can be done through a combination of water efficiency measures and offsetting. Natural England particularly welcomes nature-based solutions where these are available. Whilst a range of measures are likely to be possible, it will be important to ensure that any measures take the form of mitigation rather than compensation to the Habitats Sites, in order to comply with the 2017 Regulations. This means that measures

[18] Therival, R., Drury, C. and Hepburn, R., undated. Achieving Water Neutrality in the South East Region: Discussion Paper.

[19] https://www.waterwise.org.uk/knowledge-base/a-review-of-water-neutrality-in-the-uk-2021/

[20] https://www.horsham.gov.uk/__data/assets/pdf_file/0019/106552/Natural-Englands-Position-Statement-for-Applications-within-the-Sussex-North-Water-Supply-Zone-September-2021.pdf

[21] https://www.horsham.gov.uk/planning/water-neutrality-in-horsham-district/water-neutrality-and-planning-policy

[22] https://www.horsham.gov.uk/__data/assets/pdf_file/0005/110939/Water-Neutrality-Advice-Note-Feb-2022-V2.pdf

must avoid impacts (reduction in water reaching the Habitats Sites), rather than addressing the impacts once they have occurred."

The Advice Note also clarifies the legal basis for water neutrality: *"In order to avoid an adverse effect on integrity, the conservation status of a habitat must, if favourable, be preserved. If unfavourable, it must not be further harmed or rendered more difficult to retore to a favourable status."*

In July 2021, the government committed to introduce a mandatory "product water efficiency label" which could be used to help ensure new property fittings are water efficient. They also committed to developing a roadmap for more water efficient buildings in 2022.

Although addressing environmental damage (and the risk of damage) is very important and has triggered the situation in Sussex, the current and future water resource deficits in Sussex and in the OxCam Arc area are driven not just by environmental quality drivers but also by population growth; climate change; more ambitious drought resilience standards and the need to ensure there is sufficient water available to meet future growth. Water neutrality has the potential to help address all of these drivers. Hence, its consideration need not be limited to development in areas with internationally protected wildlife sites for example.

6.2.2 Analysis

Waterwise approach to water neutrality

Waterwise[23] outline 3 steps for achieving water neutrality: reducing water use, reusing water and offsetting water use.

Table 6.1: Waterwise approach to water neutrality

Step	Option
1. Reducing Water Use	Fitting efficient products in the home
	Fitting smart meters
	Changing behaviours
2. Reusing Water	Rainwater and surface water harvesting
	Greywater recycling
	Wastewater recycling
3. Offsetting Water Use	Retrofitting buildings
	Finding and fixing leaks

Source: https://www.waterwise.org.uk/knowledge-base/a-review-of-water-neutrality-in-the-uk-2021/
Note that Step 3 "Retrofitting buildings" could comprise all the options listed in Steps 1 and 2.

Waterwise state that, "Alongside water savings, water neutrality measures also bring carbon savings, cost savings, reduced environmental impacts and improved resilience. Implementing water neutrality also enables further development by reducing its impact on the water environment."

Waterwise define "offsetting" as investing in schemes that save water in the local region such as retrofitting existing buildings with water efficient devices or water reuse systems, where the water saved through these schemes is equal to the residual mains water usage of the new development.

In the following sections we analyse the potential of a Waterwise approach to deliver water neutrality for new development in the OxCam Arc.

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[23] https://www.waterwise.org.uk/knowledge-base/a-review-of-water-neutrality-in-the-uk-2021/

Baseline situation

Aecom (2019)[24] forecast an additional demand for the OxCam Arc beyond the WRMP19 forecast of between 157 and166 Ml/d, based on a PCC of 125 litres per head per day (l/h/d). 166Ml/d would equate to additional population of 1.3 million. Based on average occupancy rates of 2.23 (WRMP19), this equates to an additional 596,000 properties.

At WRMP19, the total household water delivered in OxCam water resource zones (WRZs) was forecast to be 778Ml/d by 2044-45. The WRMP19 forecast was for 2.8 million properties in OxCam WRZs by 2045, with average final preferred per capita consumption (PCC) of 124l/h/d. There are currently 2.3 million properties in OxCam WRZs (2021-22).

Water efficiency

Research for Ofwat estimated that for a domestic building it might be possible to reduce PCC to as little as 49l/h/d with technologies such as waterless toilets, recycling showers, smart taps, waterless washing machines and the use of non-potable water. Meanwhile, a PCC of approximately 85l/h/d could be achieved by installing water efficient fittings, changing behaviours, such as not leaving the tap running when brushing teeth, using eco settings on the washing machine and dishwasher and by using a water butt in the garden.[25] Water efficient devices include aerated taps and shower heads, low flush or air flush toilets and efficient white goods (i.e. dishwashers and washing machines).

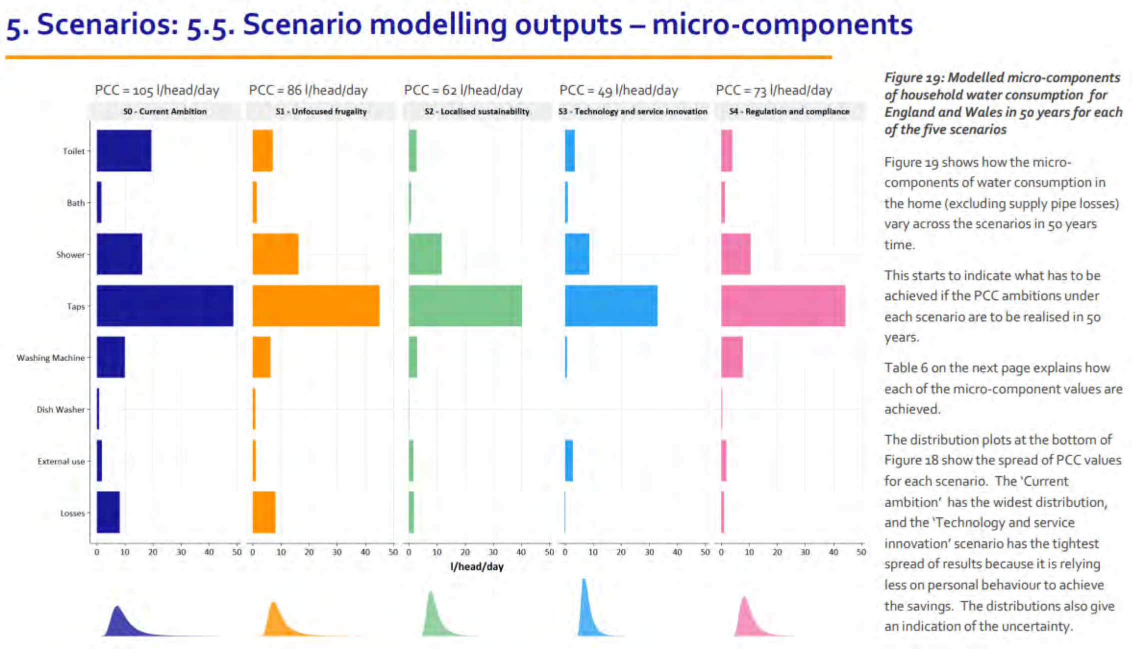
Ofwat do not distinguish between the contribution from behaviour and the contribution from efficient devices, which would be difficult to do.

Ofwat modelled micro-components of household consumption for five scenarios of ambition, as shown in Figure 6.1. This shows that for a PCC of 86l/h/d, external use is just 1l/h/d, with toilet flushing c.7l/h/d and washing machine 6l/h/d. We use these values to determine the maximum contribution of water efficiency with water reuse combined.

[24] Aecom 2019: Oxford-Cambridge Arc Evidence Base for New and Expanded Settlements

[25] Ofwat (2018) The Long Term Potential for Deep Reductions in Household Water Use

Figure 6.1: Ofwat water efficiency scenario micro-component breakdown



Source: Ofwat (2018)

A Waterwise report looking at the impact of a labelling scheme in Wales identified that houses can be designed down to 95l/h/d cost effectively using products for the domestic market that are already commercially available and to 85l/h/d using the best commercially available products.[26]

Note that a PCC of 85l/h/d cannot currently be enforced for new homes. All new homes must meet the mandatory national standard of 125l/h/d. Where there is a clear local need, local planning authorities can set out Local Plan policies requiring new dwellings to meet the optional requirement of 110l/h/d. The analysis that follows uses 85l/h/d as a benchmark, but also tests the sensitivity to this. Offsetting could be used to achieve water neutrality for any local level of water efficiency, but clearly the scale and cost of offsetting increases the higher the PCC at the development itself.

In July 2021, the government committed to introduce a mandatory "product water efficiency label" which could be used to help ensure new property fittings are water efficient. They also committed to developing a roadmap for more water efficient buildings in 2022.

It is likely that water efficiency measures to achieve 85l/h/d are largely cost-neutral, i.e. water efficient fittings, changing behaviours, using eco settings on the washing machine and dishwasher and by using a water butt in the garden cost no more than baseline installation: therefore the key costs are those involving reuse.

Direct water reuse

The following key terms and definitions have been used throughout this study:

- Rainwater Harvesting (RWH) ‑ Water captured from rainfall, through roof tops and other forms of surface runoff, treated for local non-potable consumption
- Greywater Reuse (GWR) ‑ used water captured from showers and bathroom sinks, treated for local non-potable consumption. Unless otherwise stated, excludes toilet flushing and kitchen sinks and appliances. Usually confined to sources of water with minimal biological contamination.

[26] EST (2019) Independent Review of Water Labelling in the UK https://www.waterwise.org.uk/wpcontent/uploads/2019/02/Water-Labelling-Summary-Report-Final.pdf

- Blackwater Reuse (BWR) – used water captured from foul sewerage, treated and transferred back to households for non-potable consumption. Includes all sources of used water including those contaminated by faecal matter.

Note that indirect water reuse, where treated final effluent is used to support flows in a river to enable additional abstraction for all forms of public water supply (potable and non-potable), is classified as a supply-side water resource management option. It would not form part of steps 1 or 2 of water neutrality (Waterwise approach), but could form part of offsetting, depending on how offsetting and neutrality are defined.

The unit cost of local reuse (RWH, GWR or BWR) per l/d is then dependent on how much saving is delivered through water efficiency, the cost per property of the reuse, and whether or not clothes washing can use reuse water. Anglian Water identify a range in cost for water reuse of £2000 to £4000 per property for developments of 5000 properties. Assuming an average occupancy rate of 2.23, and that reused water is acceptable for clothes washing, the results are as shown in Table 6.2 below.

Table 6.2: Unit cost of local reuse under two different scenarios of water efficiency

Scenario	Approx. cost of reuse per property	l/h/d benefit from reuse	Capex £ per l/d
86l/h/d from water efficiency.	£2,000	14	£64.13
110l/h/d baseline demand	£2,000	38	£23.63

Typical unit capex for non-selected supply-side options within one WRZ of OxCam at WRMP19 was £15 per l/d (market information table analysis). Therefore, local water reuse is likely to be economically viable with existing technology only where other significant water efficiency measures are not delivered, and for the most cost-effective forms of reuse.

In terms of the costs and benefits of rainwater harvesting and greywater reuse, Ricardo published an analysis of this for Waterwise, the Environment Agency and a number of water companies in 2020[27]. Their conclusion was that for rainwater harvesting, the technology is cost effective for new build developments; especially at scale and where wider societal benefits are included. For greywater reuse it was cost effective for larger scale new developments only. However, we observe a number of significant assumptions in the analysis, around potential water saved and flood risk benefits, which are difficult to understand; for example how a collection area of 500 square metres could offset demand of up to 2,200 cubic metres, requiring >4 metres rainfall per year. The financial “societal benefits” appear to be mainly derived from flood risk reductions, but the assumptions behind the significant benefit values are not clearly explained.

Rainwater and surface water harvesting needs careful design because water from the catchment is still being used. Greywater reuse and rainwater harvesting can increase carbon costs because of pumping and treatment, particularly at a local scale. Note that we do not assess operating costs here, which may also be significant. Scheme reliability is another key consideration: there is anecdotal evidence of problems with maintaining separate grey and potable water systems over time.

Offsetting feasibility

Assuming that water efficiency measures reduce PCC to 85l/h/d through water efficient devices, water butts and behavioural change, average external use of 1l/h/d, 7l/h/d for toilet flushing and 6l/h/d for washing machines, the maximum potential for water efficiency and reuse (greywater, blackwater and/or rainwater harvesting) combined is 77l/h/d excluding washing machines from reuse, and 71l/h/d if washing machines are included.

[27] https://waterwise.org.uk/wp-content/uploads/2020/09/Ricardo_Independent-review-of-costs-and-benefits-of-RWH-and-GWR-Final-Report.pdf

Assuming washing machines are not supplied by greywater (PCC 77l/h/d), then for the 166Ml/d additional demand scenario (maximum case of new development beyond WRMP19: 600,000 additional properties), the remaining volume of water requiring offset would be 102Ml/d. Assuming an average PCC of existing properties of 124l/h/d (WRMP19), occupancy rate of 2.23 (WRMP19) and a retrofit target of 86l/h/d (as per Ofwat 2018 study), the potential saving per property is 84 l/h/d. The number of properties requiring retrofit to offset 102 Ml/d would therefore be 1.2 million, which is 43% of WRMP19 forecast properties in the Arc by 2045.

Note that the results are very sensitive to the water efficiency target. If new properties achieve 110l/h/d PCC rather than 77, then 1.7 million retrofits are needed (61% of existing properties in the Arc) assuming a retrofit target of 86l/h/d. If retrofitting can only achieve 110l/h/d, then 3.3 million properties are needed if new properties achieve 77l/h/d (118% of existing Arc properties), or 4.7 million if new properties also achieve 110l/h/d (168% of existing Arc properties). There may be behavioural issues associated with retrofitting on this scale. People in existing houses may be unwilling to reduce water use if the perception this is simply to allow new development to happen, which itself may be unpopular.

Waterwise (2020) found that without any rainwater harvesting or water reuse it was possible to offset additional water demand through water efficiency actions on between 5 and 7 properties depending on the efficiency of the new build property (82l/h/d and 110l/h/d respectively). The analysis also found that the total benefits exceeded the total costs within 5 years. This is in line with the results of our analysis here.

It should be noted that there are significant additional offsetting opportunities from non-household buildings such as schools and hospitals. For example, analysis by Thames Water presented at a recent Waterwise smart metering event highlighted that around 26% of water supplied to non-household properties may be leaking.[28]

Offsetting costs

WRMP19 market information tables list 50 non-preferred demand and leakage options in the OxCam WRZs (excluding AWS), with total benefit of 184Ml/d, and total net present cost of £1,379m. Assuming a linear cost profile, the cost of delivering 102Ml/d retrofitting and/or leakage options would be c. £764m. This amounts to a cost of £1,285 per property for 596,000 properties. The cost per l/d saved would be £7.50. This is significantly less than any water reuse scenario, and somewhat less than some supply options. However, the uncertainties in costs and benefits (success rate) of retrofitting are very high.

Total final preferred distribution losses in OxCam at WRMP19 were forecast to be c.132Ml/d by 2045. 15Ml/d of feasible leakage options were not selected at WRMP19 by Affinity Water and Cambridge Water OxCam Arc WRZs, with a net present cost of £114m. Total final preferred distribution losses for these WRZs were forecast to be 30Ml/d.

6.2.3 Discussion

Cost effectiveness

Water efficiency measures, such as water efficient devices and smart metering, are likely to be cost effective in all new developments, given that the up-front costs of installation will be comparable to installation costs of equivalent non-efficient devices. An important consideration is the extent to which water efficient devices meet consumer expectations of quality and performance. For example, low-flow showerheads save significant water but if they do not meet householders expectations, they may simply be replaced once the occupier moves in. Any standards should take this into account, and ensure that developers install devices that achieve excellent performance (e.g. high pressure) as well as water efficiency. This might add slightly to

[28] Nathan Richardson personal communication

installation cost, or reduce water efficiency slightly, but the water saving benefits could outweigh these costs many times over if it means the devices are not replaced.

Our high-level calculations for rainwater harvesting, greywater reuse and blackwater reuse for large-scale installation (>5000 properties) suggest a minimum unit capex for these options of £24 per l/d. Smaller developments would incur higher costs for local reuse. Typical unit capex for non-selected supply-side options within one WRZ of OxCam at WRMP19 was £15 per l/d, such that on economic grounds alone, local water reuse may not be cost-competitive with supply options. However, it should be noted that the costs of alternative supply-side options available now may be significantly higher than at WRMP19, the marginal cost may be significantly greater than the average, and the costs of transferring water from potential new sources to new developments may also be significant. Supply-side options can also take considerable time for delivery, and carry various risks and issues, as discussed further below.

Conventional demand management capex is comparable with supply-side option capex, such that water offsetting is likely to be more economically viable. Our calculations suggest it could be feasible to deliver sufficient offsetting through water efficiency measures alone, but this is very dependent on the degree to which local efficiency reduces demand in new properties, and the effectiveness of retrofitting to reduce demand at existing properties.

If water neutrality is designed in a way that offers benefits beyond maintaining the supply demand balance during drought, e.g. flood risk mitigation through rainwater harvesting, reduced phosphorous loading to rivers through blackwater reuse, or reduced carbon emissions in normal year conditions not accounted for in WRMP carbon costing, then alternative funding mechanisms could be sought to help pay for water neutrality measures.

Definition of neutrality

As described in Section 6.2.1, there is as yet no fully established definition of water neutrality. The following questions remain to be answered:

- Over what timescale neutrality should be delivered?
- Over what spatial scale should neutrality be delivered?
- Should water neutrality be defined in terms of specific seasons, or dry weather conditions?

To avoid any risk of damage, any offsetting of additional demand should occur no later than the increase in demand, such that there is no net increase in abstraction at any time.

The majority of household water demand in the OxCam Arc is non-consumptive, i.e. the water used is returned to the environment as treated final effluent, which could be viewed as achieving a degree of neutrality by definition. However, this neglects the following potential issues:

- Abstraction may occur upstream of discharge points, such that sensitive water body reaches in the upper or mid catchment are impacted even if net flows in the lower catchment are unchanged. Abstraction and discharge points may be in entirely different water bodies some distance apart, guaranteeing some impact.
- Discharged water may be significantly different in terms of water quality and temperature to abstracted water, so even if flows are unchanged, the environment may be negatively impacted.
- Even if abstraction is matched by river augmentation discharges upstream, this augmentation may be ineffective if groundwater abstraction affects the water table such that augmented water is lost through the riverbed. Multiple streams, ponds or lakes could also be affected even if the main river is not.

Even if neutrality is achieved through demand offsetting (retrofitting other households), many of the risks above would remain valid if the reduced demand used for offsetting impacts different abstraction sources to those impacted by the new development. This could be the case even within a water resource zone, depending on network constraints.

As with any solution based on demand management, offsetting will need to recognise that it is susceptible to system shocks like dry weather, Covid etc. An evaluation of these risks should be a requirement of any water neutrality policy, e.g. performance during drought conditions.

Higher flows of water are not always a desirable outcome. Storm overflows and flooding are two negative consequences of increased flow in the system. The value of increased flow of water very clearly depends on timing: additional flow may be very valuable at certain times, and actively harmful at others. Defining neutrality without regard to this time-variation in value is would therefore be a missed opportunity.

Additional storage of water, or transfers of water from areas of surplus to areas of deficit, could represent water neutrality in that the net flow of water in dry weather after any new development is no less than before the development takes place. In fact, new storage could deliver net gain for dry weather flows, by enabling reduced abstraction or increased augmentation at certain times of year. However, this also needs to take account of the local effects around water quality, hydrogeology, groundwater/surface water interaction as described above.

Interventions such as Chalk Streams First have the potential to deliver net gain for the environment by moving abstraction from locations of significant impact to locations where impacts on the environment are minimised. These schemes are water neutral in the sense that the volume of water leaving the catchment is unchanged, but abstraction within the catchment is optimised to return protected areas to as natural a condition as possible.

The Natural England definition of neutrality states that “development must be equal to or less than total water use”. Achieving an overall reduction in water use as a result of new development (going beyond neutrality) could be achieved through offsetting, and this could be used to further improve resilience and provide net benefits to the environment. The Environment Act (2021) specifies a minimum 10% gain for new developments calculated using a Biodiversity Metric. This could be used as a basis for a similar level of net reduction in water demand in water neutrality guidance.

Definition of offsetting

Demand management is already undertaken in company WRMPs. “Reducing how much water is put into supply by water companies” is a best-value criterion in WRSE investment planning, which is likely to drive demand management to beyond that specified in a “least cost” plan. The System Mapping undertaken for the OxCam IWMF has shown how complex the water system is. More investment to reduce demand may deliver less environmental net gain than the same investment in other intervention types. Consideration should be given with regards to the definition of offsetting, and whether more social and environmental benefit could be derived from alternatives to reduced water demand. For example, investing in catchment management or river restoration to increase flows, improve water quality and reduce flood risk, combined with new storage reservoirs, higher abstraction at high flows and no increase in abstraction at low flows could deliver more environmental benefit than simply reducing demand for water. Offsetting could be used to finance this type of catchment-based solution, rather than to pay for retrofitting of properties to reduce demand.

In defining acceptable offsetting, it is important to note any legal obligations driving water neutrality. If one of the drivers for a particular development is to protect a Natura 2000 site, or avoid deteriorating a water body, then the benefits of offsetting must be targeted to ensure there is no net change in flows at the Natura 2000 site or water body at risk from the development. This could be guaranteed if offsetting ensures no change in abstraction at any source (rather than “netting off” abstraction increases and decreases at different sources).

Another factor to consider is that different option types come with different risks and opportunities. We set out a high-level comparison of the benefits, opportunities, downsides and risks/issues of different option types in Table 6.3 below.

Table 6.3: High-level comparison of different option types that could contribute to offsetting

Option	Benefits	Opportunities	Downsides	Risks/Issues
New Reservoir	Operational simplicity System resilience Recreation	Flood mitigation Habitat restoration Agricultural support Net low flow increase	Long lead time Aesthetics Traffic Habitat loss	Planning approval Local opposition
Desalination	Small footprint	Renewable power on-site. Hydrogen production.	Operational complexity & carbon Brine impact	Slow ramp-up
Bulk transfers	Maximise use of existing resources Net benefits from conjunctive use/drought coherence benefits.	Improved resilience to other supply risks	Operational carbon can be high	INNS transfer (raw water)
Effluent Reuse	Water neutral (flow) within catchment	Net low flow increases upstream	Downstream impacts on flow & quality	Concentration of chemicals
Rainwater harvesting	Reduced operational cost/carbon Zero lead time	Flood mitigation Cost reduction if scaled up		Health risks (water quality) Financing capex
Grey water reuse	Reduced operational cost/carbon Zero lead time Reduction in new WW	Flood mitigation Cost reduction if scaled up		Health risks (water quality) Financing capex
Black water reuse (non-potable direct reuse from the WwTW)	Water company operation – reduced risks Reduced operational cost/carbon Net reduction in WW	Flood mitigation Improved WW quality (upgrade WwTW alongside blackwater investment)	Downstream impacts on low flow volumes	Public perception
Water efficiency	Zero embodied carbon and reduced operational carbon emissions More water available for the environment			Less scope for demand-side drought action.
Reduced leakage	Reduced operational carbon emissions More water available for the environment Encourages customer behavioural change	Improved distribution network can provide resilience benefits (e.g. to freeze/thaw events)	Costs can rapidly increase as leakage levels decline	Less water returned to the environment could cause local environmental impacts
Catchment Management	Targeted measures can achieve most value for the environment. Secondary benefits can be very significant.	Multiple secondary benefits can be obtained	Water availability/ deployable output benefits often difficult to quantify	Funding mechanisms can be challenging.

Blackwater reuse feasibility

For blackwater reuse, the constraints on maximum contribution to water neutrality are as follows:

- Non-potable demand
- Environmental flow surplus

Risks around micro-contaminant accumulation and public perception mean that direct effluent reuse can only be used for non-potable purposes. Therefore, non-potable demand places an upper limit on the benefit of blackwater reuse.

Where non-potable demand is consumptive, i.e. not returned to the WwTW as effluent, blackwater reuse is also constrained environmentally by the maximum volume of effluent that can be withdrawn from the fluvial system. Environment Agency WRGIS data provides an indication of to what extent effluent flow is required to maintain good water body status. The Environment Agency calculate surplus/deficit to the Environmental Flow Indicator for both Fully licensed and Future Predicted Scenarios under the BAU and Enhanced 2050 National Framework scenarios.

Any water bodies identified as being in deficit are unlikely to be appropriate for any consumptive blackwater reuse. Therefore, the feasibility of direct reuse for irrigation, gardening and many outdoor activities is likely to be very low in these water bodies. In these water bodies, direct reuse may only be environmentally acceptable for toilet flushing and potentially washing machines. However, the Ofwat study (2018) suggests that external use could be minimised through use of water butts, so that consumptive use constraints on blackwater reuse are minor. Nonetheless, any requirements specified under IWM should include a consideration of low-flow deficits and consumptive use.

Potential carbon savings

A carbon cost is specified for all new options to meet supply demand deficits as part of the WRMP process, with net present costs calculated in line with HM Treasury Green Book guidance. At WRMP19, the net present carbon cost of new options varied between £0.01 per litre/day and >£20 per l/d. For a household saving 120l/h/d through water efficiency measures, the potential net present economic benefit of carbon savings could exceed £2000, although there is very significant uncertainty in this estimate.

Reuse options would result in carbon emissions of their own. The only WRMP19 rainwater harvesting options with quantified carbon costs are specified by Affinity Water and South East Water. These have net present carbon cost of £0.17 per l/d and £0.2 per l/d respectively. The only greywater reuse option with quantified carbon cost was specified by South East Water with net present carbon cost of £0.04 per l/d. From this limited data, local reuse appears to compete effectively with alternative supply/demand options on the basis of carbon emissions.

The Environment Agency[29] has previously published evidence that 89% of carbon emissions in the water supply-use-disposal system are attributed to "water in the home", including the energy for heating water (excludes space heating), which compares with public water supply and treatment emissions of 11 per cent. Therefore, options for water neutrality that reduce hot water consumption would have a particular carbon benefit compared to alternative efficiency measures.

Waterwise estimates that, "a 10-12% reduction in household water use could reduce greenhouse gas emissions by a similar amount to the total operational emissions of the whole UK water sector (circa 2.4 MtCO2e)." They note that, "Carbon emission savings through greater water efficiency will be particularly

[29] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291728/scho0708bofv-e-e.pdf

important in the decade or two until energy supplies are decarbonised and our homes have moved away from using fossil fuels to heat water."

Link to spatial planning

Recent experience in the Sussex North Water Resource Zone (WRZ) suggests that some LPAs in the South East are already working towards addressing the need for water neutrality, both in terms of developing a mitigation strategy and Local Plan policy additions and changes.

The OxCam IWM Framework (IWMF) will need to set the context for planning policy interventions in the Arc that relate to the four sub-systems so that they can be reflected in Oxford-Cambridge Arc Spatial Framework currently under development and LPA Local Plans that form the next tier of planning policy below the Spatial Framework.

The process in developing a Spatial Framework for the Arc Creating commenced in February 2021 with the government publishing a Policy Paper that set out how they intend to develop a Spatial Framework to help realise the ambition to support sustainable economic growth in the Oxford-Cambridge Arc. A document entitled 'A vision for the Oxford-Cambridge Arc', was issued in July 2021, together with an SA/SEA Scoping Report, for which consultation ran from 20 July 2021 to 12 October 2021. The results of that consultation are yet to be issued and no further documents or news updates have been issued by DLUHC since then.

Given the uncertain progression of the Spatial Framework, the OxCam IWM Framework (IWMF) will need to explore the extent to which it encourages (or stipulates) planning policy at Arc (via the Spatial Framework) or LPA (via Local Plans) level. Paragraphs 1.2, 1.7 and 1.10 of the Spatial Framework Vision explain that "*the Spatial Framework will form national planning policy and transport policy for the Arc and local planning and local transport authorities must have regard to it when preparing local transport and local development plans and policies, and it will be capable of being a material consideration in relevant planning decisions in the area".* The intended 'have regard' duty means that it may not be necessary for Local Plans to repeat national planning policy on water issues for the Arc (including water neutrality) that is set out in an Arc Spatial Framework.

Given the importance of the planning system in managing and controlling the majority of development that will form part of the Arc proposals, it seems prudent to seek to set strong and clear policy requirements in the Arc Spatial Framework, particularly for issues such as water neutrality that are novel, challenging for the development sector and unlikely to be addressed in any current Local Plans covering the Arc. The wording of policy will need to carefully balance the intended aims and outcomes of water neutrality with commercial considerations so that the policy is proportionate and does not unduly hamper the development industry, given the importance of realising the overall Arc aims.

In the event that no spatial planning framework is established, LPAs will need to work closely together to define and coordinate solutions to common constraints within a catchment where it is likely that one LPA will hold the solutions to another LPA's constraints - e.g. in flood risk or water/nutrient neutrality.

Long-term delivery

Water neutrality is not guaranteed to remain permanent: efficiency of use, whether through efficient appliances or behavioural change, and/or reuse may decline over time, both for the development itself and any offsetting measures, whether they are based on retrofitting, behavioural change or on alternative measures, such as catchment management or new storage. Ensuring permanency of the desired outcomes requires mechanisms for monitoring and enforcement, either through regulation or incentivisation. Incentivisation could be in the form of delayed payments to developers or occupiers, or with water bill incentive mechanisms. For example:

- A water company could charge developers a fee for delivering the equivalent capex of new supply/demand options, assuming that long-term efficiency is 125 l/h/d.

- The developer pays for its optimum portfolio of water neutrality measures, and passes both sets of costs on to the home buyer.
- The home buyer then receives bill rebates based on actual water saved each year. Smart water meters could be used to monitor water efficiency savings on a daily basis to encourage behavioural change.
- For any subsequent home sales, the up-front cost is passed on to the next buyer, less any rebates received.

This and any other options for ensuring long-term neutrality should be explored further. The OxCam IWMF also needs to set out what measures would be taken if water neutrality fails to deliver: for example, this could lead to reducing planned housing growth, or delaying development until sustainable supply options can be developed.

Delivery timescale may also be affected by the neutrality driver. If some aspects of neutrality are intended only to protect a Natura 2000 site or water body from deterioration due to a local abstraction, then time-limited neutrality for these aspects could be acceptable if the abstraction can be replaced by alternative water resources after a certain time period.

Further work underway

Imperial College is currently undertaking an evidence-based approach to develop a “Water Neutrality Index”, which covers both water quantity and quality.

Affinity Water is undertaking a £2.9m pilot study under Ofwat’s “Water Breakthrough Challenge”, to, “deliver a sustainable, water-saving solution in response to new housing developments being built … to minimise water demand and offset water consumption with new technologies, to ensure the total water use in three communities remains the same as it was before the new homes were built.” The project is “spread across three clusters of 1,000 homes to better distribute risk… gauging different approaches at different sites”. The approach at each of the three groups is as follows:

- Site 1: technology installation in residential homes – for instance water efficient shower heads and washing machines, water saving tap fittings, rainwater harvesting systems and alarming of overflowing toilets.
- Site 2: community-based approaches such as the installation of grey water re-use systems and commercial grade toilet systems at non-residential properties and the use of community liaison officers to drive customer behavioural change
- Site 3: hybrid solution comprising approaches from sites one and two, with the aim of understanding the strength of impact of both approaches at scale, and whether one approach provides the necessary benefits or if a combination of both is required

Residents will “be able to monitor water usage via a bespoke app… which will also allow detailed monitoring and analysis of anonymised trial data…, layer technology data from multiple sources to form a single view of customers water usage, provide behavioural “nudge” and enable remote monitoring and preventative maintenance for devices and technologies.”

The stated objectives are to “save” 112,000 litres per year per home, equivalent to 300l/d, though it is unclear how much of this is to be delivered through reductions in local demand and how much through offsetting.[30]

6.2.4 Summary

- Water neutrality for the OxCam Arc development scenarios assessed is technically feasible overall, but would be very challenging to achieve, is highly dependent on the PCC reductions delivered at retrofitted

[30] https://utilityweek.co.uk/achieving-water-neutrality-across-3000-new-homes/

properties (and hence on customer willingness to change behaviour), and significantly dependent on the PCC achieved locally by new Arc properties
- A combination of local water efficiency and water offsetting is economically viable and likely to be affordable for new residents (cost <1% of property price)
- Rainwater harvesting, greywater reuse and blackwater reuse are likely to be more expensive than offsetting under most scenarios, when assessed only from a water resources basis. They would be most appropriate for large developments with higher levels of external use, for properties that cannot or do not want to achieve low levels of consumption by other means. However, they may offer benefits beyond maintaining the supply demand balance in drought, such as flood risk mitigation, operational carbon savings and reduced wastewater pollution. Alternative funding mechanisms could be sought to account for these benefits.
- The primary driver for neutrality is where an increase in abstraction places unacceptable pressure on designated sites or water bodies sensitive to abstraction. This will in most cases be a temporary problem, where the 5 yearly WRMP process of maintaining the supply demand balance subject to environmental constraints cannot keep pace with new development. However, the ability to transfer water between WRZs at relatively low cost means that even where there is no local impact of abstraction on sensitive sites, any increase in demand will negatively impact the system as a whole. This highlights the essential nature of the duty for LPAs to cooperate whereby WFD failure can be triggered from changes anywhere in the system. It would be economically efficient for new developments to account for the marginal costs of delivering new water resources to the region from their additional demand.
- For neutrality to be effective, it is critical to consider whether offsetting will enable no increase in abstraction from any water source, or whether increase in abstraction from one source will be offset by reductions from a different source. In the latter case, environmental damage may still occur local to the increased abstraction.
- Constraining offsetting to reducing demand for water does not necessarily provide best environmental or social value. Different option types each come with their own benefits, downsides, opportunities, risks and issues. Offsetting could be redefined in terms of measures which deliver maximum environmental net gain, at least as much as would be delivered by equivalent demand reduction against every one of a specified set of outcomes. However this must be done taking account all possible effects of increased abstraction, changes in water quality, hydrogeological interaction, impacts on all hydrologically sensitive features in a catchment (e.g. ponds, small streams), etc.
- Water neutrality is not guaranteed to remain permanent: efficiency of use and/or reuse may decline over time, both for the development itself and any offsetting measures. Ensuring long-term neutrality requires mechanisms for monitoring and enforcement, either through regulation or incentivisation, e.g. rebate payments over time. The OxCam IWMF also needs to set out what measures would be taken if water neutrality fails to deliver, for example, delaying further growth until such time as new water resources can be delivered to mitigate any damage already caused.
- A portfolio of options in combination (e.g. appliances, behavioural incentives, local reuse and different types of offsetting) may help to minimise risks of declining neutrality over time. It would also help to identify the most effective interventions to deliver neutrality, enabling an evidence base to be built to test alternatives against one another.
- Mechanisms to ensure long-term neutrality should be further investigated and specified in policy.

6.3 Nutrient neutrality

6.3.1 Background

Nutrient neutrality is a concept that is being promoted as ‘a means of ensuring that development does not add to existing nutrient burdens’[31]. The concept followed a European Court of Justice judgment in November 2018, the so-called 'Dutch Nitrogen Case', which in effect set new, higher environmental standards for developers to protect sensitive habitats from the impacts of elevated nutrients from wastewater discharges. Following the judgement, in SACs, any new development must comply with the EU legislation that sets the recommended limits for nutrient levels in the water.

In practice this means that all developments in affected areas will have to demonstrate nutrient neutrality by ensuring that nutrient load generated from the development is less than or equal to the nutrient load generated by existing land use. This ensures that development does not add to existing nutrient burdens to designated sites, and this provides certainty that the whole of the scheme is deliverable in line with the requirements of the Conservation of Habitats and Species Regulations 2017.

Affected areas are any management catchments which contain internationally and European designated sites including SAC, SPA and Ramsar sites formerly identified as Natura 2000 (N2K) catchments in unfavourable conditions. These are sites protected under the Conservation of Habitats and Species Regulations 2017 and are often failing due to elevated nutrient levels.

The same compliance principle applies to WFD as it does to the Habitats Regulations, as for example demonstrated in German ECJ caselaw C-461/13. A collective failure of LPAs leading to too much nutrient (or too little water resource) would lead to WFD failure. This would and should drive neutrality in a very similar way to damage to protected sites.

Many nutrient-related failures are driven by flooding: for example most failing Habitats sites fail due to nutrients entering sites via flooding. However, if we tackle flooding (flood less often and less severely) the Habitats sites could recover with the same nutrient load in the watercourse, for example as demonstrated at Portholme Meadow SAC/SPA.

Natural England issued guidance initially to councils within the Solent catchment area on the South Coast and have now issued guidance to a total of 20 local authorities which cover Kent, Cornwall, Somerset, Wiltshire, Gloucestershire and Herefordshire[32]. Natural England has advised that permission cannot be legally granted for developments that are not nitrogen and phosphorous neutral, calling into question the delivery of enough new homes to meet housing need in these areas. According to the LPAs, the total housing need in the affected areas amounts to 33,700 homes per year. According to a study by Savills[33], the volume of new homes being delivered in the Solent region could fall by 50-70% from existing levels, as a direct result of nutrient neutrality unless mitigation schemes are established.

It is recognised that many WwTWs within the OxCam region are close, in their current capacity, to achieving their TAL. The TAL is defined for each nutrient as the lowest nutrient concentration that can be reliably achieved by existing wastewater treatment technologies. Where WwTW permit nutrient limits are at or near TAL, any increased demand on the wastewater system associated with new developments may result in increased nutrient load entering receiving water bodies from final effluent. Nutrient neutrality would entail offsetting the additional load from WwTW final effluent by reducing nutrient inputs from other sources, ensuring no increase to the current nutrient burden entering the water body.

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[31] https://www.push.gov.uk/wp-content/uploads/2020/06/Natural-England%E2%80%99s-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf

[32] https://www.savills.co.uk/research_articles/229130/319723-0https://www.savills.co.uk/research_articles/229130/319723-0

[33] https://www.savills.co.uk/research_articles/229130/319723-0https://www.savills.co.uk/research_articles/229130/319723-0

6.3.2 Analysis

Natural England approach to nutrient neutrality

Natural England's approach to nutrient neutrality advises that a nitrogen budget is calculated for all new developments that have the potential to result in increases of nutrient, specifically nitrogen, in entering designated sites. A nutrient budget is used to determine with sufficient and reasonable certainty that the development does not adversely affect the integrity, by means of impacts from nutrients, on the relevant internationally designated sites[34]. This would allow the total nutrient load per annum derived from the development that would exit the WwTW to be calculated. This load would be adjusted to account for existing nutrient inputs from current land use and to account for land uses proposed within the development. If there is a nutrient surplus calculated from the net change that would result from the development, then mitigation would be required to achieve neutrality. The purpose of the mitigation measures is to avoid impacts to the designated sites, rather than compensating for the impacts once they have occurred, by achieving net zero nutrient burden.

Natural England calculate the net change in nutrient load via four stages as follows:

7. Calculate Total Nitrogen (TN) in kilograms per annum derived from the development that would exit the WwTW after treatment
    a. Calculate additional population
    b. Confirm water use
    c. Confirm WwTW permit and treatment level
    d. Calculate Total Nitrogen (TN) in Kg per annum that would exit the WwTW after treatment derived from the proposed development
8. Adjust nitrogen load to account for existing nitrogen from current land use
9. Adjust nitrogen load to account for land uses with the proposed development
10. Calculate the net change in the Total Nitrogen load that would result from the development

We apply this approach at a high level to calculate an approximate net change in nitrogen load for a likely scenario of OxCam Arc additional development. A similar methodology would be needed for phosphorous when determining actual nutrient neutrality.

Potential nitrogen net change

A high-level calculation to illustrate the potential net change in nitrogen load that could result from the proposed development in the OxCam arc has been carried out in line with the Natural England approach[35]. The results are presented in Table 6.4 below, including any assumptions.

Table 6.4 Stage 1: estimated total nitrogen load from OxCam Arc development wastewater

Step	Value	Note on data uncertainties
1) Calculate additional population	1300000	• AECOM (2019) 1.3 million people. WRMP19 2.3 average occupancy rate for OxCam: • 540k additional properties.
2) Confirm water use level (l/h/d)	110	The dwellings shall not be occupied until the Building Regulations Optional requirement of a maximum water use of 110 litres per person per day has been complied with." (Natural England , 2020)

[34] https://www.push.gov.uk/wp-content/uploads/2020/06/Natural-England%E2%80%99s-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf

[35] https://www.push.gov.uk/wp-content/uploads/2020/06/Natural-England%E2%80%99s-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf

Step	Value	Note on data uncertainties
3) Receiving WwTW environmental TN permit limit. (mg/l)	9	This would require verification. 9 mg/l has been used as an example concentration permit that may be in place at a WwTW across the OxCam region. Of course, there may be individual works that have stringent guidelines and those that do not currently have a permit.
4) Calculate Total Nitrogen (TN) in Kg per annum that would exit the WwTW after treatment derived from the proposed development	6.1	Assume discharge to be at 90% of consent limit. Deduct acceptable TN loading (2 mg/l TN)
Result: Tonnes/TN/Year	**318**	This number is indicative only with key assumptions on land use change, future permits and assumed nutrient loading.

Source: Nitrogen losses from Natural-England's-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf (push.gov.uk)

An estimate of the impact of changes in land use is presented in Table 6.5 and Table 6.6. A study commissioned by Natural England from ADAS modelled the nitrogen loss for different farm types across the river catchments that drain to the Solent, which specifies losses of between 25 kg/ha (general cropping) and 70 kg/ha (pigs and poultry).[36] Assuming an average housing density of 100 units per hectare and 540,000 new properties implies 5,400 hectares of development. If all of this development replaced general cropping land, the total avoided nitrogen load would be 135 tonnes/year.

Table 6.5 Stage 2: estimated total nitrogen load from current land use

Step	Value	Note on data uncertainties
1) Total area of existing agricultural land (ha)	5,400	Assume average housing density 100 units per ha and 540,000 new properties.
2) Identify farm type and confirm nitrogen loss (kg/ha/yr)	25	Natural England study (ADAS modelled) suggests losses of 25 kg/Ha for general cropping
3) **Nitrogen load from current land use Tonnes/TN/Year**	135	Multiply area by nitrogen loss

Source: Nitrogen losses from Natural-England's-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf (push.gov.uk)

Table 6.6 Stage 3: estimated total nitrogen load from future land use

Step	Value	Note on data uncertainties
1) New urban area (ha)	5,130	Assume average housing density 100 units per ha and 540,000 new properties.
2) Nitrogen loss from future urban area (kg/ha/yr)	14	From sewer overflows and from drainage that picks up nitrogen sources on the urban land
3) New SANG / open space	270	Assume 5%
4) Nitrogen loss from SANG / open space (kg/ha/yr)	5	Nitrogen loss draining from new designated open space or Suitable Alternative Natural Greenspace (SANG)
3) **Nitrogen load from future land use Tonnes/TN/Year**	73	Sum of products of areas and nitrogen loss

Source: Nitrogen losses from Natural-England's-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf (push.gov.uk)

Making all the assumptions listed above, the high-level estimate for net change in nitrogen loading from OxCam Arc additional development of 540,000 properties would therefore be 256 tonnes nitrogen per year,

[36] Natural-England's-latest-guidance-on-achieving-nutrient-neutrality-for-new-housing-development-June-2020.pdf (push.gov.uk)

once all properties are occupied. The spatial distribution of offsetting capacity is presented in terms of “equivalent property numbers” in the hotspot analysis in Annex D.

Using Natural England’s range in nitrogen loading from farmland of 25kg/ha to 70kg/ha, a range in area of farmland required to offset 256 tonnes of additional nitrogen from OxCam Arc development would be between 3,570 and 10,000 hectares, if the agricultural nitrogen loading was removed entirely from the land. The total area of the OxCam Arc is 1,148,541 hectares (all land types), with 707,000 hectares arable land and 235,000 pasture. 10,000 hectares is c.1% of the total arable and pasture land combined of the OxCam Arc.

We also sensitivity test the analysis to key assumptions. 9mg/l is at the lower end of WwTW permitted concentrations specified in the Natural England tool. The upper end is 27mg/l, which results in net nitrogen loading from OxCam new development of 1200 tonnes per year. Halving the land use change nitrogen savings, net loading could conceivably be 1,400 tonnes per year. This could increase total required area of land for offsetting to c.50,000 hectares, c.5% of OxCam total arable and pasture land.

We note that baseline growth forecast for OxCam WRZs is approximately equal to the additional growth values assessed here. Therefore, to offset all the additional nutrient load of all properties would require approximately double the land area assessed here.

This analysis assumes no contribution to neutrality from treatment upgrades or wetland solutions, and also assumes all nutrients must be offset. In reality, this would not be the case, and required offsetting areas would decrease as a result.

Potential nitrogen offsetting

Assuming an agricultural land value of £20,000 per hectare, the cost of offsetting, based on a 9mg/l wastewater nitrogen permit limit, would be £200 million, or c.£370 per new property. This assumes the land has zero value after nitrogen loading is removed, which of course would not be the case. For example, the UK natural capital accounts put the total value of woodland ecosystem services at £3.3 billion in 2017[37] from a total woodland area of 3,719,000 hectares, excluding any benefits to water quality. This represents a value of £1,000 per ha per year, equivalent to a net present value of c.£20,000. Therefore, even without allowing for water quality benefits, Grade 1 arable land could be converted to woodland at only the cost of tree planting and woodland management, although impacts on national food security should also be considered.

Higher treated nitrogen wastewater concentrations would mean more land required for offsetting, which would increase cost. For detailed offsetting decisions, a comparison of treatment with alternative offsetting approaches would be required.

This analysis also ignores any seasonal effects, such as agricultural loading being lower in the summer and higher in the winter. This again could increase the area of land required for offsetting.

Lastly, this evaluation also does not take account of food security considerations. Current land values provide an indication of the economic value of food production, but they are based on current global food production and distribution capacity. If UK access to global food is reduced for any reason, then the value of UK land for food production may increase.

Phosphorous offsetting

Defra’s Farmscoper[38] data suggests that average phosphorous losses from agricultural land (kg/ha) are an order of magnitude lower than nitrogen losses by mass. However, the technically achievable limit for phosphorous in treated wastewater effluent is an order of magnitude lower than the 2 mg/l nitrogen

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[37] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/woodlandnaturalcapitalaccountsuk/2020#asset-value-of-woodlands

[38] https://catchmentbasedapproach.org/learn/farmscoper-tool/

concentration used in the nitrogen neutrality calculation. Therefore, it is likely that phosphorous offsetting would be feasible with similar land change requirements as specified above for nitrogen.

We test this further using Cornwall County Council's Phosphate Budget Calculator[39]. This shows that for a WwTW with discharge concentration of 0.9 mg/l, an area of land between 10,000 and 50,000 hectares would be necessary to offset the additional phosphate load from 500,000 new properties. The calculation is very sensitive to how freely draining is the soil (and hence how much phosphate runs off the soil and into surface water bodies, and how much is lost to groundwater, which is deemed to be an acceptable mitigation for phosphate). This suggests that converting up to c.5% of arable and pasture land in the OxCam Arc to land without phosphate runoff could enable nutrient neutrality for all new development at the level of the Arc on an annual basis. The situation will be more complex locally, and it may not be possible to offset all nutrients in certain catchments. It also does not account for seasonal effects, as discussed further below.

Potential mitigation measures

Nutrient neutrality means that affected developments must calculate their nutrient impact from wastewater and counterbalance through mitigation. Natural England[40] specifies the key benefits of nutrient neutrality to be:

- Developments can proceed without causing any further deterioration to designated sites.
- Potential to provide multiple benefits to the natural environment and community.
- Permanent contribution to Nature Recovery Network (NRN)[41] outside of designated sites

Although the identification of potential mitigation measures will have to be done on a case-by-case basis, these are likely to include a combination of traditional treatment solutions (e.g. upgrades to WwTWs) and catchment management options. Catchment options can include interventions aimed at reducing nutrient load from agricultural activities, urban runoff and sewage.

Catchment mitigation options as an alternative to increased or improved treatment capacity could include the following:

- **Treatment wetlands:** A more sustainable and potentially more cost-effective alternative to traditional tertiary treatment solution. Treatment wetlands including integrated constructed wetlands can be deployed on site or at discharge point. They are constructed ecosystems containing aquatic emergent and marginal vegetation that use biotic and abiotic processes to treat nutrients and provide a multitude of wider environmental and social benefits, including reduced flood risk and sediment loading. Reduced frequency of flooding to reduce the sediment and nutrient load entering protected sites may in itself solve the problem driving unfavourable status. The site footprint could be significant and would need to be taken into account in any nutrient offsetting calculations.
- **Sustainable Urban Drainage Systems (SuDs):** These can be deployed in urban areas to capture and filter urban runoff, slow the flow and reduce the particulate pollutant load entering the main watercourses. Examples of SuDS include porous pathways, soakaways, tree planting, filter strips, swales, green walls. For offsetting wastewater nutrient loads, SuDs would have to be delivered to mitigate existing runoff, not additional runoff from the new development. We note that the type of SuDs is important in terms of impact on water quality: here we are primarily referring to "Green SuDs", which generally improve water quality, whereas "Grey SuDs" can result in water quality problems for groundwater.
- **Reducing nutrient loads from agricultural land and farmyard:** This can include a wide range of mitigation measures, including:

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[39] Nutrient neutrality in Cornwall - Cornwall Council

[40] Natural England standard PowerPoint template (local.gov.uk)

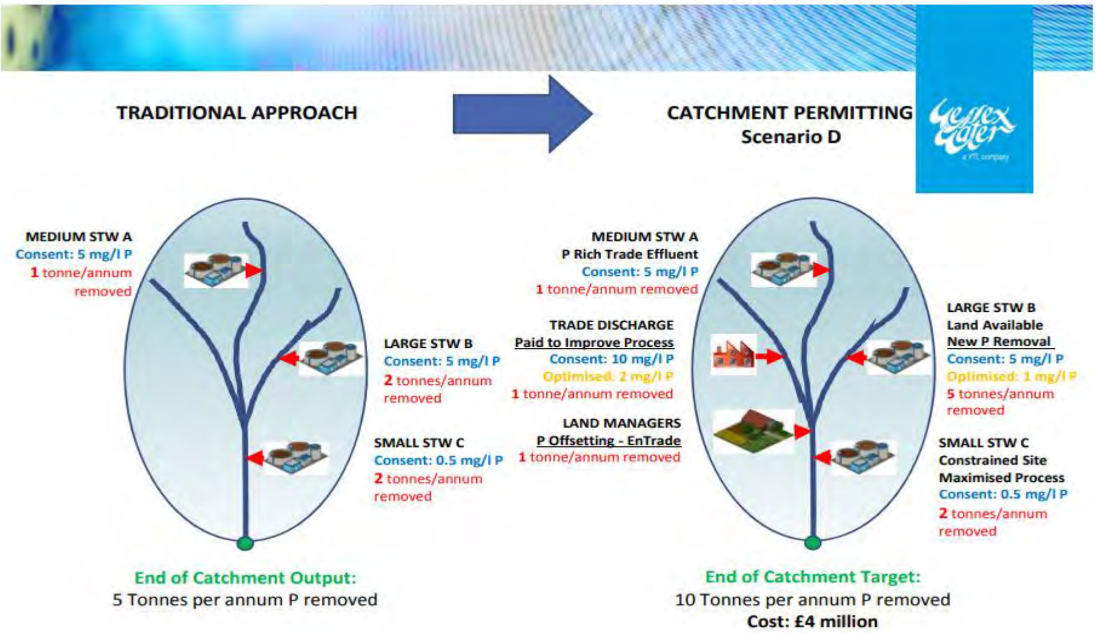
[41] The NRN is a national network of wildlife-rich places and a major commitment in the government's 25 year environment Plan and part of the forthcoming Nature Strategy.

- On farm nutrient budgeting to optimise use of fertiliser and reduce nutrient loss
- Improve soil health to reduce risk of surface runoff
- Avoid manure application in areas prone to surface runoff and direct connectivity with water courses
- Woodland creation
- Wetland or active floodplain creation with the aim to intercept flows and sediments as well as providing a mean to reduce nutrient input to the main watercourse.

- **Catchment permitting (CP):** The linking of two or more permits in a catchment to achieve water quality objectives. It allows the water company to take a more flexible approach at reduced regulatory risk. It is a concept that has been discussed widely over recent years. In the right circumstances CP has the potential to reduce cost and achieve more for water quality compared to conventional permitting. (Environment Agency 2020). A catchment permitting trial has been undertaken in the Bristol Avon catchment, involving 24 WwTWs. "Each WwTW has been assigned a 'stretch target' for phosphorus load reduction expressed in tonnes per year with an annual reduction target of 46.6 tonnes for the whole catchment (this is in addition to existing load reductions). Investment under this trial is £20M lower than the traditional approach (capital investment at all sites)."[42] Interim results after the first 6 months of the trial in 2017 claimed to show a reduction of approx. 37 tonnes of phosphorus per year.

A diagram showing how catchment permitting can work is presented in Figure 6.2 below.

Figure 6.2: Catchment Permitting Example Diagram



Source: Wessex Water http://www.waterindustryforum.com/documents/uploads/Catchment%20Mgt%20EXAMPLE%202%20-%20Wessex.pdf

Table 6.7 provides a summary of the potential benefits, opportunities, downsides and risks/issues of upgraded physical infrastructure compared to integrated catchment solutions.

[42] https://conferences.aquaenviro.co.uk/wp-content/uploads/sites/7/2017/08/Lydia-OShea-Wessex-Water-PAPER.pdf

Table 6.7: Overview of the principal mitigation types for nutrient neutrality

Measure	Benefits	Opportunities	Downsides	Risks/issues
Upgrade treatment works, sewers and storage tanks	• Clear outcomes • Operational simplicity	• Can be achieved on owned land and not reliant on third party stakeholder collaboration.	• May not be enough to achieve nutrient neutrality • Potentially high cost • Carbon intense solution • Aesthetics • Odour • Constrained by technologically achievable limits	• Planning approval • Public perception • Climate change and future population growth may cause additional pressure on existing sewage network, meaning nutrient benefits can be temporary and lost to other pressures
Integrated catchment solutions	• Contributes to catchment resilience • Biodiversity net gain • Amenity, aesthetic and recreational value • Cost efficiency • Reduced OPEX costs • Aligns to Defra's 25-year plan for Natural Capital objectives • Reduced soil loss and riverine sediment	• Integrated approach – has the potential to address multiple drivers • Flood mitigation • Potential carbon sequestration and flood resilience co-benefits • Potential to link to climate emergency pledges • Wider water quality benefits • Co-benefits with flood resilience	• Outcomes may be less certain than for conventional treatment • Long lead time • Funding mechanisms more complex • Needs careful monitoring to ensure benefits not double counted, and to establish accurate baseline: shouldn't count bad to good practice as offsetting	• Planning approval for some solutions • Third party reliance • Regulatory acceptance • Long-term commitment/maintaining momentum • Long term maintenance requirements • Climate change could reduce the effectiveness of some solutions, e.g. through higher winter rainfall

We note that phosphorus increases and subsequent mitigation are likely to be more challenging than nitrogen. No attempt is made here to quantify the additional phosphorus load or the scale of mitigation required. Stringent WwTW permit limits for phosphorus are often already in place, and more will likely follow ahead of the new development. Opportunities to utilise WwTW (treatment or wetland) mitigations could therefore be limited.

6.3.3 Discussion

Applicability to OxCam Arc

Although Natural England has not to date issued any guidance to the local authorities in the OxCam Arc, a nutrient neutrality approach is likely to be applicable for consideration in developments across the OxCam region, with 75 Natura 2000 sites across the management catchments, and all management catchments intersecting or hydrologically connected to an internationally designated site. The potentially large number of new properties forecast could lead to the requirement for significant mitigation measures to deliver nutrient neutrality and ensure that the new developments do not add to existing nutrient burdens on designated sites.

Taking an integrated approach to nutrient mitigation could help to deliver best value for stakeholders and the environment. This could mean assessing the potential to include treatment wetlands in the design of new or upgraded WwTW, including sustainable urban drainage systems in the designs of new developments (SuDS) and where applicable adopt catchment balancing approaches to offset for any increase in nutrient loads. Retrofitted SuDS and floodplain restoration could also be used as an offsetting option to achieve nutrient neutrality. In either case, water quality modelling should be undertaken to quantify the potential reduction in nutrient loading to the water body and any relevant Natura 2000 site, taking account of the impacts of infiltration on all possible receptors – both for nutrients and any other contaminants.

Definition of "nutrients"

The Natural England's latest guidance on achieving nutrient neutral housing in the Solent focusses on nitrogen, driven by compliance with the Conservation of Habitats and Species Regulations 2017. "There is evidence that inputs of both phosphorus and nitrogen influence eutrophication of the water environment. However, the principal nutrient that tends to drive eutrophication in the marine environment is nitrogen and this is supported by modelling and evidence… The best available evidence is for focus in the Solent harbours to be on nitrogen reduction, and reduction in both nitrogen and phosphorus in the Medina catchment. However, this approach may be refined if greater understanding of the eutrophication issue is gained by thorough new research or updated modelling."

We understand that Natural England are also applying the nutrient offsetting approach to phosphorous in several catchments (e.g. the Avon, Camel, Lugg). From the point of view of meeting WFD objectives on freshwater body status, phosphorous is of equal if not greater relevance: phosphorous is specified as a pressure impacting more water bodies than nitrogen.

Consideration should be given as to whether neutrality applies to all nutrients, and under what circumstances neutrality should be required: only where designated sites are at risk of impact or where nutrients are a potential driver of non-good water body status. The value of neutrality may vary for different nutrients in different locations, depending for example on what is the limiting nutrient for eutrophication. This should also be taken into account when deciding on how neutrality is achieved.

Need for nutrient neutrality

The primary driver for nutrient neutrality to date has been to ensure compliance with the Conservation of Habitats and Species Regulations 2017 to ensure recommended limits for nutrient levels in the water at Natura 2000 sites are not exceeded. However, SACs are not the only water receptors at risk of impact from increased nutrient loads. Other designated sites are also at risk, and the ecological, chemical and overall WFD status of many river and lake water bodies is currently constrained by nutrient loading. WFD status is now as important a driver behind nutrient neutrality as compliance with the Habitats Regulations.

Zero net increase in nutrient levels in a catchment resulting from a new development would not always be necessary to achieve water body or Natura 2000 site objectives, as some catchments may be able to absorb some increase in nutrient levels with no negative impacts on the status of any water body or designated site.

Further to this, where sites or water bodies are at risk, ambition should not necessarily be limited to no net increase in nutrient levels. A percentage reduction in nutrient levels, beyond baseline levels, could be desirable at these sites or water bodies, in the same way that new developments must now achieve 10% biodiversity net gain to comply with the Environment Act.

Similarly, interventions to mitigate the impacts of local development may be most effectively delivered in a water body further upstream. Dynamic whole-system water quality modelling could be used to determine the optimum set of interventions for a given development.

The simplest and clearest option might be to stipulate that nutrient neutrality be applied to meet legal and statutory obligations for no deterioration of any Natura 2000 site or water body, and once this risk is avoided, to deliver net gain for the environment associated with nutrient pollution, but allowing flexibility in where any measures take place: encouraging offsetting where it will deliver the greatest environmental net gain, or greatest improvement in water body status.

If nutrient neutrality was mandated everywhere, specifying all new development to pay for complete offsetting of 100% of additional nutrient loads, this could penalise development sites that are in locations where risks of nutrients are already low, therefore perversely failing to incentivise selection of these sites.

An important consideration for offsetting is the timing and seasonality of nutrient loading. Agricultural loading is more likely following heavy rainfall in autumn/winter period when the risk of eutrophication is lower. In contrast wastewater loading would occur year-round, including summer months when eutrophication risk is highest. Therefore offsetting summer wastewater loading with reduced annual total agricultural loading might not be sufficient to protect a Natura 2000 site or prevent water body deterioration. Offsetting might have to be specified on a monthly or seasonal basis.

Options for achieving neutrality

As discussed in Section 6.2, nutrient neutrality measures are likely to be a combination of traditional treatment or sewage capacity solutions and catchment solutions. Achieving nutrient neutrality will require mitigation measures that reduce nutrient concentration and/or flow within urban and/or rural areas. This could include treatment wetlands associated with existing or any new WwTWs to further reduce nutrient loads from sewage discharge but also smaller wetlands further upstream with the aim to intercept runoff and nutrients and “slow the flow” of discharge into water bodies.

Condition assessment of sites and features would need to be undertaken to understand the individual environmental context of the designated sites and thus the requirements for nutrient neutrality. However, Natural England advise a precautionary approach is undertaken when addressing environmental uncertainty and in calculating nutrient budgets. Therefore, nutrient budget calculations should apply precautionary buffer to the total nutrient load calculated for developments to ensure risk to the receiving environment is suitably accounted for.

Catchment permitting could be proposed as a potential alternative catchment mitigation measure. It has the potential to improve water quality further compared to conventional permitting by reconsidering permit arrangements and incentivising overperformance, improving river water quality across a wider area of the catchment.

One potential issue is the availability of land for offsetting purposes within the catchment area of any designated site or water body at risk from increased nutrient loading. If a WwTW is close to technical achievable limit for nutrient treatment, and there is insufficient nutrient loading from existing land in the catchment, then it may be impossible to avoid nutrient deterioration at the designated site or water body, even with offsetting. In this case, the legal obligation not to deteriorate water body or impact Natura 2000 site could only be met by transferring the waste water to a different catchment. This may prevent development if the associated costs are too high, or delay development to allow time for the transfer infrastructure to be approved and delivered. We evaluate this risk further via the Hotspot mapping (see Annex D).

High flow synergies

Currently, the primary drivers of nutrient neutrality are to prevent any increase in nutrient load damaging Natura 2000 sites that are not in Favourable Condition, or preventing the achievement of Favourable Condition, and to prevent any deterioration in WFD status. Nutrient damage is most likely to occur at times of low flow/dry weather, when elevated levels can cause algal blooms and eutrophication. However, some of the catchment interventions relevant to nutrient neutrality offsetting also have the potential to address issues associated with high flows, such as wastewater overflows and flooding, both of which are very much under public scrutiny at present.

Traditionally, increased flows have been addressed by building bigger sewers, storage tanks and upgrades of treatment works. However, with the combined effect of climate change and population growth, the OxCam Arc region can expect a significant increase in storm flows from urban areas and this approach may no longer be affordable in the future. In addition, recent press coverage has applied more focus on the issue with storm overflows and their impacts on the environment and bathing quality. In combination there is a strong case to look at more sustainable ways of managing sewage. Rather than investing in solutions that only mitigate the impact, adopting nature-based solutions could help improve the assimilative capacity of the water environment, both in terms of flow and water quality. This would contribute to increasing resilience to the effects of climate change and population growth, as well as delivering environmental improvements. There is also a consideration that wetlands and other nature-based solutions might exacerbate environmental problems in low flow situations by holding back effluent flow, often due to increased evapotranspiration, that would otherwise be supporting rivers during the summer. These factors could be addressed through dynamic catchment mass balance modelling.

Link to spatial planning

A key driver for nutrient neutrality is the lack of adequate consideration of additional nutrient loading from new development in the development management process in spatial planning. This has been in evidence in the South East and South West of England over the last four years following the so-called 'Dutch Nitrogen Case', where Natural England objections to development proposals were unexpected and without an obvious solution, served to stall a number of applications over a number of LPAs. Similarly, the European Court of Justice Weser case, C-461/13, showed that decline of the quality of the surface waters under WFD is no longer allowed. Planning officers in LPAs are unlikely to know at present where WwTWs are at or near TAL for nutrients or other determinands that are likely to increase with new development. A key aim of the integrated water management framework for the OxCam Arc is to provide spatial planners with this type of information. Our hotspot mapping output may be one way of addressing this gap.

Comments in Section 7.1.1 on the need for planning policy on water neutrality are broadly the same for the issue of nutrient neutrality. The wording of policy will need to carefully balance the intended aims and outcomes of nutrient neutrality with commercial considerations so that the policy is proportionate and does not unduly hamper the development industry, given the importance of realising the overall Arc aims.

The need for nutrient neutrality at a given development would depend on the risks of associated increased nutrients to any special areas of conservation, other protected areas or water bodies downstream. The means of achieving nutrient neutrality would depend on the capacity of treatment to mitigate increased concentrations. Both sets of information are important for spatial planners to be aware of early in the planning process.

Another important consideration is the degree to which local planning authority (LPA) boundaries align with water body catchment boundaries. A new development within one LPA may impact a special protected area or water body in a neighbouring LPA. Nutrient risk assessment and mitigation planning should be based on areas at risk of impact, irrespective of LPA boundaries. This may require different LPAs to work together, or for a regulator to ensure planning makes allowance for this potential issue. Alternatively, there could be a ‘plan’ for each catchment that each LPA applies through their own policies.

The existing water planning framework advocates collaborative working in a partnership approach on a hydrological basis (across political boundaries) to ensure integrated management of the whole catchment system. Catchment partnerships are specified within this to develop a shared understanding of water issues and to co-design shared solutions. Integration with FCERM projects can also reduce the frequency of nutrient deposition by reducing flood risk.

Work in the Solent suggests that where nutrient mitigation is located makes a significant difference to its effectiveness and therefore the efficiency of land use change (Environment Agency personal communication). This has an impact on the land take required. Spatial planning could, via the Arc Spatial Framework, identify areas in the Arc likely to be most effective for nutrient mitigation, ensure they are ‘earmarked’ in this way, and that this is considered alongside other needs, e.g. locations for FCERM projects, or habitat creation.

Link to Flood Risk

Flooding can be a particularly important system driver of nutrient pollution: flood runoff may play a disproportionately significant role in nutrient and sediment loading of protected sites and water bodies. Taking intensive agriculture out of production to create new flood storage options on that land, for example by removing defences in order to bring it into 'active floodplain' usage, could reduce nutrient loading to protected sites in three ways:

1. Avoided fertiliser application reduces the quantity of nutrients entering the environment
2. New active floodplain absorbs nutrients sourced elsewhere
3. New active floodplain reduces flood run-off, reducing the frequency and magnitude of pollutant loads to water bodies and protected sites

Offset delivery mechanisms

Our high-level calculation shows that where feasible, offsetting additional nitrate loads from new development wastewater could be delivered affordably. A review of the UK natural capital accounts suggests that options for offsetting could provide significant added value in delivering a wide range of other ecosystem services, particularly in the case of converting agricultural land to woodland.

In this case, financing the interventions should be done in proportion to all the value delivered against different forms of natural capital. Improved water quality is one natural capital asset, but others would include carbon sequestration, air pollution mitigation, recreation, flood prevention and timber. The UK natural capital accounts suggest that the total value of these non-water quality ecosystem services could equal the value of growing food, even on highly productive agricultural land. Including water quality benefits as well could result in significant net benefits of land conversion.

ELMS provides one mechanism for funding some of the ecosystem services related to offsetting through land management. Tier 2 payments, for “Local Nature Recovery”, and Tier 3 payments, for “Landscape Recovery”, could both contribute to funding co-benefits of nutrient neutrality. The latter aims to achieve large scale long-term projects and would require collaboration of groups of farmers. However, ELMS may not be sufficient to account for all co-benefits, especially as there is currently a competitive aspect to Tier 3 funding, rather than a payment for all goods delivered. A review of funding mechanisms relevant to potential nutrient offsetting interventions should be carried out in order to establish how offsetting should be delivered. The accountability and coordination of programmes of actions could be challenging and will require careful consideration.

Another important consideration is to what extent any offsetting measures are simply good practice behaviour that farms should be implementing anyway. A baseline position should be established before any measures are identified as acceptable means of offsetting. The development of offsetting interventions and delivery mechanisms could also help to deliver good practice, by identifying how to influence behavioural change, which is relevant to both achieving good practice everywhere as well as going beyond good practice to facilitate offsetting.

Links to water neutrality

The additional nutrient load from any new development depends on the per capita consumption associated with the additional demand. Options for offsetting additional demand through local reuse have the potential to further affect nutrient loading of final effluent into the environment. For example, blackwater reuse, where a proportion of treated final effluent is returned to the development for non-potable use has the potential to further reduce nutrient loading.

Decisions about whether and how to achieve water neutrality should therefore take account of any nutrient benefits. This may make reducing demand and/or local water reuse more cost effective than if appraised only on the basis of maintaining the supply demand balance.

Long-term delivery

Nutrient neutrality through offsetting is not guaranteed to remain permanent: land users may change their practices after initial offsetting measures are introduced. Ensuring permanency of the desired outcomes requires mechanisms for monitoring and enforcement, either through regulation or incentivisation. For monitoring and enforcement, the IWMF needs to decide who the independent monitor would be, their funding mechanism and status. Incentivisation could be in the form of annual payments to land owners, based on independent monitoring of nutrient runoff at suitable time intervals, compared to the minimum of:

- a baseline rate observed historically from the site, and
- a standard baseline rate for good practice of similar land types

The historical baseline is important to ensure that offsetting savings are genuine. The latter is important to avoid over-rewarding land owners who have simply moved from bad to good practice.

Another process would be necessary to ensure that if any offsetting intervention is unsuccessful, nutrient neutrality is still delivered by other means: for example, through upgraded WwTW treatment processes or alternative offsetting measures, such as active floodplain restoration. Integrating offsetting measure performance with water company annual performance reviews may be one means of doing this.

To minimise risks to the environment, it may also be desirable to deliver offsetting interventions several years prior to new house completion, to test their success rate, so that if any do not perform as hoped, there is time to deliver the capital asset construction as alternative nutrient mitigation before nutrient loads increase and avoid any temporary deterioration. A twin-track approach may be necessary whereby enabling work for capital asset delivery is undertaken by water companies (funded appropriately, perhaps by developers) in parallel to offsetting trials, so that any WwTW assets can be delivered as rapidly as possible.

These issues around ensuring long-term neutrality should be explored further with economic regulators and representatives of other funding mechanisms (e.g. ELMS, carbon sequestration financing).

Further investigation

The Environment Agency’s catchment challenge data specifies 138 of 342 water bodies where nutrients are a pressure impacting good status. A baseline for current nutrient loading has not yet been calculated due to the large number of assumptions in the high-level methodology applied here. As part of any subsequent work, for specific development locations, comparable land use estimates for nutrient loading can be calculated to compare with known local WwTW permits and nutrient loads. The next steps following initial land area proposals could be to use Farmscoper data and dynamic water quality modelling to understand specific land use and current nutrient loading. This methodology could be used to assist in the selection of optimal site locations.

Cranfield University has evaluated Farmscoper for finding cost-effective measures to reduce diffuse agricultural pollution in a Norfolk catchment, finding it to be a useful software tool for providing guidance to farmers and agronomists on the selection of mitigation measures, but that further work needs to be done on establishing how realistic the prices are and what constraints there are against implementing the low (or money saving) cost options.

Imperial College is currently undertaking an evidence-based approach to develop a “Water Neutrality Index”, which covers both water quantity and quality. They have also developed new software for integrated modelling of the catchment water system, including simulation of the integrated urban water cycle, tracking water and pollutants through the water cycle, making it simpler to understand system impacts of interventions.

Oxford University has established a water quality institute, with the aim of identifying problems which can be addressed by fundamental research. It has a focus on emerging contaminants, so may not be directly relevant to nutrient neutrality, but could help to identify whether the scope of neutrality should be extended out to other aspects of water quality, and if so which ones.

There may be value in incorporating some or all of this academic work into future phases of nutrient neutrality policy development.

The concept of nutrient neutrality is currently defined in terms of total nutrient loads. Another consideration is the impact of development on total wastewater flow: offsetting nutrients elsewhere in the system may not be adequate if WwTW flow still increases beyond permitted levels.

6.3.4 Nutrient neutrality summary

- High-level calculation indicates that between 3,570 and 10,000 hectares of combined arable/pasture farmland would be required to offset the potential net change in nitrogen loading resulting from the proposed development in the OxCam Arc, subject to assumptions on land use nitrogen losses and WwTW permit limits. This is equivalent to 1% of the total combined arable and pasture land currently in use in the OxCam Arc area. For phosphorous, neutrality offsetting would require between 10,000 and 50,000 hectares of combined arable/pasture farmland, approximately 5% of arable/pasture land in the Arc.
- The cost of offsetting could be minimal if all ecosystem services associated with change in land use are recognised and valued appropriately.
- No deterioration of water bodies and protected areas is a statutory requirement. Therefore, any new development must avoid this. Avoidance could be delivered directly through treatment enhancements, or through local offsetting, e.g. through catchment measures. It may be desirable to include an element of net gain, in a similar way to 10% biodiversity net gain specified for new housing development.
- A key consideration is where should nutrient offsetting take place. Interventions to mitigate the impacts of local development may be most effectively delivered in a water body further upstream. Whilst local or upstream mitigation may be essential to avoid deterioration, some portion of nutrient neutrality may not be needed to mitigate no-deterioration. In which case, delivery in the same catchment as the development may not maximise the environmental benefits of offsetting.
- One potential issue is the availability of land for offsetting purposes within the catchment area of any designated site or water body at risk from increased nutrient loading. If a WwTW is close to technical achievable limit for nutrient treatment, and there is insufficient nutrient loading from existing land in the catchment, then it may be impossible to avoid nutrient deterioration at the designated site or water body, even with offsetting.
- Offsetting for nutrient neutrality could provide additional benefits to the catchment in addressing other problems, such as risk of wastewater overflows and flooding. We would attempt to quantify these synergies further through integrated MCA (see Section 7)
- Nutrient neutrality through offsetting is not guaranteed to remain permanent. Land users may change their practices after initial offsetting measures are introduced. Ensuring long-term neutrality requires mechanisms for monitoring and enforcement, either through regulation or incentivisation, e.g. rebate payments over time.
- Dynamic catchment/urban water quality modelling is recommended to deliver risk assessments and identify where the greatest environmental benefits could be gained from reduced nutrient loading, and how/when. It could also be used to identify optimum portfolios of options to mitigate risk and deliver benefits.
- An important consideration for offsetting is the timing and seasonality of nutrient loading. Agricultural loading is more likely following heavy rainfall in autumn/winter period when the risk of eutrophication is lower. In contrast wastewater loading would occur year-round, including summer months when eutrophication risk is highest. Therefore, offsetting summer wastewater loading with reduced annual total agricultural loading might not be sufficient to protect a Natura 2000 site or prevent water body deterioration. Offsetting might have to be specified on a monthly or seasonal basis.

6.4 Flood Risk Planning

NPPF policy directs vulnerable development away from areas of flood risk and contains two tests for development to pass in order for LPAs to determine that development is acceptable, in policy terms, and in particular for development in areas of existing flood risk. Firstly, the Sequential Test, as set out in Paragraph 161 of the NPPF seeks to ensure that a sequential approach is followed to steer vulnerable new development to areas with the lowest probability of flooding. The flood zones as defined in the Strategic Flood Risk Assessment by the relevant council for the area concerned, and provide the basis for applying the Sequential Test. The vulnerability of various new developed is defined in Annex 3 of the NPPF.

The aim of the Sequential Test is to steer vulnerable new development to Flood Zone 1 (areas with a low probability of river or sea flooding). Where there are no reasonably available sites in Flood Zone 1, LPAs should take into account the flood risk vulnerability of land uses in their development management decision making functions. They should apply the Sequential Test and consider reasonably available sites in Flood Zone 2 (areas with a medium probability of river or sea flooding), applying the Exception Test if required. Only where there are no reasonably available sites in Flood Zones 1 or 2 should the suitability of sites in Flood Zone 3 (areas with a high probability of river or sea flooding) be considered for the development, taking into account the flood risk vulnerability of land uses and applying the Exception Test if required.

The Exception Test, as set out in Paragraph 160 of the NPPF, is a key development management tool, therefore, to ensure that flood risk to people and property will be minimised and managed satisfactorily, while allowing necessary development to progress in situations where suitable sites at lower risk of flooding are not available. Paragraph 164 of the NPPF seeks to ensure that flood risk mitigation is secured, and states that for the scheme to pass the Exception Test, it must “a) provide wider sustainability benefits the community that outweigh flood risk, and b) that the development will be safe for its lifetime, taking account of the vulnerability of its users, without increasing flood risk elsewhere and, where possible, reduce flood risk overall”.

Flood risks for new development are accounted for in the existing National Planning Policy Framework (NPPF) through the Sequential and Exception tests. However, the application of these tests is mixed in the development management process, such that breaches of both tests by, and Environment Agency objections on, planning applications can be ignored by LPAs when deciding planning applications. Furthermore, climate change is likely to increase flood frequency in future, such that flood zone areas may change significantly over the lifetime of new development. On this basis, it may be appropriate for the OxCam IWMF to explore with DLUHC and Defra the potential to refine the sequential and exception tests for new housing development, for example preventing development in Flood Zone 3 under any circumstances.

6.5 Policy considerations

We identify the following potential changes to policy and regulation as a starting point for further evaluation in the next phases of the IWMF development.

6.5.1 Catchment-based approach

Nutrients, water resource and flooding all play out and interact at catchment scale: the actions of one authority impact highly significantly on other areas. For example:

- Flooding from the upper and middle catchment waterbodies can deliver nutrients to protected sites in the lower catchment water bodies, which become unfavourable status with respect to the Habitats Regulations. If we substantially reduce flooding upstream, nutrient loading could be far less significant, even becoming compliant from a legal perspective for most terrestrial ecology designations.
- Combined sewage overflow events resulting from surface water flooding cause river pollution but also prevent high-flow abstraction to reservoirs (such as Grafham).

6.5.2 New design standards

All new homes must meet a design standard of 125 l/h/d per capita consumption (PCC), and this can be lowered to 110 l/h/d by Local Planning Authorities (LPAs) where there is compelling need.

- New home water efficiency could be mandated at 110l/h/d or even lower
- Rainwater harvesting, greywater or blackwater reuse could be mandated for all new developments above a certain minimum number of properties. In many cases this will not be cost effective when viewed solely from a water resources point of view, and wider benefits need to be quantified and evaluated. The flood risk benefits of rainwater harvesting may often be significant, but we find only limited evidence for these being quantified in existing studies. The decisions for specifying on-site reuse in development plans may be context-specific and site-specific.
- The Greater London Authority London Plan Policy G5 requires all major developments to include urban greening as a fundamental element of site and building design.[43] The policy introduces the use of an Urban Greening Factor (UGF) to evaluate the quantity and quality of urban greening provided by a development proposal. A similar policy could be applied to the OxCam Arc.
- No-development buffer zones could be mandated to protect riparian corridors from encroaching development.
- SuDS could be mandated for all new developments, or made compulsory based on certain criteria.

New design standards, e.g. mandating on-site reuse or reducing the acceptable PCC standard would reduce demand but would account for only a proportion of impacts and would not steer development locations, or provide additional funding to cover the cost of mitigating for remnant impacts. It could also end up being more costly than alternative offsetting measures, and there are risks associated with reuse and enhanced demand management technology that is at a relatively early stage of development.

6.5.3 Planning policy

In relation to improved IWM standards for local plans, the current impacts, costs and opportunities of water and wastewater resources are not fully accounted for in planning development decisions. Developers pay a contribution for water under the Water Industry Act 1991, but this is limited to connection costs and the costs of “other water mains”.

- Expanding developer contributions to cover the full whole-life costs of water-related impacts of new development (priced via the cost of short-, medium- and long-term mitigations) could provide a market signal for locating properties away from the areas of highest impact, as well as encouraging innovative demand management, and funding remaining impact mitigation in full, following the “polluter pays” principle set out in the 25 Year Environment Plan.
- However, the benefits could take more time to accrue and are potentially less certain to be delivered than design standards or policies such as water/nutrient neutrality.

The following changes to planning policy could be made for all development in the OxCam Arc:

- Planning approval could be made contingent on the pre-existence of, or parallel investment in, adequate supply and treatment infrastructure for water and wastewater. This could mitigate the short/medium term risks of development on sensitive water bodies or sites before new resources can be brought online.

[43] https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/london-plan-guidance/urban-greening-factor-ugf-guidance

- Development spatial planning could be fully integrated with water system planning, such that water resources, drainage and wastewater, flood risk and local development planning is aligned and reconciled in an iterative process.
- Water neutrality could be mandated for all new developments in the OxCam Arc via planning policy in the Arc Spatial Framework, but further consideration should be given to the definition of neutrality and the definition of offsetting. Any planning policy on water neutrality should balance strategic needs and opportunities alongside specific more localised pressures in catchments with Natura 2000 habitat in (or at risk of being in) unfavourable condition, and where water abstraction is a factor in its deteriorating condition.
  - If mandated, water neutrality should firstly ensure that additional abstraction to supply the development does not negatively impact any sensitive site or water body. Where there is no risk of direct impact, or where reducing only a portion of the additional demand is enough to mitigate any such impacts, offsetting the remaining demand should be done in the way that achieves best value for the environment.
- Nutrient neutrality could be specified for new developments in the OxCam Arc via planning policy in the Arc Spatial Framework, where neutrality is defined in terms of limiting additional net nutrient loading from development as required in order to avoid deterioration in status of any designated site or water body, irrespective of site or water body location.
- Water and nutrient neutrality could include an element of net gain for any site or water body impacted by nutrients at present. This net gain could be specified locally or at a location where the most value is derived from the % reduction in nutrient load.
- Biodiversity Net Gain could be enhanced to encourage offsetting that maximises water-related benefits through MCA. Chalk streams could be endorsed as sites for BNG offsetting, inclusion in Nature Recovery Networks and Local Nature Recovery Strategies
- Best practice soil remediation could be a requirement of brownfield site development
- Policy could be specified regarding paving over front gardens, e.g. for parking. The IWMF could identify properties where paving over is not allowed., or design standards for changing use of front gardens, e.g. to gravel only.
- Garden city restrictions could be specified for all new development, specifying runoff requirements for any extensions or garden change of use, perhaps based on location.
- Maintaining historical drainage patterns could be mandated for all new development.

6.6 Strategic planning & coordination

Water and nutrient neutrality could be delivered via changes to regulation, such as new building design standards and offsetting requirements, in conjunction with market incentives, for example through charging developers for whole-system impacts of new development, with charges reduced to account for any sustainable on-site initiatives.

However, changes to regulation and market incentives alone cannot lead to development which delivers best value for the environment and all relevant stakeholders, because of the systemic nature and complexity of the challenges. Regulation and incentives alone would in effect pass all responsibility for taking account of water in development decisions onto LPAs and developers, who may not always be best placed to make these decisions. Water Cycle Studies are intended to assess the constraints and requirements on the water environment that may arise from development in the area, but there is no clear mechanism to ensure that complete water system impacts are accounted for fully in development decisions, and any residual impacts are mitigated in full.

Strategic planning and coordination could overcome these issues by specifying that key tasks are undertaken by the most appropriate stakeholders, in consultation where necessary, designing out disbenefits of development before they occur. One LPA may contribute to another LPA's environmental problems through new housing development driving increased abstraction or discharge of new wastewater from/to sensitive water bodies. As importantly, one LPA may often hold the solutions to another LPA's constraints, for example an upstream flood storage scheme may be critical to avoid flooding of a protected site with nutrient-rich water. Collective strategic planning is likely to be significantly more effective and economically efficient than unplanned water and nutrient neutrality. We consider this fundamental for the OxCam Spatial Framework to address, or in the absence of a Spatial Framework, for LPAs to address collectively.

Effective strategic urban and infrastructure planning for water resources, wastewater and flooding, including the most effective mitigations for any chosen development site, will require knowledge of supply networks, abstraction constraints, water body pressures, flood risks, designated sites, and may need to take place at a broader scale than individual catchments. This may be best delivered through a partnership of:

- Water companies, who have the best knowledge and control of their assets, and whose planning accounts for the regional system already in WRMP, WINEP and DWMP
- Regulators, with knowledge and responsibility of the wider pressures on catchments, flood risks and enforcement of environmental regulation
- CABA partnerships with detailed local knowledge of local river catchments.

Water UK explore this approach further in their paper, 21st Century Rivers Ten Actions for Change (2021)[44].

Examples of the potential benefits of more strategic urban planning with respect to water would include:

- Designing blue-green corridors in urban areas that enhance flood resilience and provide space for cycle paths and tree planting that enhance urban form, reduce road traffic (and associated pollution), sequester carbon, and improve biodiversity.
- Design transport earthworks in ways that create flood storage and provide flood protection.
- Implement catchment-based solutions that enhance water quality and reduce flood risks while concurrently off-setting the need for grey infrastructure, thereby reducing costs and the carbon footprint of the development in the Arc.

Urban design in which transport and flood management are designed together emerges as a priority. Similarly, an emphasis on nature-based solutions will be important.

We note that growth in water demand is not driven by housing development alone. Household occupancy is equally important and may be driven upwards by growth in employment opportunities, forcing more people into the existing housing stock. Temporary increases in demand associated with daily or seasonal migration to/from the Arc for work or leisure may also be important contributors to demand, especially at critical demand periods. Strategic planning should take account of these effects, when deciding whether economic growth plans are likely to drive migration into a catchment whose water body status could be deteriorated by additional abstraction irrespective of plans to build new homes.

6.7 IWM requirements summary

6.7.1 Key Learning

- Water neutrality is technically feasible but would be highly challenging to achieve at scale across the OxCam Arc
  - Even with an ambitious (85 l/h/d) efficiency target for new homes, and mandated greywater reuse or rainwater harvesting, 1.2million properties (43% of forecast 2045 properties) would require retrofitting to 85 l/h/d to offset the demand from an additional 600,000 new properties in full. The retrofit number could be up to 5 million properties if water efficiency is less ambitious or successful

[44] https://www.water.org.uk/rivers/wp-content/uploads/2021/09/report.pdf

- Water neutrality is not essential in the long term for development to be sustainable. It may well be necessary in the short-medium term to meet legal obligations in some places, to prevent deterioration of some designated sites or water bodies
  - Emerging regional plans show that historical over-abstraction of water is an order of magnitude higher than the increase in abstraction forecast from population growth
  - Emerging regional plans do not require all available feasible supply options to be selected, even under the worst-case scenarios for water resource supply/demand balance. However, the options not selected are likely to come with significant lead times (> 10 years).
  - It should be possible to meet the additional demand for water from OxCam growth, but only with sufficient time to deliver new supply options and transfer water to new demand centres. This time could be significant in places (> 10 years)
- Water efficiency measures, such as water efficient devices and smart metering, are likely to be cost effective in all new developments and worthwhile to reduce the demand for water and wastewater services.
  - Water efficient appliances have the potential to offer significant savings compared to conventional appliances. Up-front costs of installation are likely to be comparable to installation costs of equivalent non-efficient devices.
  - Implication: specifying water efficiency standards for new-home appliances would be a no-regrets policy.
- When including the costs of transferring water, on-site water reuse is likely to compare favourably with supply-side options as an alternative to enhanced PCC (< 110 l/h/d). Where flood risk benefits and local water quality benefits from reduced runoff are significant, and are accounted for fully, on-site water reuse may well out-compete supply-side interventions on cost.
  - The unit cost of local reuse (RWH, GWR or BWR) per l/d is dependent on how much saving is delivered through water efficiency, the cost per property of the reuse, and whether or not clothes washing can use reuse water. Costs of c. £23 to £64 per l/d are likely with current technology, compared to marginal unit capex of supply options of c. £15 per l/d (not including transfer costs).
  - Flood risk and local water quality benefits may also be derived but these are location-specific and there is currently a lack of evidence to quantify these benefits.
- Nutrient neutrality of all new properties in the Arc could be technically achievable for the Arc overall on an annual basis through treatment and offsetting. However, it may not be achievable in a way that mitigates environmental damage due to seasonal differences between nitrate loading from agricultural runoff and wastewater.
  - Nutrient neutrality would require some degree of offsetting through land use change, due to technologically achievable limits in WW treatment.
  - Applying the Natural England approach to nitrate neutrality to the OxCam Arc based on land use and growth scenarios shows that taking c.1% of agricultural land out of use could offset nitrate loading from the additional wastewater of 600,000 new properties. Comparing phosphorous loading from farmland with nitrogen suggests that similar scale of land use change could offset wastewater phosphorous from a similar number of properties.
  - Nutrient loading from land runoff is highest in autumn/winter. To avoid environmental damage, nutrient neutrality is likely to be necessary in summer months, when risk of eutrophication is highest.
- Nutrient neutrality will not always be necessary to prevent damage to designated sites or water bodies.
  - Eutrophication and other environmental issues are subject to “limiting factor” constraints. Damage will only occur where there is an increase in a limiting pressure on the designated site or water body: an increase in any other pressure may not cause damage
- There is significant potential for catchment (nature-based) solutions (NBS) to contribute major benefits to water body status, but delivery is constrained by:

    a. a lack of modelling tools and approaches to quantify benefits at scale
    b. disjointed planning processes unable to adequately recognise combined benefits
    c. inadequate delivery and funding mechanisms for multi-benefit NBS schemes involving multiple stakeholders
  - High-level nitrate neutrality calculations demonstrate significant potential for changes in land use to impact key WFD nutrient pressures
  - Review of planning processes and systems mapping show complexity of existing delivery and funding mechanisms
- Urban planning decisions do not currently take account of the full costs of development on water sub-systems
  - Water cycle studies provide a useful overview for urban planning, but focus mainly on wastewater permit compliance, and do not include detailed costs.
  - Developer contributions are limited to local connection costs and the wider network, and do not cover any impacts on: upstream water resource; downstream wastewater treatment or offsetting; or additional flooding impacts.

6.7.2 Implications

- Where water neutrality is both necessary and not possible to deliver, development must be limited until sufficient new supply-side resources can be delivered. Water companies and the Environment Agency are best placed to identify these locations, given a need to take account of water delivery networks
- Specifying water efficiency standards for new-home appliances would be a no-regrets policy.
- It would be beneficial to encourage rainwater harvesting and/or greywater reuse by appropriate mechanisms. Mandating both or either should be done locally on the basis of local water supply constraints, flood risk and water quality risks.
- Nutrient neutrality is likely best applied as a targeted measure to development where the relevant nutrient is a limiting factor to site or water body status, and where it can be delivered in a way that is effective to prevent damage.
- Where additional nutrient loading cannot be effectively offset to prevent damage, wastewater should be transferred to an appropriate site elsewhere, or development specified elsewhere. These locations could be identified through dynamic catchment modelling.
- Dynamic catchment modelling should be piloted to assess its ability to improve strategic planning of catchment management to deliver improved environmental outcomes
- Water planning processes require better integration to fully account for co-benefits in decision-making
- The IWMF should account for the full costs of development on water sub-systems when deciding where development is located
- Delivery and funding mechanisms for catchment solutions need streamlining

7 Discussion and conclusions

7.1 Integrated solutions appraisal

Framing the development of the IWMF as a systems process is highly beneficial. Water resources, wastewater, flooding and environment are interconnected systems, influenced by urban development, agriculture, public water supplies, etc. Existing individual planning frameworks for water resources, wastewater, flooding and environment already provide good means of delivering objectives specific to each individual sub-system. We therefore consider that integrated planning would be best achieved through alignment with these existing planning processes in order to overcome remaining challenges and deliver on opportunities made available through appraising the system as a whole.

New development can affect the water environment in complex ways due to interactions between sub-system elements. On the basis of current evidence it is not possible to define a schedule of shortlisted IWM options in an OxCam IWM plan due to the different scales over which water resources, wastewater, flooding and environmental interventions must be appraised. An OxCam IWM Framework should specify improved linkages between existing planning programmes rather than trying to specify detailed schedules of options or replace any existing planning programmes.

Generic option types appraised in every core water sub-system have the potential to provide significant secondary benefits across at least one other water sub-system. High-level MCA scoring of generic option types show all option categories scoring highly against criteria relevant to more than one water system. The consideration of synergistic co-benefits across the four systems must result in the achievement of a higher level of environmental benefit.

At present, the selection criteria for portfolios in each core system are not consistent – flooding and WFD portfolios commonly have cost-benefit criteria in addition to an overall ambition. Existing “best value” WRMP and DWMP MCA criteria do not capture whole water-system benefits. Integrated options appraisal requires consistent MCA criteria across different sub-system planning processes. As a starting point, we have tabled 14 criteria to capture the whole water system requirements, against which interventions should be measured.

Strategic planning for water is necessary to determine optimal spatial plans, as well as to specify optimal portfolios of interventions to mitigate development. Strategic planning should use locally appropriate catchment-based evidence to address the challenges of flood risk, water quality, water resources and associated nature recovery.

7.1.1 Potential coordination role for OxCam IWMF

To draw together implications of the pilot modelling study and the further development of metrics, it is necessary to provide a working proposal of the coordinating role that the IWMF would provide. Given that the role requires proactive coordination of different planning processes, we assume an IWMF coordination office would be required. The office would be able to act as both a central database for information on interventions across all sub-systems, a conduit of data between these subsystems and a representative voice for water with other planning systems. We propose the following outline of tasks for the operation of the IWMF:

1. Coordinate opportunities for co-development and co-funding of options with multiple benefits. This would enable options to appear in more than one planning framework portfolio with an assumed cost share relating to the relative benefits to each system – such as a flooding option with a water resource co-benefit that could be included in a WRMP as well as a FRMP with a proportion of the cost included for appraisal in each planning assessment.
2. Coordinate development of options that have in-combination effects – such as environmental flow and water quality benefits that enhance availability of water resources.

3. Identify conflicting strategies and opportunities to mitigate disbenefits of options.
4. Coordinate policy recommendations such as developer requirements for environmental benefits (environmental neutrality or enhancement).
5. Provide a common voice for water in wider system integration – with, for example, transport and energy system planning

The IWMF office would develop buy-in for common planning approaches so that each planning framework presents compatible options:

- a common set of metrics (as presented in this report)
- a common set of planning assumptions (such as optimism bias)
- a consistent set of management targets and performance thresholds
- a common set of scenarios
- a consistent categorisation of options

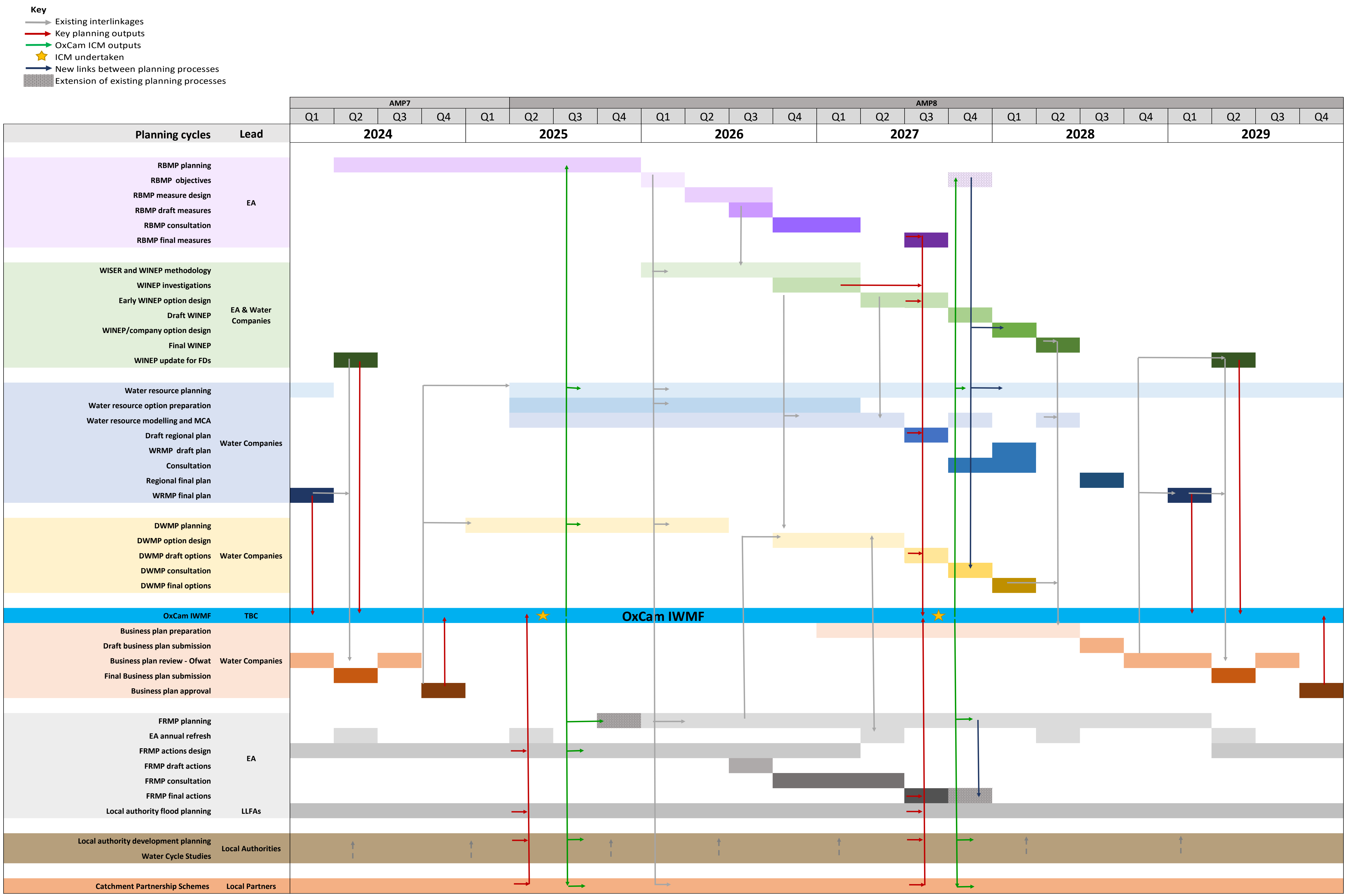
The IWMF coordinator would be able to provide coordinated policy recommendations across the different planning frameworks. This common voice would extend to managing integration between the water system and other systems such as transport, energy, housing, land use, agriculture, urban design and net zero ambition. As yet, the operational procedures of the higher tiers of ELM have not been made clear. We understand that regional planning offices such as OxCam will provide an important voice in the development of landscape schemes under ELM. The system mapping exercise identified some areas for this kind of wider system integration.

A means by which IWM and ICM would add value to current planning processes is shown below in Figure 7.1.

- Grey arrows show the existing interlinkages (as presented in Figure 2.3).
- Red arrows show where key planning outputs feed into the IWMF coordination channel.
- Green arrows show where OxCam ICM outputs feed back into existing planning processes.
- Gold stars show where ICM could be undertaken.
- Dark blue arrows show proposed new links between existing planning processes. This is necessary in particular where ICM outputs may require some local post-processing before feeding into WRMP, WINEP, DWMP and FRMP. For example, the ICM will output impact on pollutant concentrations and river flow, but this will need translating into any impact on WFD status and impact on property flood risk banding.

Hashed cells show where we think the duration of existing planning processes could be extended to enable better alignment with integrated planning. At this stage we have not considered potential changes to the planning frameworks, but have assumed timelines and scopes remain as based on current arrangements.

Figure 7.1: Proposed planning interfaces with OxCam IWMF



7.1.2 Role of modelling within the IWMF

Dynamic integrated modelling would provide a robust means of undertaking integrated MCA. It would also allow different planning frameworks to be informed by a live set of options under consideration across the other planning frameworks, a high-level view of the potential synergies across subsystems, and enable collaborative development of combining options. The modelling would identify in-combination effects of different options, such as low flow and water quality measures that combine to enhance water resource availability and environmental benefits; or where options have negative impacts that could be mitigated through collaborative working.

To undertake integrated MCA, management targets/thresholds for key performance indicators must be identified for use in the integrated modelling. This could be done by testing subsystem portfolios in the model which are known to deliver on subsystem objectives against a given scenario, and reviewing performance indicators accordingly to set thresholds. Thresholds could also be set to meet high-level objectives, such as no growth in groundwater abstraction anywhere. To support the development of integrated, adaptive plans of options across subsystems, performance indicator targets and option analysis could then be used to specify option portfolios which maximise overall performance at minimum cost for various scenarios, taking account of consistent social and environmental “best value” criteria. “Adaptive plan” indicator thresholds could also be identified to inform decisions over major infrastructure taking account of in-combination effects.

Water quality, environmental flow and water resource objectives can be quantified directly through mass-balance models, such that their integrated MCA criteria can be appraised in integrated modelling directly. Flood risk appraisal requires geospatial modelling to determine performance, which is best undertaken within planning frameworks. However, integrated modelling could be applied to deliver integrated MCA if flood risks are specified as performance thresholds, represented by high flow proxies in the integrated model, which could also be used to identify in-combination risks and synergies across planning frameworks.

Between now and the end of AMP8, we identify three points at which integrated catchment modelling would be particularly useful to overcome existing gaps and take best advantage of opportunities for IWM, working with existing processes and timelines:

1. In autumn/winter 2022, after submission of draft regional water resource plans, DWMP, and FRMP: integrated MCA to trial evaluating proposed portfolios of options in combination for possible co-benefits, and opportunities for more effective integrated plans of options, as part of IWMF detailed design in phase 2 of OxCam IWMF. This could potentially inform final WRMP, DWMP and PR24 decision-making.
2. Early in the planning process of AMP8 (2025): to identify options with significant potential for co-benefits, for detailed appraisal in regional water resource planning, WRMP, WINEP, DWMP, FRMP, etc.
3. In 2027, after submission of draft regional water resource plans, DWMP, and FRMP: integrated MCA to evaluate proposed portfolios of options in combination for possible co-benefits, and opportunities for more effective integrated plans of options.

7.1.3 Summary of Proposed Changes by Interface

Table 7.1 summarises how the interface between different planning processes could be improved through IWMF and use of an integrated catchment model (ICM).

Table 7.1: Potential interface changes under OxCam IWMF

Interface	Current Approach	Potential approach under IWMF	IWMF Timing
RBMP with WINEP	RBMP sets the objectives for each River Basin. WINEP sets the water company-funded measures to deliver those objectives	Reassess WFD objectives for each WB pressure in light of integrated catchment modelling (ICM) of draft WRMP and DWMP. Ensure that overall investment across all pressure objectives is effective.	Once draft regional water resource plans published (trial Q4 2022, implement Q4 2027, etc)
WRMP with WINEP	WINEP confirms abstraction licence changes, to be taken account of in WRMP	ICM identifies changes in low flow resulting from draft WRMP, DWMP and FRMP, WINEP and catchment measures in combination, which feeds back into WINEP to reassess required licence changes. WINEP then re-informs WRMP.	Once draft regional water resource plans published (trial Q4 2022, implement Q4 2027, etc)
RBMP & WINEP with DWMP	RBMP & WINEP set objectives and required WWTW permit limits to meet those objectives	ICM determines the effects of draft WRMP, DWMP, WINEP and FRMP in combination on river quality. RBMP reassess how this affects WB performance against objectives and reassesses required permit limits. This information feeds back into final DWMP.	Once draft regional water resource plans published (trial Q4 2022, implement Q4 2027, etc)
WRMP and DWMP with FRMP	FRMP only takes into account previous WRMP and DWMP when determining flood risks. FRMP feeds into DWMP but impacts of draft DWMP or WRMP interventions on flooding not taken into account in FRMP	ICM determines impacts of draft WRMP, WINEP and DWMP on river high flows. This information is fed into FRMP to model impact of change in high flows on property flood risks, and therefore any potential change in flood defences required. FRMPs are updated accordingly.	Once draft regional water resource plans published (trial Q4 2022, implement Q4 2027, etc)
SWMPs with DWMP and FRMP	DWMPs coordinated with SWMP and FRMP, but not consistently across all local authorities?	ICM tests draft DWMP with SWMPs and FRMP measures against various growth scenarios and identifies any in-combination effects, risks and opportunities, based on river high flow indicator. Any potential risks/opportunities passed back to EA or LLFAs to evaluate with detailed flood modelling.	Once draft regional water resource plans published (trial Q4 2022, implement Q4 2027, etc)
WRMP, DWMP, WINEP and FRMP option development.	Integrated Options generally not identified: options typically designed to address one issue. SROs may then be developed to maximise co-benefits.	ICM used to proactively identify new catchment-based options which perform well against multiple criteria. These options to be fed into option appraisal for draft WRMP, DWMP, WINEP and FRMPs.	Immediately after final WRMP, DWMP and company business plans published? (Q2 2025, Q2 2030, etc)
Land management with WINEP, WRMP, DWMP, FRMP	Land management decisions based primarily on profit maximisation taking account of ELMs, WINEP and regulatory requirements. WINEP catchment measures based on catchment modelling targeted to single objectives (nitrate, pesticides).	ICM used to identify land management change at a water body scale that could be potentially material to any WRMP, RBMP or flooding objectives. Information used to identify potential options for draft WRMP, WINEP, FRMP and DWMP (with associated detailed modelling), and to suggest potential co-funding opportunities.	Immediately after final WRMP, DWMP and company business plans published? (Q2 2025, Q2 2030, etc)
Local Authority Local Plans with WRMP, DWMP, WINEP, FRMP	Water Cycle Studies used to inform LPs. WRMP, DWMP, FRMP take account most recent published LPs, along with trend-based forecasts: water companies propose preferred approach for consultation	ICM used to appraise alternative development locations impacts on water body flows and quality. And to identify scale of catchment measures that could be used to offset these impacts (with appropriate net gain). EA and water companies consult with Local Authorities (LAs) in local planning. Any specific mitigation options could be identified through detailed catchment modelling by EA/water companies. How this modelling is funded is TBC in Phase 2/3 of OxCam IWMF.	Early stages of LA Local Planning

7.2 IWM requirements

The close relationship between growth and environmental capacity would be best addressed with a catchment-based approach to IWM. Flooding, environment and water quality systems operate, to a high degree, within catchment boundaries. Water resource systems operate regionally as water is transferred at this scale.

Urban planning decisions do not currently take account of the full costs of development on water sub-systems. The IWMF should account for the full costs of development on water sub-systems when deciding where development is located. The IWM standards for compliance by developers and local government will be important in determining the ambition for the Arc and creating opportunities for developers to find innovative solutions to the achievement of that ambition at the local level.

To comply with the 2017 WFD Regulations and Habitats Regulations, water companies must not cause a deterioration in status of any water body or statutory protected site. There are several water bodies in the OxCam Arc where an increase in water abstraction or increase in pollutant loading would cause deterioration in status. In these cases, the abstraction of additional water for new development would cause water companies to be non-compliant with statutory legislation without intervention. Intervention could involve water neutrality measures to prevent increase in abstraction from relevant water sources, and/or nutrient neutrality measures to prevent any increased loading of nutrients to sensitive water bodies or protected sites. Any offsetting measures must take account of seasonal and spatial risks to ensure no damage or deterioration anywhere at any time.

We note that growth in water demand is not driven by housing development alone. Household occupancy is equally important and may be driven upwards by growth in employment opportunities, forcing more people into the existing housing stock.

In some cases, avoiding damage or deterioration may not be feasible with local off-setting and the only way of mitigating increased demand for water or wastewater services would be through the delivery of major new infrastructure. In these cases, no new housing development or growth in work space should be permitted until this infrastructure is fully operational, which may take a number of years. Identifying these locations within the Arc requires detailed local hydrological and water quality modelling, which has not been undertaken in Phase 1 of this work. In water bodies at risk of deterioration, the precautionary principle should be followed: evidence should be provided to show how no increase in abstraction from sensitive sources will be achieved, and/or no increase in nutrient concentrations at any sensitive water feature above safe limits. This should be done in consultation with water companies, the Environment Agency and Natural England.

Water and nutrient neutrality should be understood as being tools within the development of the IWM standards, rather than standards themselves – as relying on neutrality alone will not create the environmental enhancement to which the OxCam Arc is committed. A key concern, that requires further analysis, is the scale over which water and nutrient neutrality would be deployed as a planning tool.

Water neutrality (for growth beyond baseline) at the scale of the OxCam Arc is technically feasible but would be highly challenging to achieve. It would require PCC limits set lower than currently possible under planning policy, and is highly dependent on the willingness of existing households to change their water consumption behaviour. The latter may be especially challenging if the driver behind this is to enable delivery of new housing developments that are unpopular locally.

Nutrient neutrality is likely to be technically achievable for the Arc overall on an annual basis. However, it may not be achievable everywhere in a way that mitigates environmental damage, due to seasonal differences between nitrate loading from agricultural runoff and wastewater. Nutrient neutrality will not always be necessary to prevent damage to designated sites or water bodies. It is likely best applied as a targeted measure to development where the relevant nutrient is a limiting factor to site or water body status, and where it can be delivered in a way that is effective to prevent damage. Where additional nutrient loading cannot be effectively offset to prevent damage, wastewater should be transferred to an appropriate site elsewhere, or development specified elsewhere. These locations could be identified through dynamic catchment modelling.

There are risks in water and nutrient neutrality offsetting associated with:

- Measuring at the right scale to ensure no damage to or deterioration in any environmental site/body
- Maintaining long-term offsetting benefits (e.g. diminishing returns of nature-based solutions if not managed effectively);
- Measuring against the right baseline (good practice);
- Social viability and impacts on rural communities.

The OxCam IWMF needs to set out what measures would be taken if water neutrality fails to deliver, for example, delaying further growth until such time as new water resources can be delivered to mitigate any damage already caused.

Water efficiency measures, such as water efficient devices and smart metering, are likely to be cost effective in all new developments and worthwhile to reduce the demand for water and wastewater services. Specifying water efficiency standards for new-home appliances would be a no-regrets policy. It would be beneficial to encourage rainwater harvesting and/or greywater reuse by appropriate mechanisms. Mandating both or either should be done locally on the basis of local water supply constraints, flood risk and water quality risks.

7.3 Concluding remarks

The regional water resource planning processes created under the Environment Agency's National Framework for Water Resources has achieved a major development in coordinated planning. It has addressed water resources and to some degree environmental planning objectives. The development of these plans continues to be a complex and demanding activity. In comparison, the ambition of the OxCam Arc which aims to integrate a larger number of planning frameworks is greater still. Our assessment is that a coordinated and centralised high-level approach to modelling options would enable the efficiencies of co-developed, multi-benefit options to be realised at scale. This approach would identify the cross-system synergies and provide the unified perspective on where effort is needed to realise these opportunities.

We propose that it would be more efficient to develop this high level-overarching view of the synergies than to rely on each planning framework to develop its own approach to interacting with all of the other system frameworks – an approach that would be more onerous and lack the consistency of a unified overview. The interaction between planning frameworks and integrated modelling proposed in this project provides building blocks for how that overarching coordination could be achieved.

A. Technical group

A technical group of subject matter experts across various organisations provided inputs to the project at various stages. Members of the technical group and their organisations are listed as follows. We note that membership of the technical group does not imply endorsement of any/all of this report or its content.

Table A.1: List of contributors and their organisations

Name	Organisation
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Richard Reynolds	Anglian Water
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Victoria Lemmon	Anglian Water
Daniel Clark	Cambridge Water
Alys Bishop	Central Bedfordshire LLFRA
Adrian Brookes	Defra
Ashley Holt	Defra
Gruffydd Waldron	Defra
Phoebe Barrett	Defra
Amy Shaw	Environment Agency
Angela Wallis	Environment Agency
Caroline Sutton	Environment Agency
Ceri Lewis	Environment Agency
Chris Swain	Environment Agency
Daniel Curtis	Environment Agency
David Forrow	Environment Agency
David Griggs	Environment Agency
Iain Page	Environment Agency
Jatinder Singh Mehmi	Environment Agency
Jenny Forsyth	Environment Agency
Jenny Gough	Environment Agency
Palmira Arenax-Laborda	Environment Agency
Paul Bryson	Environment Agency
Steve Hopper	Environment Agency
Tom Nichols	Environment Agency
Helen Stafford	Environment Agency
Andrew Chapman	Environment Agency
James Bristow	Homes England
Adam Wallace	Natural England

Name	Organisation
Don Porcelli	Oxford University
Alex Nickson	Thames Water
Marie Raffin	Thames Water
Ben Fitzsimons	Water Resource East
Nathan Richardson	Waterwise
Meyrick Gough	WRSE

B. Legal and policy background

B.1 Spatial planning

The National Planning Policy Framework (NPPF)[45] was first published in 2012 and updated in 2018, 2019 and 2021. It sets out the government's planning policies for England and how these are expected to be applied in local and neighbourhood plans, of which paragraphs 20 and 153 are most relevant to water. Paragraph 153 states that "plans should take a proactive approach to mitigating and adapting to climate change, taking into account the long-term implications for flood risk, coastal change, water supply, biodiversity and landscapes, and the risk of overheating from rising temperatures. Policies should support appropriate measures to ensure the future resilience of communities and infrastructure to climate change impacts, such as providing space for physical protection measures, or making provision for the possible future relocation of vulnerable development and infrastructure."

Paragraph 20 of the NPPF on strategic policies (in Local Plans) states that "strategic policies should set out an overall strategy for the pattern, scale and design quality of places, and make sufficient provision for (inter alia) b) infrastructure for transport, telecommunications, security, waste management, water supply, wastewater, flood risk and coastal change management, and the provision of minerals and energy (including heat)".

B.2 Environment

Improving the environment is the key driver for this project. The Environment Act 2021[46] sets out legislation to restore natural habitats, increase biodiversity, reduce waste and make better use of resources. It aims to halt the decline in species by 2030, require new developments to improve or create habitats for nature, and protect the health of rivers. It sets a duty on water companies to secure a progressive reduction in the adverse impacts of discharges from storm overflows. New duties also require the government to publish a plan to reduce sewage discharges from storm overflows by September 2022.

The Environment Act requires an environmental improvement plan to be published setting out steps the government intends to take to improve the natural environment over a period of at least 15 years. The first environmental improvement plan, the 25 Year Environment Plan[47], was published in 2018, setting out government action to help the natural world regain and retain good health. It aims to deliver cleaner air and water in cities and rural landscapes, protect threatened species and provide richer wildlife habitats.

The Water Environment (Water Framework Directive) (England & Wales) Regulations 2017 (referred to as the WFD Regulations) provide a framework for managing the water environment in England. Under the WFD Regulations, a river basin management plan (RBMP) must be prepared for each river basin district.

RBMPs set out the statutory environmental objectives for water bodies including those for Internationally, European and Nationally Protected Areas for nature conservation and landscape such as Ramsar sites, European sites (eg SPAs and SACs), National Parks, AONBs and SSSIs. As a consequence, they are the key strategic plan for water. As public bodies, Local Authorities are required to 'have regard' to the RBMPs[48].in exercising their functions, including as Local Planning Authority.

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[45] https://www.gov.uk/guidance/national-planning-policy-framework

[46] https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted

[47] https://www.gov.uk/government/publications/25-year-environment-plan

[48] Under Regulation 17 of the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003, as amended

River Basin Management planning (and associated Ministerial Guidance), the Water Industry Price Review Process, as well as Defra's Catchment Based Approach policy framework are particularly important. All drive analysis on the state of the water environment, and development of potential solutions. A consultation is underway on recently published updated draft RBMPs which specify several "implementation principles" for partners to consider when developing their water management initiatives. Initiatives should:

- take a collaborative place-based approach – align initiatives on water, and pool resources to achieve more than partners can achieve alone
- make evidence-led decisions – work with partners to build the evidence base and use it to make evidence led decisions that are explicit about the intended benefits of actions and transparent about the assumptions used
- take account of future and changing risks to delivery – in particular, the effects of climate change and population growth to make sure actions perform as intended over their lifetime
- consider a range of possible futures (for example 2°C and 4°C temperature rise by 2100) and use flexible approaches that enable solutions to be modified in the light of changing circumstances or new information
- contribute to net zero – minimise greenhouse gas emissions and maximise carbon capture aiming for net zero
- build catchments resilient to warmer water temperatures, more frequent floods and drought, and rising sea levels – choose measures that help natural assets cope with or recover from shock
- work with natural processes – where possible choose nature-based solutions to protect and improve natural water assets and deliver multiple benefits
- promote restoration and recovery of freshwater, estuarine and coastal habitats and species – this will provide resilience to climate impacts

RBMPs specify a programme of measures to meet their objectives. Measures are based on programmes of investigations to understand why some water bodies are not meeting the default objective of good status or potential. These measures are costed in water company business plans, individual project appraisals, government published figures and the Environment Agency's business plans. Costs associated with rural land management sector are produced using the Environment Agency's Cost of Agricultural Measures (CAM) tool. In all catchments, the most cost-effective measures are selected, for example, low cost measures were preferred against higher cost land use change. However, the effectiveness of measures at a catchment scale in reducing diffuse water pollution from agriculture is not well understood.

An impact assessment was carried out by the Environment Agency in 2015[49] to specify environmental objectives and actions in a set of updated RBMPs, based on cost/benefit appraisal. In appraisals for surface waters the Environment Agency used the National Water Environment Benefit Survey (NWEBS) willingness to pay values to estimate some of the benefits (in pounds sterling per km or km2) of improvements to the water environment from society's perspective. NWEBS provides benefits from WFD status improvements (bad to poor, poor to moderate etc.) per km (or km2) of river, lake, estuary or coastal water affected, based on willingness to pay values which capture aesthetic, recreational and existence benefits. For groundwater appraisals, values were transferred from previous peer-reviewed economic assessments to monetise some ecosystem service benefits. Where benefits cannot be monetised they were captured qualitatively for each catchment to record whether benefits or disbenefits to ecosystems services are 'significant', 'noticeable but not significant' or have 'no net change'. This is based on the ecosystem services framework to assessing benefits, as specified in the Treasury's 'Green Book supplementary guidance: environment'. Benefits are only appraised sufficiently to decide whether or not the benefit/cost ratio is greater than or less than 1.

The water industry national environment programme (WINEP) is the programme of work water companies in England are required to do to meet their obligations from environmental legislation and UK government policy. It is the primary mechanism for delivery of RBMP and WFD objectives. Other mechanisms include:

[49] Impact_assessment_update_to_the_RBMPs_for_England_s_water_environment__2015_.pdf (publishing.service.gov.uk)

changes to abstraction licences outside of WINEP; Priority Catchment integrated catchment solutions; Environment Agency Environment Programme and Flood and Coastal Erosion Risk Management (FCERM) capital programme; Catchment Sensitive Farming Rural Development Programme; Development Planning - Statutory Biodiversity net gain; Drainage and Wastewater Management Plans; Environment Land Management Scheme; Highways England Strategic Road Investment Strategy; Local Nature Recovery Strategies; Regulation of agricultural and rural land (including targeted regulation of protected areas such as Nitrogen Vulnerable Zones); Water Industry Green Recovery Programme. Mechanisms fall under various types including:

- Advice
- Incentives
- Partnerships
- Regulation
- Strategic Planning
- Guidance
- Policy change

The Water Abstraction Plan 2017[50] sets out how water abstraction management will reform over the coming years. It states how this will protect the environment and improve access to water in line with the RBMPs. The plan has 3 main parts to: address unsustainable abstraction; develop a stronger catchment focus; modernise regulation. The Catchment abstraction management system (CAMS) translates the RBMPs and the Water abstraction plan into the licensing policy. CAMS is a standard approach to assess the amount of water available for further abstraction licensing, taking into account what the environment needs. The UK Technical Advisory Group (UKTAG) is responsible for developing environmental standards and conditions for achieving WFD requirements for rivers and lakes. The standards vary by river type and flow, with stricter standards at lower flows and for water body types considered more sensitive to abstraction. UKTAG identify percentage change from natural flow for differing river ‘types’ and at different flows, which are translated into an Environmental Flow Indicator (EFI). The EFI is set at a level believed to support Good Ecological Status. Abstraction Licensing Strategies are specified for each management catchment in England, setting out how abstraction will be managed.[51]

The EFI defines ecologically acceptable deviation from natural flow at various points in the flow curve, grouped according to the deemed sensitivity of the river: there are three Abstraction Sensitivity Bands (ASB). A greater reduction is acceptable when flows are high than when they are low. For example, the percentage of allowable deviation from natural flows of an ASB3 (the most sensitive) river is 24% at Q30 and 10% at Q95.[52]

The Catchment Based Approach (CaBA) is an inclusive, civil society-led initiative that works in partnership with Government, Local Authorities, Water Companies, businesses and more, to maximise the natural value of our environment. Catchment partnerships bring local knowledge and expertise, and are active in all operational catchments across England.

Meanwhile, Natural England are leading development of a national framework of green infrastructure standards, committed to in the 25 Year Environment Plan (2018)[53]. These aim to contribute to healthy, resilient places and an improved water environment by mainstreaming the planning, creation and stewardship of good green and blue infrastructure for multiple benefits including flood and water management. The framework is planned for launch in Spring 2022 and will include a set of principles,

[50] https://www.gov.uk/government/publications/water-abstraction-plan-2017/water-abstraction-plan
[51] Managing water abstraction - GOV.UK (www.gov.uk)
[52] CaBA CSRG Strategy MAIN REPORT FINAL 12.10.21 (catchmentbasedapproach.org)
[53] https://www.gov.uk/government/publications/25-year-environment-plan

standards, design code and national mapping including for blue infrastructure. The application of the standards will principally be through place-makers such as local authorities and developers.

B.3 Water resources

Water companies prepare a water resources management plan (WRMP) every five years, setting out how they intend to achieve a secure supply of water for customers, and a protected and enhanced environment, as required by the Water Industry Act 1991. WRMPs are primarily specified to maintain continuity of supply, relying on licensed abstraction limits to protect the environment, and taking account of abstraction licence volumes identified in WINEP. WRMPs should now reflect the ambitions of the 25 Year Environment Plan (2018), including:

- setting ambitions for environmental sustainability and resilience
- supporting nature recovery
- using natural capital in decision making
- using a catchment approach
- delivering net gain for the environment

Water resources are also of critical importance to agriculture, particularly spray irrigation, power supply, industry, and food and drink processing. These resources are allocated through abstraction licences, issued and managed by the Environment Agency to meet RBMP objectives. Licences specify abstraction limits of one or more designated time period (e.g. annual, daily) and may be subject to environmental flow or level constraints. Maintaining sufficient water resources for non-PWS activities is the responsibility of licence holders, who may for example build storage to mitigate periods of dry weather, although regional water resource planning groups should now work with local business sectors that use non-mains supplies to seek innovative, cross-sector solutions including funding arrangements.

Local Plans have a role to play in determining demand for additional water via the per capita consumption (PCC) requirement for new homes and any other building standards specified for water use.

B.4 Drainage and wastewater

The Drainage and Wastewater Management Plan (DWMP) framework outlines how environmental risks should be assessed using agreed planning objectives. Companies establish planning objectives against which catchment constraints are to be assessed and interventions developed. Planning objectives are the identifiers which trigger when a risk should be investigated further and directs the solution that may be required. They are used in the Baseline Risk and Vulnerability Assessment (BRAVA) stage of the DWMP to understand the level of risk a catchment holds, and how complicated it might be to mitigate that risk. Future scenarios are modelled against each Planning Objective which is then scored in a band (Not significant; Moderately significant; Very significant) depending on the risk compared to threshold levels.[54]

Six common planning objective criteria are used by all water companies[55]:

- risk of sewer flooding in a 1 in 50-year storm
- storm overflow performance
- risk of wastewater treatment works quality compliance failure
- internal sewer flooding risk
- pollution risk
- sewer collapses risk

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[54] drainage-and-wastewater-management-plan.pdf (anglianwater.co.uk)

[55] BRAVA-planning-objectives-for-the-first-cycle-of-DWMPs.pdf (water.org.uk)

Additional bespoke planning objectives are specific to each individual company's priorities and developed with local stakeholder consultation. Anglian Water's draft DWMP planning objective definitions are presented in Figure B.1 below.

Figure B.1: DWMP planning objective definitions

Planning objective definitions:

Risk of Sewer Flooding in a 1 in 50 Storm
1 in 50 design storm event, which equates to a 2% probability of the rainfall event occurring in any given year.

Storm Overflow Performance
The number of spills from Storm Overflows (SOs).

External Sewer Flooding Risk
The number of outside areas within a boundary curtilage flooded by water from our sewers.

Internal Sewer Flooding Risk
The number of properties flooded internally by water from our sewers.

Pollutions Risk
Number of pollution incidents classed as Category 1-3 by the Environment Agency.

Sewer Collapses
Number of sewer collapses.

Dry Weather Flow (DWF) Compliance
Percentage of measured DWF vs permitted DWF.

WRC Quality Compliance
Compliance with the environmental obligations outlined as the sanitary standards in the permit.

Access to Amenity Areas
Amenity score per catchment based on green space use.

Green Infrastructure
Amount of green infrastructure within a catchment

Alongside the Planning Objectives outlined above, the DWMP also asks us to review our assets in all catchments for their resilience against a range of measures.

Source: Anglian Water DWMP Strategic Context report[56]

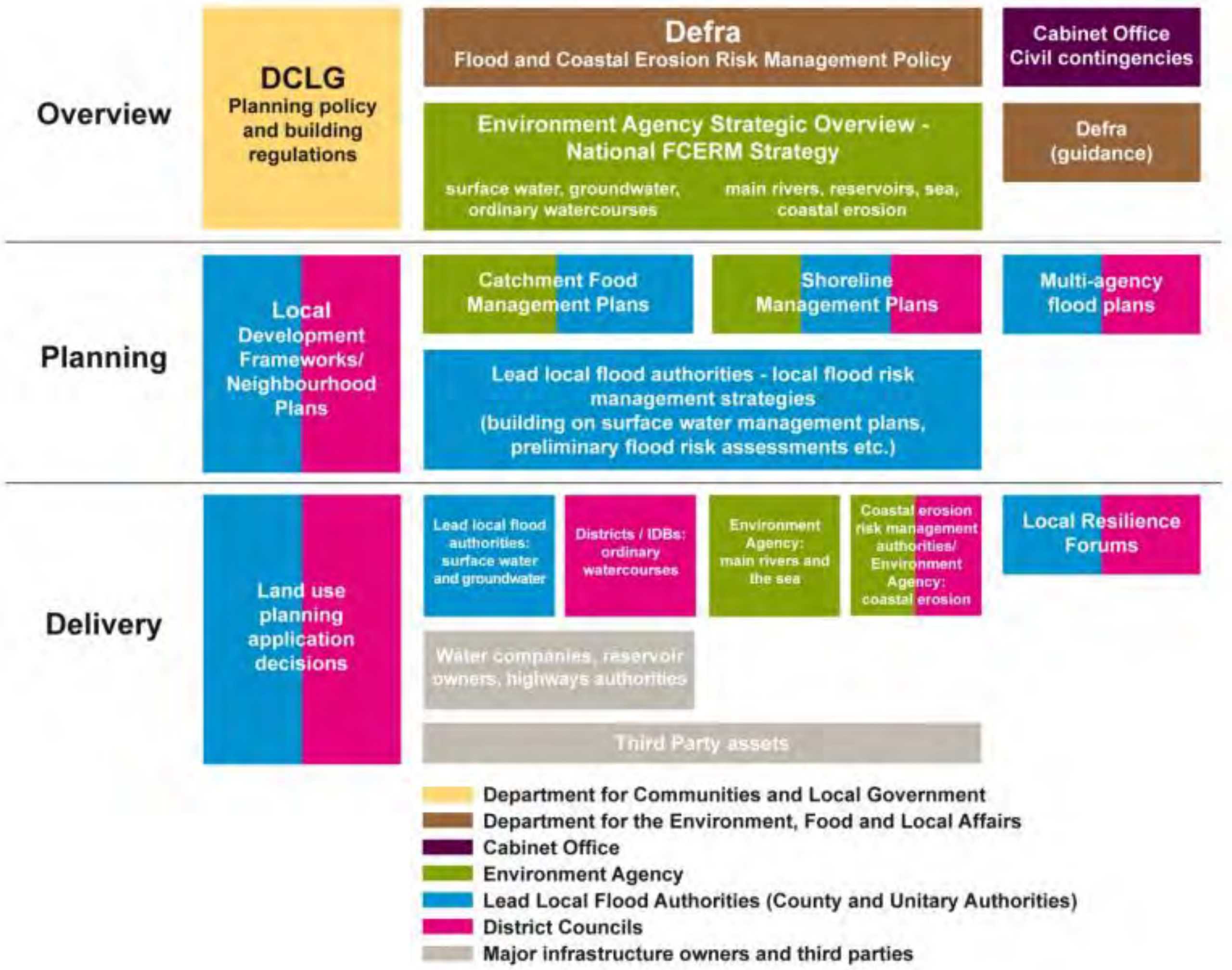
WINEP, WRMP and DWMP are funded by water company customers (in proportion to their property rating or water used), subject to scrutiny by Ofwat in the Price Review. Ofwat evaluates funding requests against criteria including Need, Best Option, Cost Efficiency and Customer Protection. It also specifies "outcome delivery incentives" for performance commitments associated with the key obligations of the water company. If water companies do not demonstrate effective plans, then those plans may not secure additional enhancement funding, or funding only in part, and the companies will have to deliver their objectives through baseline funding (effectively reducing profit). If they fail to deliver their objectives, they may suffer financial penalties, further eroding profit, and/or be subject to legal action if they break a statutory requirement.

B.5 Flood risk management

Flood risk management, planning and delivery in England is undertaken by a number of different organisations. In 2014, the overview of roles and responsibilities was as shown in Figure B.2. We note that the Department for Communities and Local Government (DCLG) has been replaced by DLUHC, but otherwise the structure remains broadly the same in 2022.

[56] drainage-and-wastewater-management-plan.pdf (anglianwater.co.uk)

Figure B.2 2014 Overview of the main roles and responsibilities for flood and coastal erosion risk management in England



Source:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/381939/FCRM_Long_term_investment_scenarios.pdf

The National FCERM Strategy for England describes what needs to be done by all risk management authorities (RMAs) involved in flood and coastal erosion risk management for the benefit of people and places. This includes:

- the Environment Agency
- lead local flood authorities (LLFAs)
- district, borough, metropolitan, county and unitary councils (as LPAs)
- internal drainage boards (IDBs)
- highways authorities
- water and sewerage companies

The Environment Agency publishes a Long-term Investment Scenarios study (LTIS), an economic assessment of future flood and coastal erosion risk management for the next 50 years. It evaluates the challenges of managing flood and coastal erosion risk in the face of asset deterioration, climate change and a growing population. LTIS sets out the total national level of investment if flood risk investment is delivered in all the places where the benefits are greater than the costs.

The Environment Agency produces Flood Risk Management Plans, specifying the nature of flood risk and tables of measures identified to manage flood risk within the River Basin Districts. These include flood defences, which are appraised based on benefit/cost ratios. Historically, a ratio of at least 8 has been required to obtain public funding for a flood defence to go ahead, although this requirement is less relevant now where partnership funding is available. Flood zones are defined based on existing risk of flooding from rivers and the sea, as described in Table B.1.

Table B.1: Flood Zones Definitions

Flood Zone	Definition
Zone 1 Low Probability	Land having a less than 1 in 1,000 annual probability of river or sea flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding; or land having between a 1 in 200 and 1 in 1,000 annual probability of sea flooding. (Land shown in light blue on the Flood Map)
Zone 3a High Probability	Land having a 1 in 100 or greater annual probability of river flooding; or Land having a 1 in 200 or greater annual probability of sea flooding.(Land shown in dark blue on the Flood Map)
Zone 3b The Functional Floodplain	This zone comprises land where water has to flow or be stored in times of flood. Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and its boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)

Source: https://www.gov.uk/guidance/flood-risk-and-coastal-change#flood-zone-and-flood-risk-tables

LLFAs produce Surface Water Management Plans (SWMPs), which include an investigation of surface water flooding problems within a borough or area and provide detailed modelling and mitigation options appraisal for areas with the highest risk of surface water flooding, known as "wetspots". They also produce Flood Risk Management Strategies (FRMSs), statutory documents which provide guiding principles and objectives that help to manage flood risk within the LLFA.

Strategic Flood Risk Assessments (SFRAs) are produced by district, borough, metropolitan, county and unitary councils to inform development in their authority administrative area. They provide information about the flood risk and flood management in their authority administrative area, used to inform the baseline water system description and capacity assessments.

Water Cycle Studies (WCS) are produced by District Councils to assess the constraints and requirements on the water environment that may arise from development in the area.

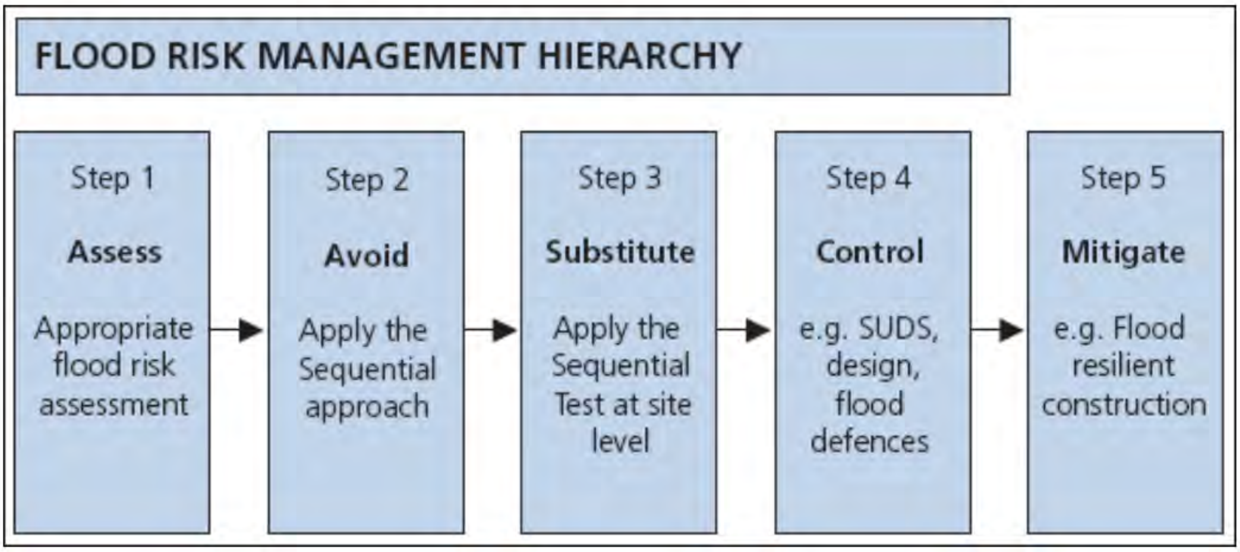
Some LPAs such as Greater Cambridge are combining WCSs with SFRAs to create IWM Studies, which also seek to integrate the issues through narrative and evaluative means where the data itself typically does not integrate.

A major challenge for all RMAs, including LPAs, has been taking a pro-active and catchment based approach to climate adaptation as required by the NPPF. The Localism Act 2011 'duty to cooperate' has thus far not been applied to compel LPAs to do this across boundaries. Flood modelling is still being integrated to a catchment or sub-catchment level - for example a fenland model is underway to take a forward look at climate change and options to address it.

The EA is undertaking various other catchment scale studies to build full catchment portraits and test options to address climate change and land use change. Growth provides both risks and opportunities to deliver flood resilience

Any Flood Risk Assessment should be in line with the NPPF and FCERM and should apply the Flood Risk Management Hierarchy i.e. assess, avoid, substitute, control and mitigate as shown in Figure B.3.

Figure B.3: Flood Risk Management Hierarchy



NPPF policy directs vulnerable development away from areas of flood risk and contains two tests for development to pass in order for LPAs to determine, in their development management functions, that it is acceptable, in policy terms, and in particular for development in areas of existing flood risk. Firstly, the Sequential Test, as set out in Paragraph 161 of the NPPF seeks to ensure that a sequential approach is followed to steer vulnerable new development to areas with the lowest probability of flooding. The flood zones as defined in the Strategic Flood Risk Assessment by the relevant council for the area concerned, and provide the basis for applying the Sequential Test. The vulnerability of various new developed is defined in Annex 3 of the NPPF.

The aim of the Sequential Test is to steer vulnerable new development to Flood Zone 1 (areas with a low probability of river or sea flooding). Where there are no reasonably available sites in Flood Zone 1, LPAs should take into account the flood risk vulnerability of land uses in their development management decision making functions. They should apply the Sequential Test and consider reasonably available sites in Flood Zone 2 (areas with a medium probability of river or sea flooding), applying the Exception Test if required. Only where there are no reasonably available sites in Flood Zones 1 or 2 should the suitability of sites in Flood Zone 3 (areas with a high probability of river or sea flooding) be considered for the development, taking into account the flood risk vulnerability of land uses and applying the Exception Test if required.

The Exception Test, as set out in Paragraph 160 of the NPPF, is a key development management tool, therefore, to ensure that flood risk to people and property will be minimised and managed satisfactorily, while allowing necessary development to progress in situations where suitable sites at lower risk of flooding are not available. Paragraph 164 of the NPPF seeks to ensure that flood risk mitigation is secured, and states that for the scheme to pass the Exception Test, it must “a) provide wider sustainability benefits the community that outweigh flood risk, and b) that the development will be safe for its lifetime, taking account of the vulnerability of its users, without increasing flood risk elsewhere and, where possible, reduce flood risk overall”.

B.6 Wider policy considerations

Through our regulatory and policy review, system mapping and evidence gathering, we identify a number of ways in which policy and/or regulation, beyond urban planning, could be enhanced to support delivery of the environmental ambitions within the OxCam Arc. These changes are for consideration in the next phases of IWMF development, and potentially beyond the scope of the OxCam IWMF.

- Chalk streams could be assigned statutory protection and priority status to drive investment in water-resources infrastructure, water treatment, stronger planning controls and catchment-scale restoration. This could be achieved via Environment Act biodiversity targets, 30x30 Nature Compacts, Nature Recovery Network stated priorities, and/or Ministerial Guidance on River Basin Management Plans and strategic policies statement to Ofwat.[57]
- Monitoring of water bodies could be enhanced and standardised, with delivery supported through citizen science and voluntary initiatives. This could for example significantly improve understanding of storm overflow impacts on water bodies.
- A manual of river restoration best-practice principles and guidelines could be commissioned[58]
- A single, evidence-based, long-term plan for rivers could be created between Government, regulators, water companies, agriculture, highways and other sectors, as proposed by Water UK[59].
- Compulsory rules for farming could be specified as part of qualifying for new Sustainable Farming Incentive (SFI) payments, for example: compulsory buffer field margins; no ploughing near field gateways; no gateways at downhill edge or corner of fields; turn ploughs across downhill edge of sloping fields; no crop-lifting after end of October; mandatory over-winter cover crops.
- Enhanced ELMs SFI payments could be specified for zero till, green swales in field dips, settlement ponds, hedge restorations (especially where perpendicular to slope).
- Higher tier ELM incentives (Local Nature Recovery or Landscape Recovery) could prioritise restoration of headwaters, spring-line fens, riparian zones and floodplain.
- Highways policy could mandate that roadside drainage should not feed directly into chalk streams, instead directed either into plugged ditches or to settlement areas.
- Abstraction Sensitivity Banding could be reviewed, for example to specify higher status for headwaters than heavily modified lower reaches of some rivers.
- WFD water body assessment points, associated targets and boundaries could be reviewed to ensure that the EFI methodology adequately protects ephemeral and headwater streams and is appropriately applied in reaches where flow is of lesser significance.
  - EFI assessment points tend to be at waterbody boundaries, and include all wastewater discharges upstream. Stream headwaters may be upstream of these discharges and experience quite different flow conditions, such that the EFI may not be sufficient to protect the most environmentally sensitive reaches of the river.
- Restoration of flow to overcome WRGIS deficits could be prioritised based on ecological benefit of additional flow, taking account of other pressures.
- The Abstraction Incentive Mechanism could be reviewed for effectiveness and updated as necessary
- Regulation of fertiliser use could be improved, with more targeted use for crop types, e.g. organic manure nitrogen may be too high for wheat. Rotational livestock/arable cropping could be incentivised in preference to slurry spreading. Wider crop variety rotation could be encouraged. Should agricultural regulation around manure spreading be reviewed to enable more effective livestock/arable rotation? Regulation at moment says can't spread manure winter/autumn?

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[57] CaBA CSRG Strategy MAIN REPORT FINAL 12.10.21 (catchmentbasedapproach.org)

[58] CaBA CSRG Strategy MAIN REPORT FINAL 12.10.21 (catchmentbasedapproach.org)

[59] Water UK 2021: 21st Century Rivers Ten Actions for Change

- Farm business planning training could be rolled out to share best practice, help farmers deal with shifting global markets, etc.
- Catchment Permitting could be rolled out across the OxCam Arc, replacing individual WwTW permitting.
- Strategic land use planning could be expanded out beyond housing development, rather than relying on market incentives.

C. Evidence sources

C.1 Environment Agency

C.1.1 Catchment data[60]

The Environment Agency's Catchment Data Explorer was used to compile the following for each water body in the OxCam Arc:

- Classifications
- Challenges
- Objectives
- Measures
- Protected Areas

Table C.1: Data sources, items, and application

Dataset	Data Items
Classifications	Water body operational catchments Hydro-morphological designation. Overall, ecological, chemical, and quantitative status. Element classifications
Challenges	Activities and pressure tiers relating to specific water body challenges
Objectives	Overall, ecological, chemical and quantitative status objectives & justifications. Element classification objectives & justifications.
Measures	Draft river basin management plan summary programmes of measures & potential additional programmes of measures
Protected Areas	Protected areas as specified in relevant Directives mapped to water bodies

This data was used to populate the system maps and GIS maps, to determine weightings for the multi-criteria analysis, and to identify option types.

C.1.2 Discharge consents

Consented Discharges to Controlled Waters with Conditions were downloaded as an access database file from the Defra Data Services Platform on 6 November 2021.

Table C.2: Discharge consent data and application.

Database	Data Items
Consents_active	Discharge consent locations and corresponding water bodies
Effluents	Permitted dry weather flow rates for each consent
Determinands	Concentration limits for various determinands for each consent

Permitted dry weather flows (DWFs) were compared to both operational catchment areas, water management catchment areas and historical low flows (Q95s) from the National River Flow Archive (NRFA) to provide an indication of the artificial contribution to flows in each water body. Low flow data is defined in terms of "Q95", the flow rate which is exceeded for 95% of the historical record. DWFs considered in the analysis included trade (cooling, processing, and site drainage), sewage (final treated effluent and sewer

[60] https://environment.data.gov.uk/catchment-planning

storm overflow) and agricultural surface water contributions, excluding flows received on land and to groundwater. DWFs were summed for each catchment with the contribution from each effluent type calculated.

The Consented Discharges data also specifies determinand concentration limits, which can be used as an indication of receiving water body capacity at low flows in terms of water quality; the lower a concentration limit and the closer it is to the technically achievable limit (TAL), the less capacity the receiving water body has to receive more wastewater. TAL is the minimum determinand concentration in effluent that can be delivered with existing treatment technology. This information is used as part of a Hotspot Mapping (reported separately).

C.1.3 Event duration monitoring – storm overflows

The event duration monitoring dataset relates to the performance of storm overflows, provided by Water and Sewerage companies for the 2020 regulatory annual return. This was accessed from the Defra data platform to understand the frequency and duration of storm overflows. The data is subject to a conditional Environment Agency licence.

C.1.4 WINEP

The Water Industry National Environment Programme (WINEP) was downloaded from the Defra Data Services Platform on 11 November 2021. Schemes were compiled and mapped in terms of their Core Obligation, Action Type, and Driver. They were also added to the compiled option set, with information from WINEP used as part of the MCA scoring.

Proposed permit limits for phosphorous concentration were used in preference to discharge consent determinand limits where applicable, to inform wastewater capacity constraints.

C.1.5 Flood risk assessments

The following Environment Agency maps were downloaded to provide high-level information on the current flood risk status and level of defence within the OxCam region:

Table C.3: Flood risk assessment data and application.

Dataset	Description
Flood Map for Planning: Flood Zone 2	Area of land at risk of flooding in a 0.01% annual exceedance probability event, ignoring the presence of defences.
Flood Map for Planning: Flood Zone 3	Area of land at risk of flooding in a 1% annual exceedance probability event ignoring the presence of defences.
Risk of Flooding from Surface Water Hazard: 0.1%, 1% and 3.3% annual exceedance probability	Three separate GIS layers showing the flood hazard rating for flooding from surface water that could result from a flood with a 0.1%, 1% or 3.3% chance of happening in any given year.
Flood Risk Areas	Locations where there is believed to be significant flood risk from both fluvial or pluvial flooding. Help to define where flood risk management plans are needed.
AIMS Spatial Flood Defences	Map of flood defences currently owned, managed or inspected by the EA.
Flood Map for Planning: Areas Benefitting from Defences	Areas that benefit from the presence of defences in a 1 in 100 (1%) chance of flooding each year from rivers. These areas would flood in a 1% AEP event if the defences were not present.
Flood storage areas	Areas that act as a balancing reservoir, storage basin or balancing pond to reduce flood risk.

In addition to this, a review of the 2015-2021 Flood Risk Management Plans for the Thames and Anglian River Basin Districts was also undertaken. This included a review of the nature of flood risk within each of the

River Basin sub-catchments and a review of the tables of measures identified to manage flood risk within the River Basin Districts. These tables of measures were collated and where possible, coordinates were added to map the schemes. A review of the draft 2021-2027 Flood Risk Management Plans has also been undertaken. Information about the flood risk and management strategies for areas identified as Flood Risk Areas (nationally identified areas with a high risk of flooding) was extracted from the plans and coordinates were added allowing the Flood Risk Areas to be mapped.

A list of current and future flood risk management projects had been provided by the Environment Agency. Where possible, coordinates have been added allowing the scheme to be mapped. Mapping of these schemes informs the capacity assessment allowing the identification of areas where additional flood risk protection is being considered.

C.1.6 WRGIS surplus/deficits

The Environment Agency provided us with confidential surplus and deficit quantities for each water body from the Water Resources GIS (WRGIS) under the 2050 business as usual and 2050 enhanced scenario:

1) The information provided is based on WRGIS dated February 2019, where natural flows, groundwater recharge and abstraction rates have been estimated for 2050.

2) This data is based on integrated water bodies which are a combination of Water Framework Directive Cycle 2 water bodies and Abstraction Licensing Strategy assessment points.

3) It is an estimate of the surplus/ deficit against Environmental Flow Indicator (EFI) in Ml/d for both Future Predicted and Fully Licensed Scenarios.

4) It is the average of Low (Q70) and Very Low (Q95) flow conditions based on total upstream catchment outflows and sub-catchment outflows.

5) It is based on analysis under AFIXK, one of the 11 possible ensembles from the Future Flows dataset.

6) The Environment Agency allowed the future predicted abstraction and discharge rates to exceed the fully licensed rates as this represents where abstractors may require more water in 2050 compared to what they are licensed to abstract now.

7) The Environment Agency has not changed the modelling of reservoirs or regulated river systems to account for the potential impacts of climate change.

C.1.7 Source Protection Zones

New development in the OxCam Arc has the potential to impact the water quality of abstractions for public or private water supply. The Environment Agency must protect groundwater sources used to supply drinking water from pollution and it does so through the definition of source protection zones, which show the level of risk to the source from contamination. This could be from any activity that might cause pollution in the area. Three zones are defined as follows:

- Inner zone – SPZ1. This zone is 50-day travel time of pollutant to source with a 50 metres default minimum radius.
- Outer zone – SPZ2. This zone is 400-day travel time of pollutant to source. This has a 250 or 500 metres minimum radius around the source depending on the amount of water taken.
- Total catchment – SPZ3. This is the area around a supply source within which all the groundwater ends up at the abstraction point. This is the point from where the water is taken. This could extend some distance from the source point.

We use this information as part of hotspot mapping (reported separately).

C.2 Water companies

C.2.1 WRMP19

WRMP19 data was provided by the Environment Agency to show the supply demand planning tables compiled by components and Water Resource Zones. WRMP19 Market information tables published online were used to indicate the maximum potential water resources available to meet additional demand from OxCam development (feasible options not selected as preferred by 2045 at WRMP19). Feasible options included strategic supply options that are currently being progressed through RAPID gated process.

C.2.2 WRMP24

Approval was granted by Affinity Water, Anglian Water, South Staffs Water and Thames Water to access draft WRMP24 data to evaluate the latest WRSE supply demand balance for each environmental destination scenario for 2030, 2050 and 2080, and options data for SWOX and SWA. This data represents the most recent water resource information in developing the regional plan.

WRSE data includes a summary of the WRMP24 constrained feasible options (by WRZ and type), as well as which options are selected to maintain the supply demand balance under each of 9 scenarios. This information was provided in spreadsheet format.

WRE does not yet have the same breakdown of options by scenario available for review.

C.2.3 DWMP

The Drainage and Wastewater Management Plan (DWMP) framework outlines how risks should be assessed using agreed planning objectives. Planning objectives are the identifiers which trigger when a risk should be investigated further and directs the solution that may be required. They are used in the Baseline Risk and Vulnerability Assessment (BRAVA) stage of the DWMP to understand the level of risk a catchment holds, and how complicated it might be to mitigate that risk. Future scenarios are modelled against each Planning Objective which is then scored in a band (Not significant; Moderately significant; Very significant) depending on the risk compared to threshold levels.[61] The planning objective definitions are presented in Figure C.1 below.

Figure C.1: DWMP planning objective definitions

Planning objective definitions:

Risk of Sewer Flooding in a 1 in 50 Storm
1 in 50 design storm event, which equates to a 2% probability of the rainfall event occurring in any given year.

Storm Overflow Performance
The number of spills from Storm Overflows (SOs).

External Sewer Flooding Risk
The number of outside areas within a boundary curtilage flooded by water from our sewers.

Internal Sewer Flooding Risk
The number of properties flooded internally by water from our sewers.

Pollutions Risk
Number of pollution incidents classed as Category 1-3 by the Environment Agency.

Sewer Collapses
Number of sewer collapses.

Dry Weather Flow (DWF) Compliance
Percentage of measured DWF vs permitted DWF.

WRC Quality Compliance
Compliance with the environmental obligations outlined as the sanitary standards in the permit.

Access to Amenity Areas
Amenity score per catchment based on green space use.

Green Infrastructure
Amount of green infrastructure within a catchment

Alongside the Planning Objectives outlined above, the DWMP also asks us to review our assets in all catchments for their resilience against a range of measures.

[61] drainage-and-wastewater-management-plan.pdf (anglianwater.co.uk)

Source: Anglian Water DWMP Strategic Context report[62]

Anglian Water and Thames Water were both asked to provide DWMP options to mitigate the risks identified in BRAVA. Neither company is yet in a position to be able to share any of the draft DWMP options, but Anglian Water shared a list of option types for review. Generic Options were provided by Anglian Water, outlining potential options related to customer management, surface water management, combined foul and sewer systems and wastewater treatment. These options are used to identify potential DWMP intervention types which could be included in the OxCam framework.

Anglian Water also provided the table of options and expenditure profiles by WwTW specified in its Water Recycling Long Term Plan (2019), the report itself published online.

We have compiled this information for inclusion in the high-level MCA.

C.2.4 Wastewater

Anglian Water provided statistical summaries of 2020 measured flow data for all their wastewater treatment works, including Q80, Q90, max, min and mean flow. Q90 flow is also presented as a percentage of permitted dry weather flow, and sites are categorised as whether observed Q80 flow from the WwTW exceeds the dry weather permitted flow.

This data indicates where investment may be needed in wastewater infrastructure to avoid deteriorating water body status. Note, however, that the actual versus permitted flow data provides no indication of whether or not this investment is technically achievable, which requires consideration of permitted concentration values for different determinands, data which has been compiled from the published discharge consents and WINEP table.

The location and names of WwTW at risk of meeting their Technically Achievable limit were provided from Anglian Water for use in determining which WwTW are at risk of not meeting permit with any proposed increased development. Anglian Water also provided five scenarios for growth in “population equivalent” numbers for each of their WwTWs: one scenario derived from Local Authority forecasts and four scenarios derived from Edge Analytics’ four scenarios for OxCam Arc growth (Expansion growth v New Settlements for two rates of growth). This data could be used in subsequent analysis to evaluate specific development scenarios under the IWMF.

C.2.5 Surface water flooding

A data request has been submitted to Anglian Water and Thames Water to provide a list of any current or planned schemes to reduce surface water flood risk. Anglian Water stated they have four areas within the OxCam Arc, Peterborough, March, Kings Lynn and Watton, where they have a Surface Water Management Programme. A programme of measures will be implemented to try and remove surface water from the combined and foul sewer network. Data is yet to be received from Thames Water.

A range of measures to combat surface water flooding are included in DWMP potential option types. These mainly focus on the use of SuDS, measures to reduce and control the volume of surface water entering the foul and combined sewer system, and upgrades to the sewer network.

[62] drainage-and-wastewater-management-plan.pdf (anglianwater.co.uk)

C.3 Natural England

C.3.1 Protected areas

The Natural England Open Data Geoportal publishes Natural England datasets, including the location and number of protected areas across England. The number and type of protected areas which intersect waterbodies within the OxCam Arc are outlined in the table below:

Table C.4: Number and type of protected areas within OxCam Arc.

	Protected Area Type			
	Site of Special Scientific Interest (SSSI)	Ramsar Site	Special Areas of Conservation (SACs)	Special Protection Areas (SPA)
Number of sites intersecting waterbodies in OxCam Arc	**337**	**6**	**16**	**3**

SSSIs are the only protected area to have a condition/status specified. The condition of the SSSI land in England is assessed by Natural England, using categories across England, Scotland, Wales, and Northern Ireland through the Joint Nature Conservation Committee. There are six reportable condition categories: favourable; unfavourable recovering; unfavourable no change; unfavourable declining; part destroyed and destroyed[63]. The condition of individual SSSI's can be reviewed on the Natural England Designated Sites View website.

C.3.2 Natural capital

The OxCam Local Natural Capital Plan[64] (LNCP) has assessed the different habitats across the Arc and the corresponding ecosystem service, benefit, and value that they provide. The OxCam LNCP utilises the scoring matrix from Natural England's Environmental Benefits from Nature[65] (EBN) tool to understand the different services that habitats in the OxCam region offer. Natural capital assets and corresponding ecosystem services from the OxCam LNCP data were used to inform the IWMF system maps and MCA criteria.

C.4 Local authorities

C.4.1 LLFA Surface Water Management Plans

A review of the following Surface Water Management Plans (SWMPs) was undertaken:

- Cambridge and Milton
- Histon and Impington
- St Neots
- Ely
- March
- Chesham and High Wycombe
- Marlow
- Buckingham
- Wellingborough
- Kettering Borough

[63] Glossary (naturalengland.org.uk)
[64] Ox Cam LNCP
[65] The Environmental Benefits from Nature Tool - Beta Test Version - JP038 (naturalengland.org.uk)

- Daventry
- South Northamptonshire
- Northampton
- Milton Keynes
- Luton

SWMPs include an investigation of surface water flooding problems within a borough or area and provide detailed modelling and mitigation options appraisal for areas with the highest risk of surface water flooding, known as “wetspots”. Information about each wetspot and the preferred mitigation options were extracted from the reports including information about the cost and any additional benefits where this was available. A grid reference was added to each of the wetspots allowing these to be mapped.

C.4.2 Lead Local Flood Authorities Flood Risk Management Strategies

Flood Risk Management Strategies (FRMSs) are statutory documents produced by Lead Local Flood Authorities (LLFA). They provide guiding principles and objectives that to help manage flood risk within the LLFA. A review of the following FRMSs was undertaken:

- Cambridgeshire County Council LLFA
- Buckinghamshire County Council LLFA
- Northamptonshire County Council LLFA
- Oxfordshire County Council LLFA

Details of the main objectives for each LLFA were extracted from the reports helping to inform the baseline water system and capacity assessments.

C.4.3 District Council Strategic Flood Risk Assessments

Strategic flood risk assessments (SFRAs) are produced by District Councils to inform development in the region. They provide information about the flood risk and flood management in the region, used to inform the baseline water system description and capacity assessments.

The following SFRAs were reviewed:

- Cambridge and South Cambridgeshire- Level 1
- Huntingdonshire Level 1 and 2
- East Cambridgeshire
- Fenland District Council
- City of Oxford
- South Oxfordshire and Vale of White Horse
- Cherwell and West Oxfordshire
- Chiltern and South Buckinghamshire
- Wycombe
- Aylesbury Vale
- West Northamptonshire, South Northamptonshire, and Daventry
- Wellingborough
- Kettering
- Corby
- East Northamptonshire
- Milton Keynes
- Luton
- Bedford
- Central Bedfordshire

C.4.4 Water cycle studies

Water Cycle Studies (WCS) are produced by District Councils to assess the constraints and requirements on the water environment that may arise from development in the area. The following WCS were reviewed:

- East Cambridgeshire District Council
- Huntingdon District Council
- South Cambridgeshire District Council
- West Oxfordshire District Council
- South Oxfordshire District Council
- Vale of White Horse District Council
- City of Oxford District Council
- Cherwell District Council
- South Buckinghamshire District Council

The following WCS were excluded from the evidence collection as they were published before 2015:

- North Northamptonshire Council
- Northampton District Council / West Northamptonshire District Council

The following District Councils have not published a WCS:

- Chiltern District Council
- Wycombe District Council
- Aylesbury Vale District Council
- South Northamptonshire District Council

Cambridge City Council has not published a WCS, but the Greater Cambridge Shared Planning Service (GCSPS) has published an interim Integrated Water Management Study - Strategic Spatial Options Review for the Greater Cambridge area, to help inform the location and amount of development that may be planned for in the future.

The documents provide a useful compilation of information related to growth and development in each district, but we refer to the primary datasets referenced within them directly, rather than using the water cycle studies themselves for analysis.

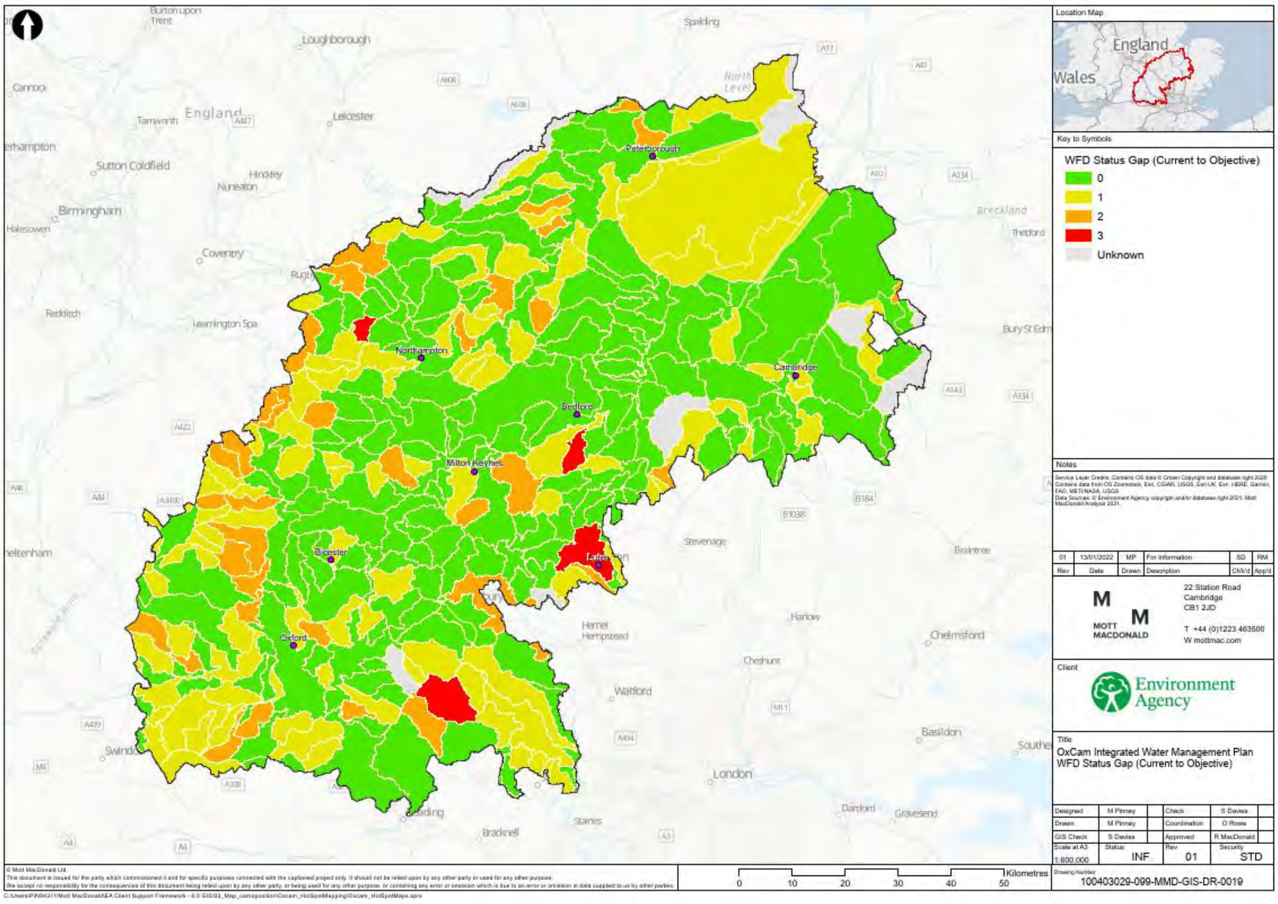
D. Hotspot desk study

To inform the IWMF development, understand the spatial distribution of key water system constraints, and support/inform developing thinking on spatial policy/land use, and potentially to inform subsequent IWMF policy, we undertook mapping of 8 key metrics, each of which indicates some degree of additional system stress relating to water. The results were also used to inform selection of pilot catchments for Phase 1a modelling (see Section 5.2). These should not be seen as provisional conclusions, noting that modelling in Phase 2 would provide further insight to inform spatial planning and infrastructure decision-making.

D.1.1 WFD status gap between current and objective

A notable gap between current WFD status and objective indicates that a water body has been identified as having challenges which should be overcome in the near future. Housing development could be a particular problem in these areas, making it more difficult to meet the WFD status objectives, and therefore development in these areas may present added risk, compared to water bodies subject to a smaller gap between current and objective status. Figure D.1 shows the gap between current and objective WFD status for waterbodies in the study area. This indicates areas potentially facing the greatest challenge to achieve river basin management plan objectives.

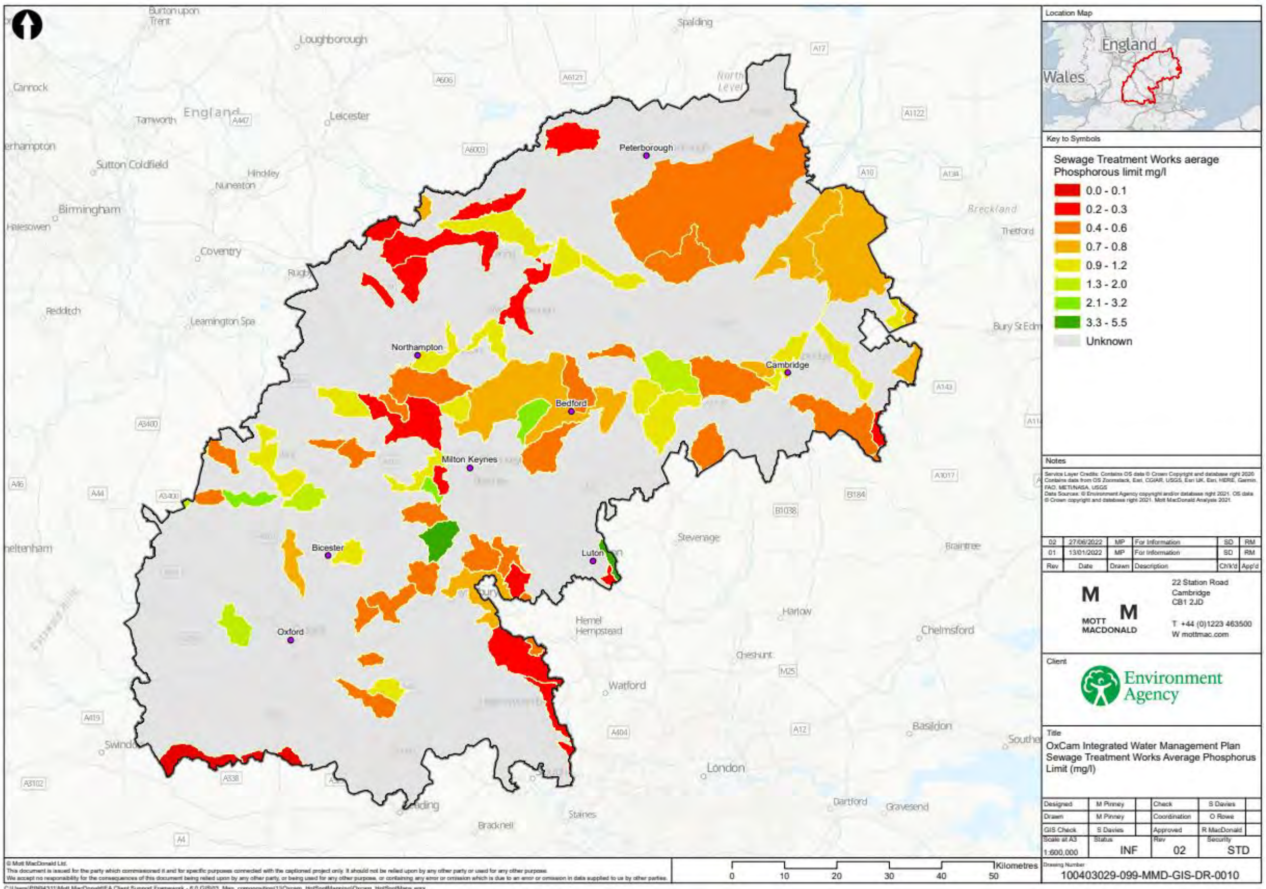
Figure D.1: Gap between objectives and current WFD status



D.1.2 WwTW consent average P limit (WINEP where specified, else existing consent)

Consented Discharges data specifies determinand concentration limits, which can be used as an indication of receiving water body capacity at low flows in terms of water quality: the lower a concentration limit and the closer it is to the TAL, the less capacity the receiving water body has to receive more wastewater (see Section 3.2.2). Figure D.2 shows the average phosphorous limit specified on discharge consents for all WwTW in each water body.

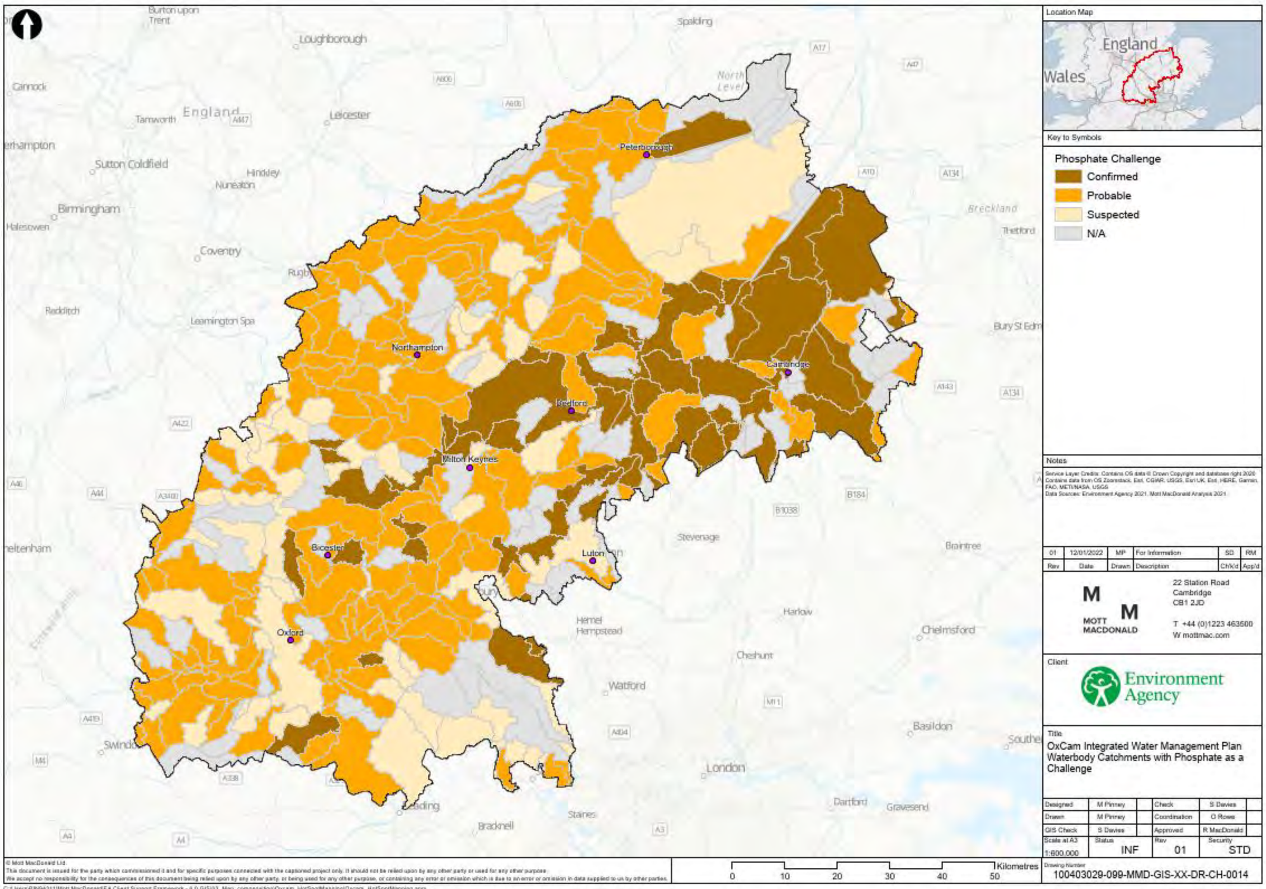
Figure D.2: WwTW average phosphorous limit by water body



D.1.3 Phosphorous challenge status

As phosphorous is one of the key challenges for OxCam water bodies, and new development has a potentially significant impact on phosphorous concentration via additional wastewater, the baseline phosphorous challenge (WFD phosphorous pressure certainty) is a potential indication that new development could add additional risk compared to water bodies without a baseline phosphorous challenge. Figure D.3 shows the WFD baseline phosphorous challenge.

Figure D.3: WFD Baseline Phosphorous Challenge



D.1.4 Potential nitrogen loading from farmland

We convert an estimate for potential nitrogen loading from farmland into an equivalent property density (properties per hectare). The more arable and livestock farm area in a catchment, the greater the total potential nitrogen loading from agriculture, and the more the potential for nutrient offsetting of new development.

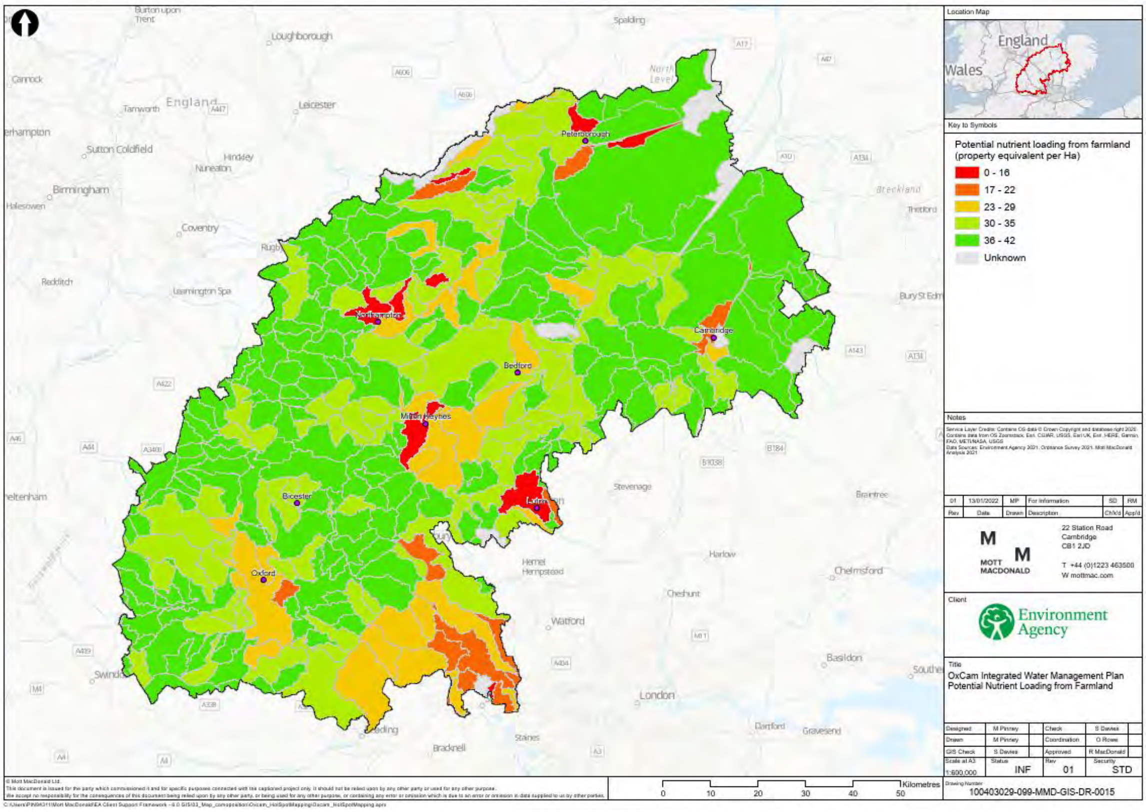
We use the Natural England study (ADAS modelled)[66] which suggests losses of 25kg/Ha per year for general cropping. We then assume that wastewater contains 6mg/l nitrogen, household PCC is 110l/h/d and occupancy 2.3 to determine a household load of 0.6kg per year, such that 1 hectare of general cropping land produces nitrogen loads equivalent to 42 new homes.

In theory, catchments with significant proportions of arable and livestock land should have greater potential to offset nutrients from new development, and therefore are better able to cope with new development from a water quality point of view.

Figure D.4 shows the property-equivalent nitrogen loading from farmland, a proxy for nitrogen neutrality offsetting potential.

[66] Natural England publishes 'nutrient calculator' and updated guidance on achieving nutrient neutral housing development - Partnership for South Hampshire (push.gov.uk)

Figure D.4: Nitrogen offsetting potential: property density equivalent to nitrogen loading from farmland



Our high-level analysis suggests that nitrogen neutrality offsetting potential is generally relatively high throughout the OxCam Arc, reflecting the significant area of arable and livestock agriculture in the Arc. There are exceptions around some urban areas and more upland wooded areas. However, Figure D.3 shows that typically these areas have less of a baseline phosphorous challenge than areas with higher offsetting potential, such that the two criteria tend to balance out (assuming phosphorous offsetting potential is relatively spatially coherent with nitrogen).

There may be some locations where new development may require transferring any wastewater elsewhere to meet a nutrient neutrality policy position, with corresponding offsetting in that receiving water body. The costs of doing so, and any negative effects that cannot be mitigated, should be taken into account in development plans.

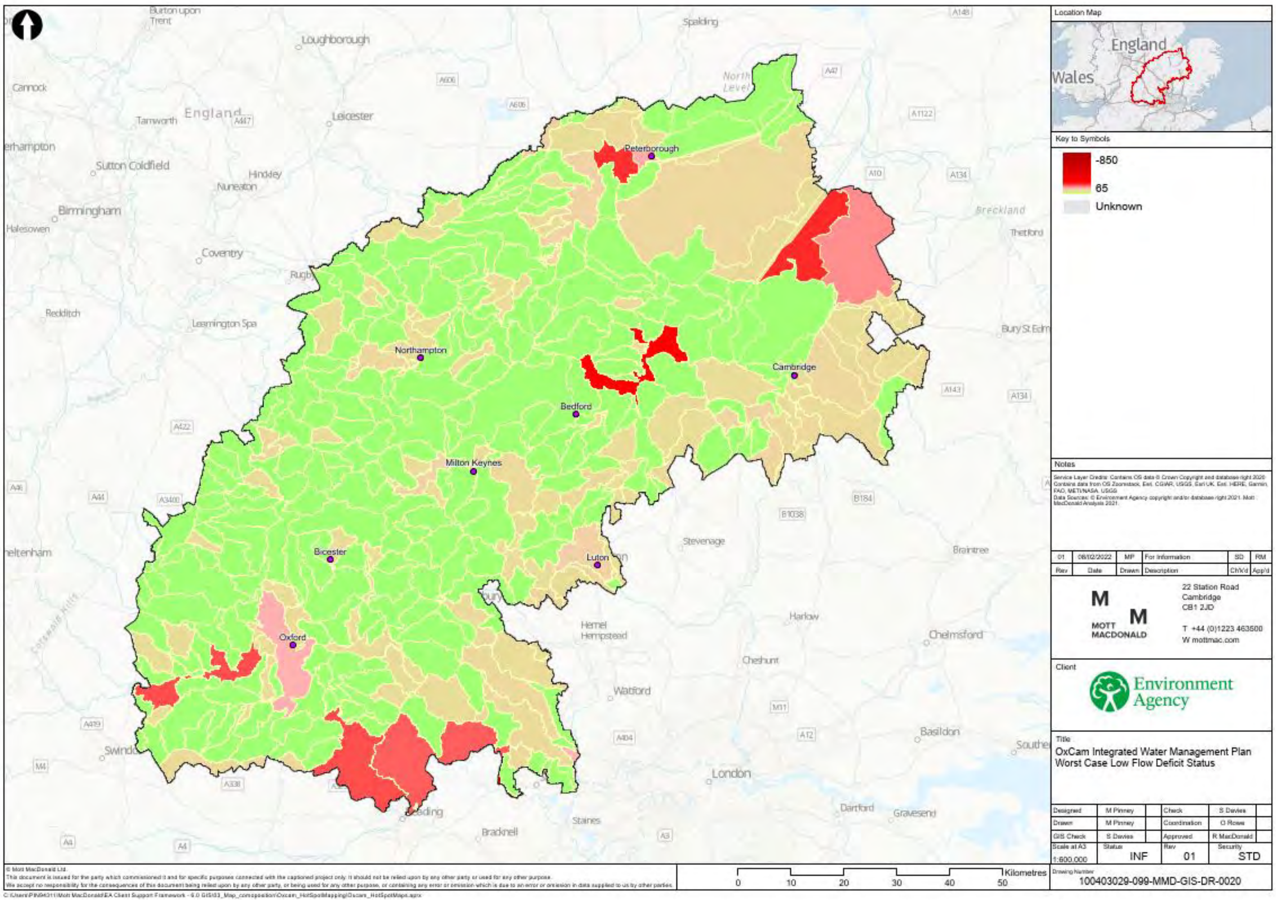
D.1.5 Environmental flow deficit

The Environment Agency estimates surplus/deficit against Environmental Flow Indicator (EFI) in Ml/d for both Future Predicted and Fully Licensed Scenarios averaged over Low (Q70) and Very Low (Q95) flow conditions based on total upstream catchment outflows and sub-catchment outflows. WRGIS deficits indicate water bodies potentially under pressure from low flows, which therefore may be less able to cope with additional pressure from new development.

We determine the largest deficit for each water body across "Business As Usual" and "Enhanced" scenarios of ambition, and across fully licensed and future predicted scenarios of abstraction, and use this deficit as a proxy for environmental flow deficit risk for hotspot mapping.

Figure D.5 shows where WRGIS suggests low flow deficits exist, and therefore where environmental flows may be experiencing greatest pressure. A significant part of the OxCam Arc has no deficit specified under any future scenario, but there are notable deficits along the southern boundary and various other locations.

Figure D.5: Worst-case low flow WRGIS deficits



D.1.6 Flood risk

<u>For hotspot mapping, a flood risk damage score was calculated using the following Environment Agency datasets:</u>

- Area in Flood Zone 2 (FZ2)
- Area in Flood Zone 3 (FZ3)
- Area at risk of surface water flooding (3.3% annual exceedance probability) (RoSWf)
- Area benefitting from defences

For each waterbody the number of properties at risk from flooding was estimated by intersecting the Environment Agency datasets with OS MasterMap data. The following calculation was then used to calculate the proposed baseline flood damage score:

Weighted annual flood damage score = Number of buildings only in FZ2 + Number at RoSWf + Number undefended buildings in FZ3*2 + Number defended buildings in FZ3*0.05

As Flood Zone 3 is the zone at highest risk of flooding, the number of undefended buildings in Flood Zone 3 was multiplied by two to represent this increased risk. The number of defended buildings in Flood Zone 3 was multiplied by 0.05 to represent the residual risk of defence failure/overtopping. These values were normalised against the largest value giving a range in annual flood damage score between 0 and 1. The process was repeated for the number of buildings in each operational catchment.

The adjustment risk factors are indicative only at this stage, to inform choice of catchment for pilot detailed MCA. We grouped up water bodies into bands of high/medium/low risk based on the scores.

A climate change flood risk score was calculated using modelled scenario data from the OxCam flood risk investment study (data provided by Environment Agency) by performing the following steps:

1. Calculating the difference of properties between the *100yr_year90_Upper_end_res* scenario (1 in 100 year event, Upper End scenario residential, 90 years in the future from 2020) and *100yr_year0_Baseline_res* scenario (1 in 100 year event, baseline scenario residential, base year: 2020)
2. Calculating the % increase of properties between the *100yr_year90_ Upper_end _res* scenario compared to *100yr_year0_Baseline_res* scenario
3. A score of 3 (high score) is given to waterbodies with a % increase of more than 100% and a difference of greater than 100 properties
4. A score of 1 (low score) is given to waterbodies with a 0-25% (0% excluded) increase in the number of properties or a difference of 1-20 properties
5. A score of 0 is given to waterbodies with no change between the 2 scenarios (0 % increase in the number of properties)
6. A score of 2 (medium score) is given to all other waterbodies

Figure D.6 and Figure D.7 show the flood risk bands determined for water bodies and operational catchments respectively. The boundaries between risk bands are arbitrary, and there is no clear pattern to the results. Figure D.8 shows the results of the climate change risk scoring for flood risk. Baseline flood risk band alone may be unlikely to influence development, as flood risk is already accounted for in spatial planning guidance: for all development larger than 1 hectare or any proposed for flood zone 3 or above, a flood risk assessment must be carried out. Building in any area identified as being at medium to high flood risk is strongly discouraged and where it is absolutely necessary, mitigations must be specified, both for the new properties and any existing property placed at further risk.

However, there are some catchments where it is difficult, if not impossible, to avoid development in areas at risk. It is these catchments where a strategic sequential approach needs applying to avoid steering strategic development in that direction. Flood risk scores could be taken into account to inform the weighting of flood protection criteria used in the next stages of MCA.

Figure D.6: Water body flood risk bands based on number of properties within each flood zone and number of properties protected

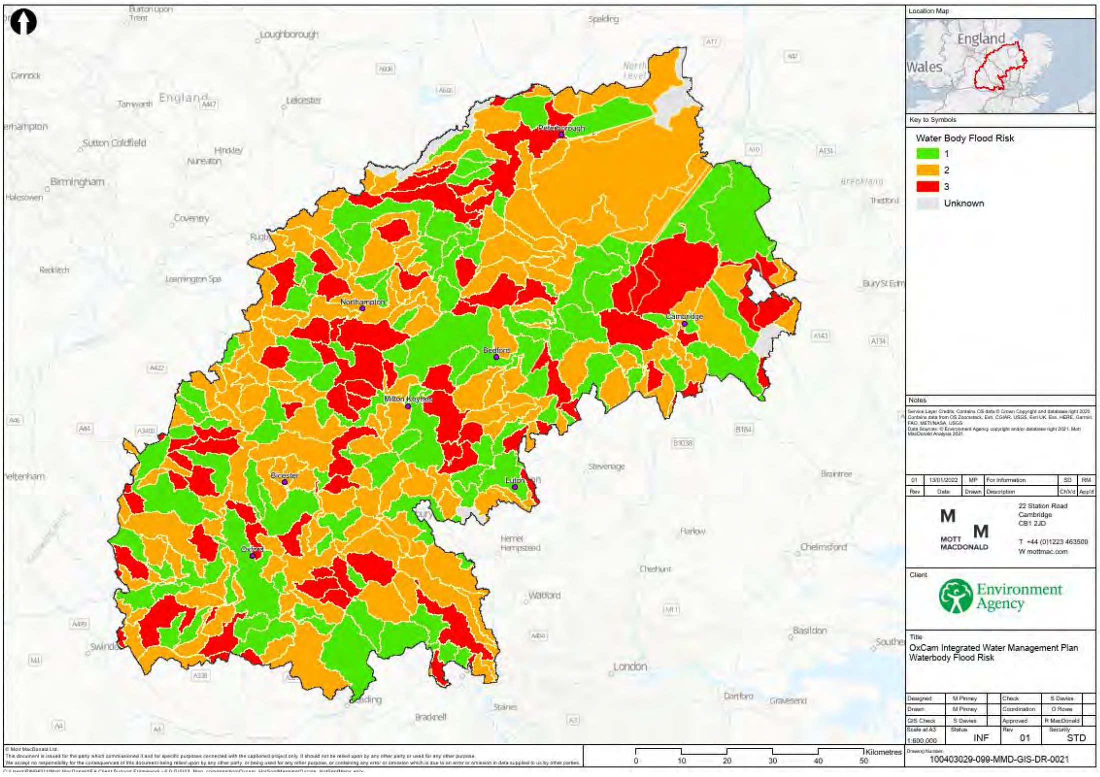


Figure D.7: Operational catchment flood risk bands based on number of properties within each flood zone and number of properties protected

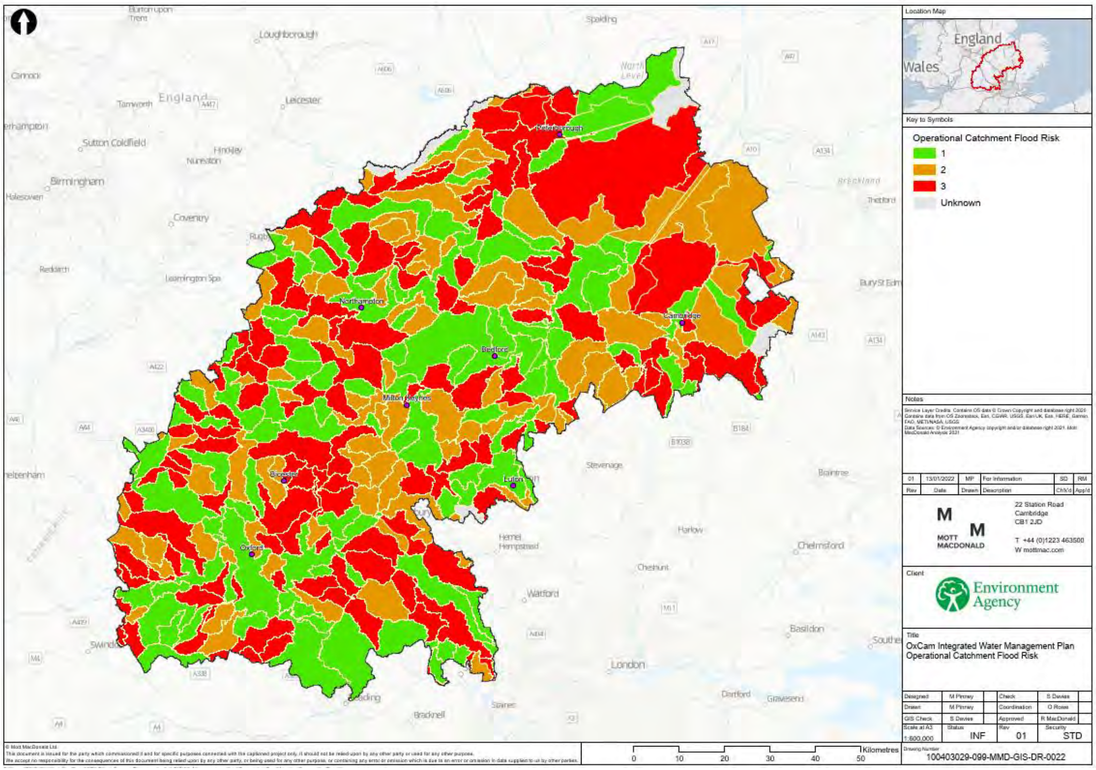
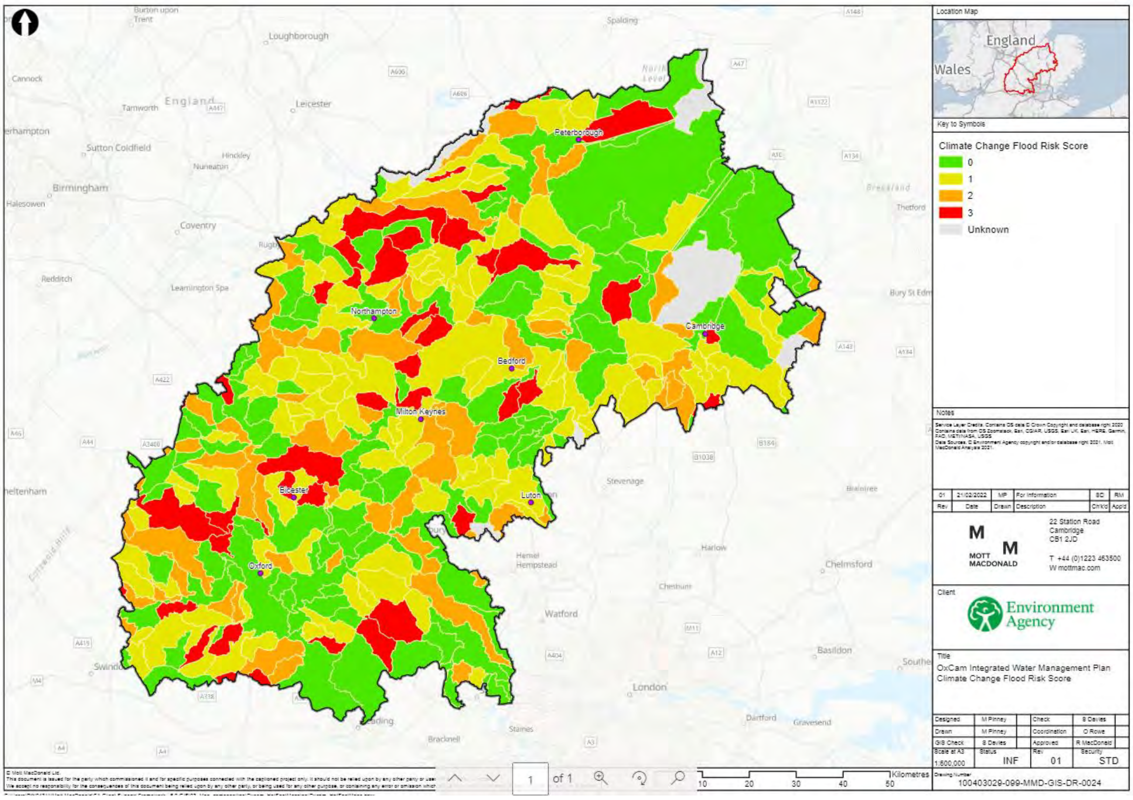


Figure D.8: Water body flooding climate change risk score

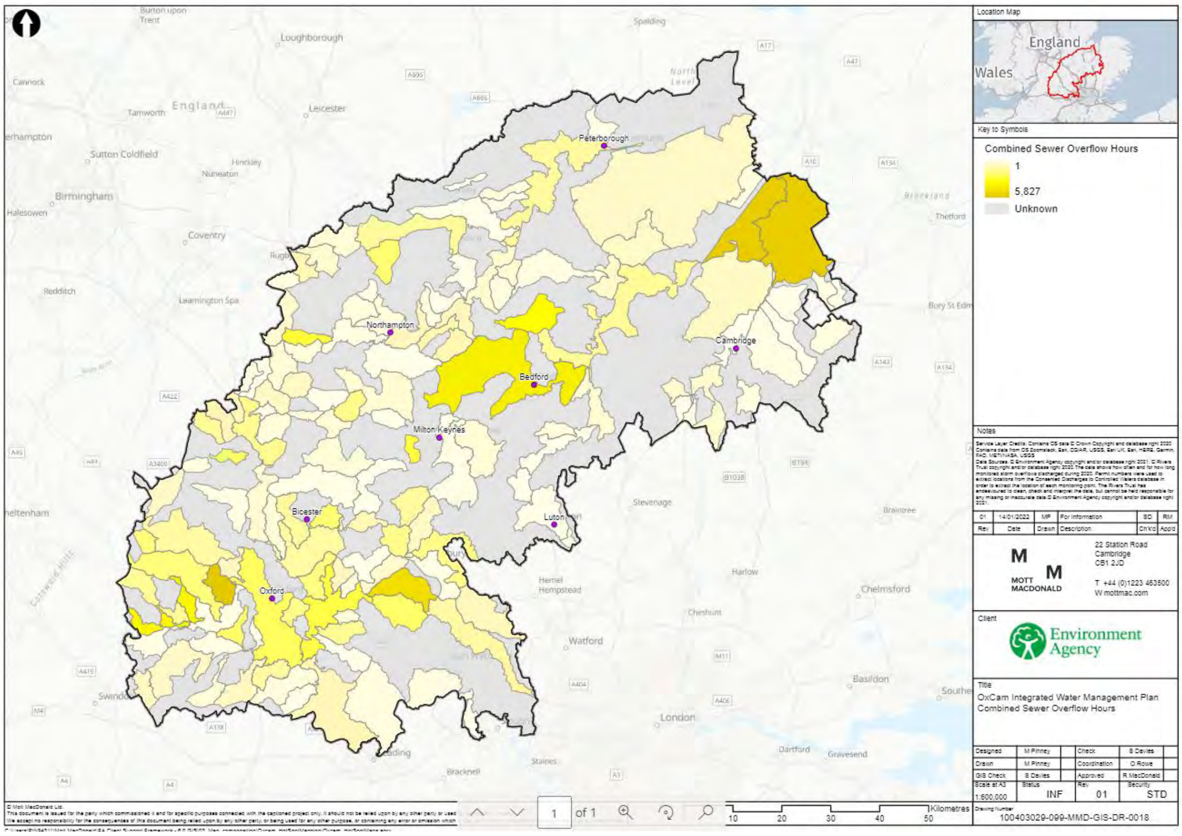


D.1.7 Hours CSO overflow

We use total hours combined sewer overflow data summed across all WwTW in a water body to indicate where wastewater infrastructure struggles to cope with existing high rainfall conditions, which could potentially impact water quality and bathing water potential. Additional wastewater from new development could exacerbate these pressures on wastewater infrastructure.

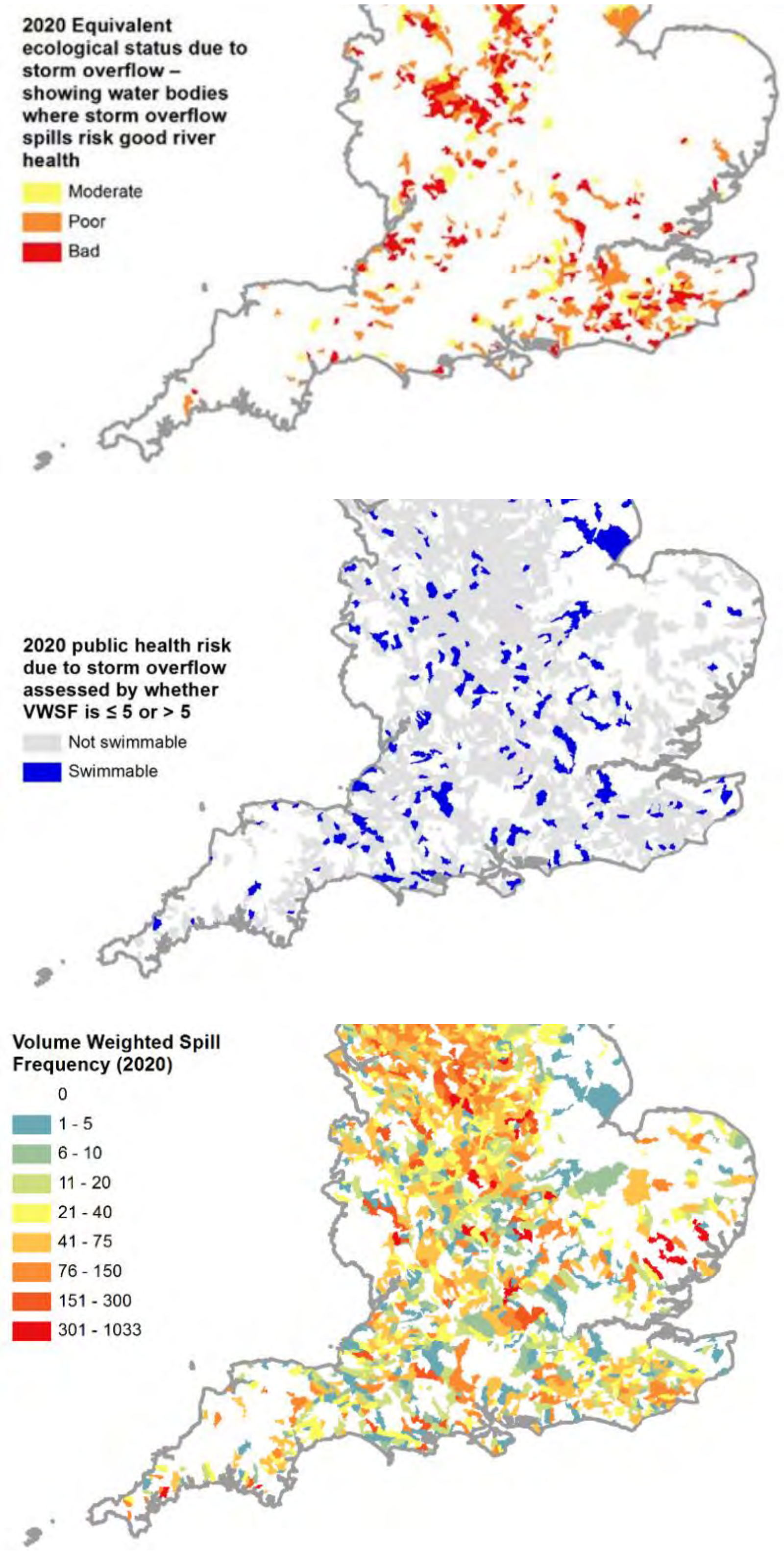
Figure D.9 shows high-flow network capacity risks based on total combined sewer overflow hours. This is a very rough proxy as it takes no account of the quality of the overflow water, and other contributing factors to high-flow water quality, such as agricultural run-off. There is no obvious pattern to the results, with many water bodies recording no overflow data.

Figure D.9: High-flow network capacity risks based on total combined sewer overflow hours



The Storm Overflows Evidence Project goes further by estimating water body metrics for the impact of storm overflows on river health, public health and social impact, as presented in Figure D.10. See Section 3.2.3 for more information.

Figure D.10: Storm Overflows Evidence Project Measures of Storm Overflow Impacts on River Health (top), Public Health (middle) and Social Impact (bottom)



Source: Storm overflows evidence project (publishing.service.gov.uk)

D.1.8 Soil health

Soil health could have a bearing on whether development is more or less appropriate in a water body catchment in that better soil health tends to improve water quality, low flow discharge, flood risk, etc. This would need to be traded off against the potential for new development to damage healthy soil.

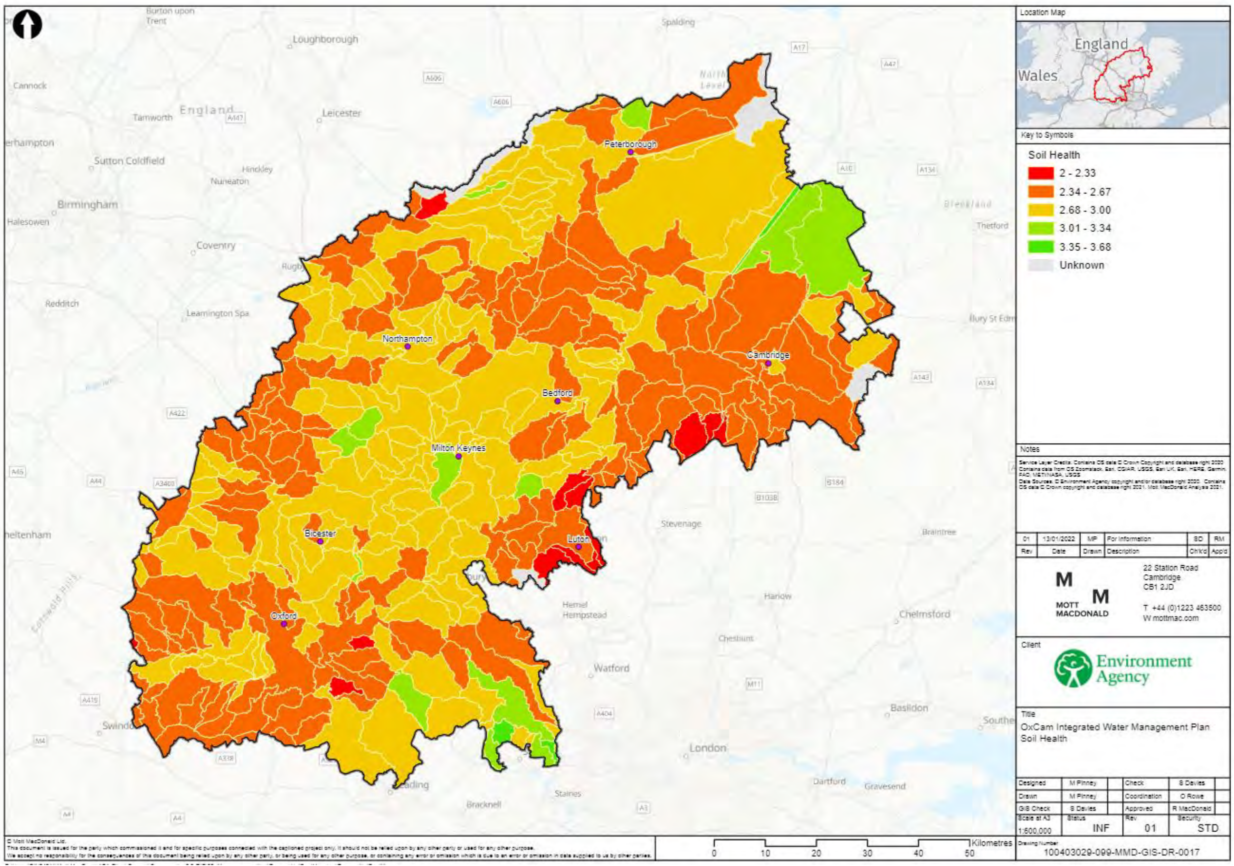
Three modelled soil parameters – bulk density, organic matter content and total nitrogen concentration – have been amalgamated to provide a high-level example of how a soil health metric could function for the catchment. These three soil measures broadly relate to the physical, biological and chemical status of the soils, respectively, all of which are crucial to maintaining soil health. Datasets (at a resolution of $1km^2$) for the three parameters were obtained from the UK Centre for Ecology and Hydrology as freely accessible datasets collated as part of the Countryside Survey and held under the terms of the Open Government Licence. By analysing the distribution of data within each dataset for the catchment, bands between 1 (poor) and 5 (strong) were devised corresponding to their indication of a healthy soil. The aggregation of band scores for bulk density, organic matter and total nitrogen concentration for each $1km^2$ grid then provides a high-level indication of soil health at the catchment scale.

Given the high number of other variables associated with soil health, further work on the metric could seek to incorporate a wider array of soil health indicators, aiming to provide a more sophisticated approximation of soil health across the catchment. Examples would include incorporating datasets relating to variables such as soil texture, pH, further nutrient concentrations (e.g. phosphorus) or soil erosion susceptibility. The latter would represent a significant improvement, and could be added to the metric through the use of SCIMAP (Sensitive Catchment Integrated Modelling and Analysis Platform). Taking into account connectivity to different watercourses, the tool helps to understand sediment erosion risk in a catchment, identifying where there is a significant source of the erosion pressure related to attributes such as land cover, topographic position and ground slope gradient. If aggregated alongside a wider array of soil properties, such as those already included, the metric could achieve a much-improved understanding of soil health across the catchment, helping to guide measures aimed at both maintaining and improving this vital environmental asset.

We are looking to incorporate a soil erosion risk criteria as well, e.g. through SCIMAP, but there are potential licensing issues associated with the data required for this.

Figure D.11 shows the mapping of our soil health metric. There appears to be some notable spatial trends in soil health, with similar scoring water bodies clustered into groups. Whilst soil health is unlikely to be a reason for preventing development from going ahead, baseline score could be taken into account in soil criterion weighting for future MCA of the Arc.

Figure D.11: Map of soil health score based on organic matter, nitrogen content and bulk density



D.1.9 Implications for the OxCam Arc

Our hotspot mapping does not identify any water bodies where new development would be completely unviable over the long term as a result of impacts on the water system. However, it could be used to identify water bodies which may be unable to both accept additional wastewater and meet WFD objectives. In these cases, either development would not be permitted, or transfers of wastewater to alternative discharge points would be necessary: to locations where additional nutrient loading would not inhibit good status, and/or where loading could be offset through catchment measures.

The mapping also shows where additional risks would exist for development that may require mitigation, and demonstrates a possible approach to weighting criteria for detailed MCA.

To fully appraise water resource risks (short to medium term impacts on sensitive sites) would require network modelling, as water abstraction points can be some way away from new centres of demand, and storage effects can require system modelling to evaluate any changes in demand on abstraction.

E. Systems mapping review

E.1 Mapping in Kumu

Kumu was used as the main mapping tool because

- It is easy to build the map with a good graphical interface.
- Data can be imported and exported in tabular form.
- It has useful visual and analytical functions such as layering of sub-maps; multiple maps in the same project, a focus tool to examine links of numerous steps out from a selected node.
- Background data can be presented about nodes and connections when a node or connection is selected
- The maps can be embedded in a pdf document.

The overall map[67] (the "meta-map" with all nodes and links) has in the region of 450 nodes and 1200 connections. In order to make the visualisation manageable the map is presented in four different arrangements, each focussed on a different perspective: water quality, flooding, planning and development, and PWS/wastewater. The maps are organised into 19 smaller submaps addressing particular themes. Ten sub-maps address baseline environmental sub-systems such as WFD, PWS, agriculture etc and are coded identified with a codes B 01 to B10. Nine sub-maps address interventions (categories of options), such as flood defences, WRMP, WINEP etc and are coded I 01 to I09. The baseline sub-system maps overlap with important nodes such as infiltration or soil health appearing in multiple sub-maps.

The four different arrangements of the overall map (water quality, flooding, PWS & wastewater, planning and development) place different sub-maps centrally allowing these systems to be the focus of the map and to be easily legible. We describe the maps under the four headings relating to these arrangements/systems and we suggest which sub-maps are viewed in each case. (In Section E.5 we provide a link that allows all of the map arrangements to be viewed and all of the sub-maps shown – but if all 19 of the sub-maps are viewed together, they appear overly complex and are hard to read.)

Whilst sub-maps are necessary to make the system comprehensible and viewable, we stress the importance of taking a whole-systems approach, achieved by layering sub-maps together in various combinations.

Table E.1 Map arrangements

Focus area:	Water quality	Flooding	PWS and Wastewater	Planning and development
Principal maps of interest **(B0X – baseline submap** **I0X – intervention submap)**	B03 – WFD	B02 – Flooding	B07 – PWS	B04 – Planning and Development
	B05 – River Health	I03 – Flood defences	B03 – WFD	B09 – Selected ecosystem services
	I02 – NFM	I04 – Flood response and recovery	B08 – Wastewater	I05 – Flood placemaking
	I06 – ELMS	I05 – Flood placemaking	I06 – ELMS	I01 – SuDS
	I01 – SuDS	I02 – NFM	I02 – NFM	I02 – NFM
		I01 – SuDS	I09 – DWMP	B03 - WFD
			I07 – WRMP	B05 – River Health

[67] Systems mapping demonstration OXCAM • Flooding / Untitled view • Kumu

Focus area:	Water quality	Flooding	PWS and Wastewater	Planning and development
			I01 - SuDS	
			I08 - WINEP	
Also relevant	B 06 – Agriculture			
	B10 – Farming Water			
	B07 – PWS			
	I07 – WRMP			

Kumu maps can be explored interactively by selecting and de-selecting sub-map layers and using the focus function to investigate connectivity of individual or multiple nodes.

The maps are also shown in Mott MacDonald's network viewer, hosted online in R-Shiny. This viewer adds additional ability to trace upstream and downstream impacts of nodes and is used in support of the Kumu maps which have advantages in legibility when the maps are laid out for review.

A common error in reading systems maps is to assume that green links indicate something good and red something bad, rather than meaning simply an influence to decrease or increase the value of the downstream node.

E.2 Flooding

A way into reading the baseline sub-system maps **B02 – Flooding and Intervention map and I05 – Flood placemaking** is to follow from Climate change at the bottom of the map to Amount of winter rain; up to Rural run-off and on to Flooding – surface water; right to the flood impact nodes shown in yellow; and up to Annual flood damage.

Add sub-map I01 – SuDS: these nodes influence the maps via an increase in Urban infiltration or a reduction in Flashy urban drainage (or both). They have additional links to Water quality – river and Biodiversity. SuDS all require suitable management (referred to with the node Effective design and management train for SuDS).

Add sub-map I02 – NFM: these nodes influence the rural elements of the flooding system. They have significant co-benefits to Biodiversity, Habitat, Air Quality and Low Flows.

Add sub-map I03 – Flood defences: these option types provide Flood resilience – protection. In some cases, such as Channel capacity improvement or Diversion they reduce the amount of Flooding – fluvial. In other cases, such as Engineered high ground, they do not influence the amount of flooding, but influence the impact of flooding.

Add sub-map I04 – Flood response and recovery: these option types reduce the impact of flooding.

E.3 Planning and development

A simple set of maps usefully shown together are **B04 – Planning and development**, **B09 – Selected ecosystem services**, and **I05 Flood placemaking**.

Adding maps **I01 - SuDS** and **I02 - NFM** show ways in which additional benefits could be realised.

add **B02 – Flooding** and **I03 – Flood defences** to show how the planning and development maps have important links with flooding

As well as exploring links with flooding, this map can be linked up with the **B03 – WFD** and **B05 - River Health** to identify interlinkages with these systems.

E.4 Water quality

Submap **B03 - WFD** should be read with the **B05 – River health** which links in biodiversity and habitat in more detail. To these baseline sub-maps, the following intervention maps may be added:

Add I02 - NFM: benefits of NFM to Water Quality are realised via nutrients and sediment; and via Q95: River low flows avoided – summer / autumn.

Add I06 - ELMs: benefits are realised through influence on WFD pressures, which are highlighted as key system outcomes. The ELMs submap highlights the importance of Farming financial resilience / profit as a driver for "On farm decision making towards sustainability", which drive implementation of ELM options.

Add B08 - Wastewater: the wastewater system links in to the corresponding WFD activities.

Add I01 - SuDS: the impact of Suds is shown on WFD pressures / key system outcomes at the top of the map.

Three additions can be made to this map to extend the perspective to include agriculture and its interaction with the Public water supply. (The direct interaction between the Public Water Supply, wastewater and water quality is discussed in Section 4.4.4).

Add B06 - Agriculture: "On farm decisions towards sustainability" is the central node on the Agricultural system map. It determines the extent to which ELMs and NFM interventions are undertaken and negative WFD activities are avoided. Farm financial resilience / profit is a key influence on "On farm decision making towards sustainability". Other important influences are shown by clusters around the following nodes:

- Perception of future financial uncertainty
- Diversity of farm revenues
- Farmer willingness to change
- Farming regulation
- Multi-benefit ecosystem service schemes

Use of the focus function on the system map is significant as it shows that the following key system outcomes are all within two steps of the "On farm decision towards sustainability":

- Biodiversity
- Water quality – river
- Invasive and non-native species
- Natural morphology
- Sediment
- Nutrients
- Dissolved Oxygen
- Organic pollution
- Crop resilience
- Soil Health
- Q 95: River low flows avoided – summer / autumn
- Carbon Sequestration (Further analysis, by adding the flood map, indicates that Flood resilience is also within two steps of this node.)

This highlights the significance of farmer behaviour (rural land use) on integrated water management in the OxCam Arc and draws attention to the need to engage with the complex influences on farmer decision making as listed above.

Add B 10 – Farming water: seasonality is important in the analysis of farming water. The system shows an interaction between agricultural decision making, environmental factors and system outcomes that varies from one season to another. An interesting example is highlighted by selecting both Climate change and Bare soil (winter) and selecting a two-step focus. Bare soil (winter) is an important cause of nutrients and sediments in water courses and has a direct link to winter water quality.

- Climate change drives Hotter drier summers, increasing the likelihood of a late harvest and planting of Spring crops creating Bare soil over the winter.
- Climate change also drives Higher winter rainfall, increasing Waterlogging, planting of Spring crops and Bare soil (winter).

Mitigating actions include planting of cover crops, which reduces the bare soil, and improved Soil health which improves Winter water quality.

Add B07 - PWS: The addition of the PWS shows how the seasonal factors contribute to a Resilient water resource which is a key node. There is an important loop back to the agricultural and water quality system via the node, Water companies engage with farmers.

Add I07 - WRMP: indicating WRMP options that are relevant to water resources alongside agricultural activities.

E.5 PWS & wastewater

The PWS and Wastewater maps are arranged adjacent to the WFD map in the overall map and presented so to be legible in three main ways.

- **B07 – PWS** and **B08 - Wastewater** maps together, with additional intervention/option maps
- **B07 – PWS** and **B03 – WFD** maps with corresponding intervention/option maps
- **B08 - Wastewater** and **B03 – WFD** maps with corresponding intervention/option maps

The **PWS** map has two clusters of nodes and two principal key system outcomes. The higher of the two clusters on the screen relates to water resources and focusses on the Resilient water resource node. The lower of the two clusters on the screen is focussed on the Supply demand balance – engineered WAFU benefit. The Supply demand balance is dependent on the Resilient water resource, but this dependency is mediated by engineering infrastructure, management, and customer behaviour. The influence of the WFD system on the PWS system comes via Water quality river. Low flows influence both the WFD and the PWS systems.

Add I07 – WRMP: there are a cluster of option types that influence Resilient engineering operation – PWS, Resilient engineering infrastructure – PWS and Resilient water supply to customers. A second cluster enhances the Resilient water resource, and a third cluster influences WFD pressures, such as Nutrients.

Add I08 – WINEP: WINEP options principally influence Water quality – river, and consequently Resilient water resource.

Add B08 – Wastewater: this system influences the WFD system via the sewage related WFD activities and influences the PWS system via Water quality – river and then Resilient water resource. There are important linkages coming from the flooding system to the wastewater system.

Add I01 – SuDS: these options influence the wastewater system via Flashy urban drainage and Urban runoff, influence the WFD map via Sediment and Nutrients, and the PWS map via Water quality – river.

Add I09 – DWMP: options reduce Wastewater, Wastewater pollution and enhance Resilient Engineering infrastructure – WW and Resilient engineering operation – WW.

E.6 Overall maps in Kumu

An overall version of the maps in Kumu is available here

This map may be navigated by selecting the mapping arrangement (in the drop-down box to the right of the title) and then by selecting sub-maps from the drop-down box on the top left of the mapping area.

The overall map in Mott MacDonald's network viewer is here.

F. Contaminants of emerging concern

F.1 Contaminants of emerging concern

Beyond contaminants that are routinely monitored and addressed, there are a wide range of substances that are released to the environment that are not currently regulated. Many of these have been the subject of increasing attention by the public, scientists, and government agencies, and may be subject to future regulation. Some of these have been recently developed and may be related to emerging technologies, and others may have been in use longer but are now receiving increased attention, often because of increasing use in industrial and commercial applications. Some of these are released as diffuse pollution, released widely at low levels but in aggregate can have a significant impact. These include a wide range of compounds, only some of which have been included in priority pollutant lists, including

- Micro- and nano-plastics that are highly resistant to degradation
- Pharmaceuticals and personal care products (PPCPs) (including metal nanoparticles, hormones, antibiotics)
- Per- and Poly-fluoroalkyl substances (PFAS) widely used in commercial products (e.g. in non-reactive surfaces and for stain-resistance) and in fire suppressants (e.g. in furniture, fire-fighting foams) and are highly persistent in the environment
- Pesticides used by households
- Toxic metals, including some that are in increasing demand in emerging technologies (e.g. Lithium, Nickel, Cobalt, Rare Earth Elements). These can enter into the environment bound with other compounds or as nanoparticles that may enhance migration or biological uptake.

While the widespread occurrence of many of these documented, many characteristics are not well understood, including the impact on ecosystems and human health, the rates of degradation, and the processes that control transport.

F.2 Sources

A widespread source is the roadways, where abrasion of tires, brakes, and road surfaces release pollutants, oils, grease and PAHs are released from vehicles, and platinum group metals are released from catalytic converters. These are carried by runoff and carried directly into surrounding vegetated areas, into storm drains that directly discharge into the environment, or into integrated wastewater systems. Levels of contamination around roadways is directly related to traffic density.

Other diffuse sources in urban and suburban settings include runoff from commercial and industrial sites, uncontrolled waste, railways, construction sites, faulty wastewater connections and overflows,

F.3 Impact:

Soils can serve as reservoirs for contaminants, impacting wildlife and possibly human health. Exposure to such contaminants can extend further through remobilization into the air, and by being carried deeper by percolating waters. Contaminants that reach shallow groundwaters may be discharged into nearby surface waters, and impact the quality of reservoir, river, lake and wetland waters. Private water wells also can be impacted.

Underlying shallow aquifers from which drinking water is drawn are recharged locally and can be threatened by mobile contaminants.

F.4 Future planning

Planning to mitigate the impact of these contaminants involves mapping of contaminant distributions, considering local conditions that affect contaminant degradation and immobilization, mapping the vulnerability of local surface and groundwaters, considering the distribution of private and public water supply wells, and controlling runoff.

Above from: Draft Notes on Emerging Contaminants, Don Porcelli, Department of Earth Sciences, Oxford University (27Jan 2022)

F.5 Microplastic modelling

Microplastics, small plastic objects between 5mm and 1µm in diameter, are divided into intentionally produced primary microplastics and secondary microplastics: from use, wear or fragmentation of macroplastic. Nanoplastics are deemed to be smaller than 1µm and have no defined lower size boundary. Microplastic literature is predominantly based on marine ecosystems however the flow of microplastics from land to sea is the main conduit with research identifying that proximity of urban areas to waterways positively correlates to microplastic concentrations.

Sources of microplastics into waterways can be through treated wastewater effluent, intermittent discharges/CSOs, highway stormwater runoff, biosolids, litter and city dust deposition. This can be summarised in Figure F.1 through the lens of wastewater networks.

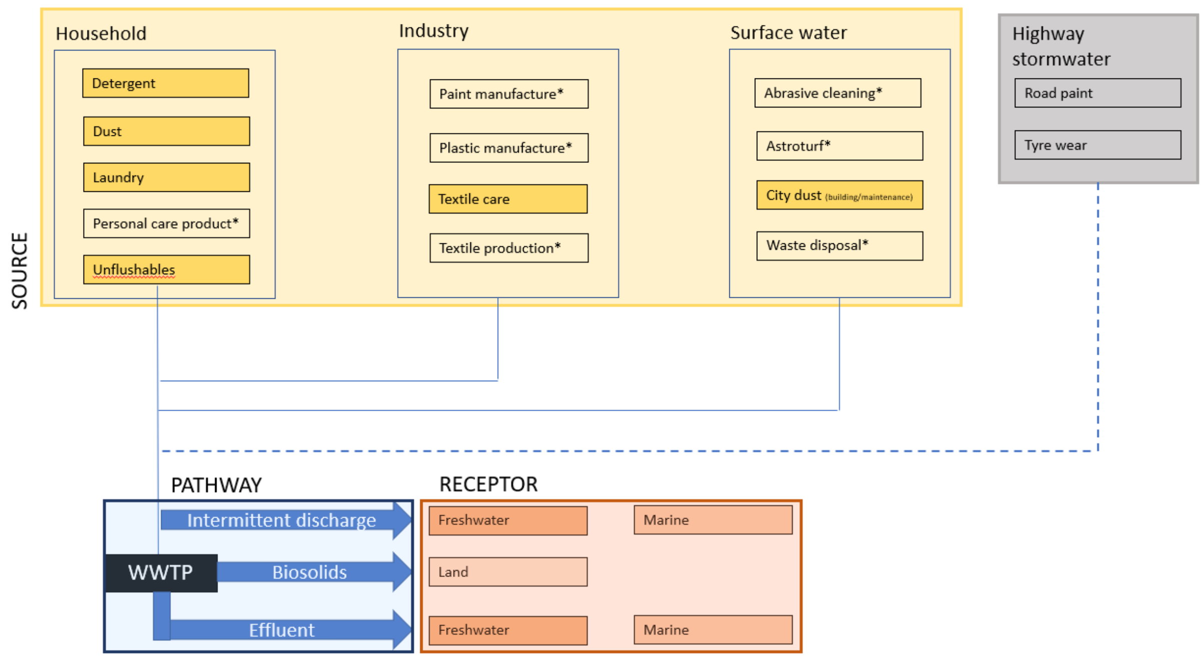


Figure F.1: Source-Pathway-Receptor representation for microplastics entering the wastewater network. Asterisks highlight where developing predicted environmental concentrations for a source will be more difficult. Highway stormwater sources should not be connected to the combined sewer however potentially can be due to cross connections.

Deposition rates for microplastics from city dust are well reported in academic literature, and concentrations in storm water runoff, wastewater and biosolids have also been reported. These values can be collated and averaged to develop a standard input for modelling. From Imperial College London research, predicted environmental concentrations have been developed for sources of microplastics entering the wastewater network and can be utilised by pollution models based on number of microplastic particles per litre or kilograms of microplastics per litre. Or instead of per litre, this can be per day.

Including new pollutants into the Imperial College London modelling would be possible provided we have:

- Deposition parameters (in kg/m2/day or similar) for various land use types
- Concentration in household wastewater (in kg/m3 or similar), if any
- Concentration reduction from WwTW process, if at all (ideally, some % reduction)

G. Review of MCA criteria currently used in water sector planning frameworks

In this annex we provide an overview of metrics used in different planning frameworks (Table G.1 to G.4).

Metrics for water resource planning are summarised in Table G.1 and have been collected from the following sources:

- WRSE Best Value Plan - wrse-best-value-plan-doc-final.pdf
- WRE Briefing Pack for Regional Planning Conferences - PR2-S_2359-WRE-factsheets-clickable-pdf-FINAL.pdf
- Company WRMPs - appendix-w-programme-appraisal-methods.pdf (thameswater.co.uk), Draft_Final_Water_Resources_Management_Plan_2019_Published_June_2019.pdf (affinitywater.co.uk) wrmp-report-2019.pdf (anglianwater.co.uk)
- Water Resources Planning Guidance (WRPG) - Water resources planning guideline - GOV.UK (www.gov.uk)

Table G.1: Metrics used in water resources planning

Criteria	WRSE	WRE	WRMPs	Include in IWMF?
Water Resources (Meeting supply demand balance)	PWS – Supply demand balance profile (Ml/d)	Public Water Supply Deficit – total deficit in each WRZ	Water efficiency and metering	Yes – modelled directly
	Provides additional water needed by other sectors (Ml/d)	Supply and supply deficits for energy and agricultural abstraction holders		Could be modelled directly
		Total export to Affinity/WRSE		Could be modelled directly
Water into supply	Distribution input (DI)			Criteria value not self-evident. Best appraised locally. Environmental flow, water quality and supply/demand balance capture the indirect value.
Leakage	50% reduction in leakage by each company by 2050 from 2017/18 baseline (%)		50% reduction in leakage by each company by 2050 from 2017/18 baseline (%)	
	% leakage reduction above 50%		% leakage reduction above 50%	
Environmental flow		Environmental Flow Requirement Deviation (EFR) Flow Duration Curves		Yes – modelled directly
Abstraction reduction	Reduction in the volume of water abstracted at identified sites (Ml/d) and by when (date)			Value of reduction captured by other criteria (environmental flow & water quality)

Criteria	WRSE	WRE	WRMPs	Include in IWMF?
Drought resilience	Achieve 1 in 500 year drought resilience (date achieved)	Annual probability of TUBS and NEUBS	Vulnerability assessment for 1 in 500 year drought	Could be used instead of SDB Ml/d. But don't need both. Ml/d easier to assign £ value if desired.
Biodiversity	Net gain score (%) (BNG)	Biodiversity units requiring replacement (through BNG)	BNG outputs HRA outputs Natural England eco-metric	Yes – as "best value" criteria. Weighting needs to be agreed – not easy to monetise.
Carbon	Cost of carbon offsetting (£m)	Capital and operating carbon footprint of supply options		Yes – as "best value" criteria. Standards exist for monetisation
Strategic Environmental Assessment (SEA)	Programme benefit (Score max)	Environment effects of construction and operation – positive and negative scores against SEA objectives	SEA outputs	Captured sufficiently by other criteria. Assigning separately would risk double-counting.
	Programme disbenefit (Score min)			
Natural capital	Enhancement of Natural Capital Value (£m)	Monetised Ecosystem Services (£/yr)	ENCA approach	
Resilience assessment (Evolvability)	Programme evolvability score		Resilience	Needs further consideration. Reliability a key consideration but maybe best assessed within subsystems. Value of adaptability and evolvability highly dependent on scheme size and planning uncertainty – best appraised within subsystems.
Resilience assessment (Adaptability)	Programme adaptability score		Resilience	
Resilience assessment (Reliability)	Programme reliability score	Public Water Supply Reliability – yrs (out of 48) of the DAC, TUBS, NEUBS and EDO curves for each reservoir	Resilience	
Customer preference	Customer preference for option type (Score)		Customer preference Promotability	No - largely independent of any systemic interaction.
Programme cost	NPV (£m) using Social Time Preference Rate (STPR)	Annualised total costs (Capex and Opex) of new supply options	NPV	Yes – a core metric
Inter-generational equity	Long Term Discount Rate (LTDR)		Intergenerational equity	No - largely independent of any systemic interaction.

Metrics for wastewater planning are summarised in Table G.2 have been collected from the following sources:

- Company DWMPs - strategic-context-document.pdf (thameswater.co.uk), drainage-and-wastewater-management-plan.pdf (anglianwater.co.uk)
- Atkins development of wastewater resilience metrics - Developing-and-Trialling-Wastewater-Resilience-Metrics-Atkins.pdf

Table G.2: Metrics used in wastewater planning

Criteria	DWMPs	Include in IWMF?
Sewage treatment works quality compliance	Modelled sewage treatment works compliance against current permit quality conditions	No – too many treatment works, each needing own criteria. Could be used to inform management target thresholds for water quality indicators.
Sewage treatment works flow compliance	Modelled compliance against daily DWF permit limit	No – too many treatment works, each needing own criteria. Could be used to inform management target thresholds for high flow indicators.
Risk of pollution incidents	3 year average annual performance for category 1 to 3 EPIs	No – too complex to appraise in regional integrated MCA. Capture using water quality indicator under high flow conditions.
Storm overflow performance	Modelled annual average frequency of discharge (number of events) from storm overflows using forecast rainfall data	No – too complex to appraise in regional integrated MCA. Capture using high flow indicators.
Internal sewer flooding risk	Risk assessed based on average of last three years performance data Modelled risk based on internal escape locations in a 1 in 30 year rainfall event	
External sewer flooding risk	Modelled risk based on external escape locations in a 1 in 30 year rainfall event	
Risk of sewer flooding in a 1 in 50 storm	Percentage of residential properties at risk of flooding in a 1 in 50 year rainfall event	
Sewer collapses	An average of the last three years of annual performance	No - largely independent of any systemic interaction
Access to amenity areas	Amenity score per catchment based on green space use	Yes – one of proposed wellbeing best value sub-criteria
Green infrastructure	Amount of green infrastructure within a catchment	No - capture via biodiversity net gain, carbon and other environmental criteria
Resilience	Single resilience metric	See Table 3

Metrics for flood risk management planning are summarised in Table G.3 and have been collected from the following sources:

- FCERM appraisal guidance - Environment Agency external corporate report template (publishing.service.gov.uk)

Table G.3: Metrics used in flood risk management planning

Criteria	FCERM	Include in IWMF?
Natural capital	ENCA approach	Captured sufficiently by other criteria. Assigning separately would risk double-counting.
Damage	Weighted annual average damage (WAAD)	Not directly. Instead use flow indicators (QMED, Q5 or R-B index) to set performance thresholds
Programme cost	CBA and NPSV	Yes – core criteria.

Metrics for water environment planning are summarised in Table G.4 and have been collected from the following sources:

- The WINEP benefits assessment tool - WINEP Wider Environmental Outcome Metrics v2.0.xlsx

Table G.4: Metrics used in water environment planning

Criteria	WINEP	Include in IWMF?
Biodiversity	Net gain in biodiversity (%) (BNG) – using The Biodiversity Metric 3.0	Yes – as "best value" criteria. Weighting needs to be agreed – not easy to monetise
Water purification by habitat	£/ha/yr valuation x Ha of habitat, wetland and Extent and condition of habitat	No – too detailed for regional IWM. Instead set performance thresholds for water quality, and use biodiversity metric for value-based assessment
Water quality	NWEBS valuation x km/km^2 water body improved	Water quality metrics could be monetised using NWEBS, but this would require information relating pollutant concentrations to water body status.
Water supply	Resource rent £/m3 valuation x Million m3 of water abstracted	Supply demand balance metric could be monetised to become a value criteria based on marginal cost of water resource options. Otherwise could be set as a performance threshold.
Climate regulation	£/tCO_2e valuation x Ha of habitat (and sequestration/emission rate tCO2e/ha/yr)	Yes – embodied and sequestered carbon as separate criteria.
Recreation	Outdoor Recreation Valuation (ORVal) tool - £/visit	Captured in social capital sub-metric
Recreation - angling	£/visit valuation x number of visitors/distance travelled	Could be captured in social capital sub-metric. Impact on decisions perhaps too small at IWM level
Food - shellfish	£/tonne of shellfish value landed x landings data – tonnes produced Water quality – classification of shellfish waters to A, B, or C	No – best appraised at a more local level. Insufficient interaction between water sub-systems.
Air quality – pollution removal	£/tonne benefit per tonne removed x pollutant removal rate (tonnes/ha/yr), Ha of habitat and extent and condition of habitat	No – best appraised at a more local level. Insufficient interaction between water sub-systems.
Hazard regulation	£/m3/yr replacement cost valuation x Ha of woodland/wetland and m3 of annual flood water storage provided by woodland	Flooding hazard captured via high flow indicators. Monetisation of annual flood water needs geospatial modelling – cannot be done in IWM.
Volunteering	£/hour/day replacement cost x estimated number of hours of nature-based volunteering	No – best appraised at a more local level. Insufficient interaction between water sub-systems. Social capital metric could include this potential.
Education	£/pupil/visit x number of educational visits by school children to nature reserves	No – best appraised at a more local level. Insufficient interaction between water sub-systems. Social capital metric could include this potential.

H. Detailed review of updates to the schedule of metrics

This Annex comprises a comparison between the schedule of metrics presented in the Phase 1 report for the high-level MCA before and after Phase 1a pilot modelling.

H.1 Water resources

H.1.1 Water resource supply

Phase 1 High-level MCA

The Supply Demand Balance is the key metric used to identify options to maintain public water supply from a drought level of service perspective, taking account of water availability.

This criterion is important everywhere to an extent, as the cost of moving water is significantly lower than the marginal cost of new resources in most WRZs. However, we do propose some spatial variation in weighting the importance of this criterion between water bodies, to reflect the fact there are some costs, potential risks and issues associated with transferring water.

Phase 1a Updates

Impacts on Supply Demand Balance can be modelled directly in regional ICM by determining the change in abstraction required to maintain number of days drought failure constant at a baseline value. Therefore supply demand balance can be included in regional MCA directly, either as a target threshold to be met, or as a value-based metric based on marginal value of water resource in the region.

H.1.2 Water network capacity

Phase 1 High-level MCA

Water network capacity is a potential constraint to population growth above and beyond the WRMP supply demand balance. WRMP SDB is appraised at a water resource zone scale, assuming each WRZ behaves like a bucket of water. In reality, there are network constraints within each WRZ, which must be considered as part of growth planning. The costs of pipeline reinforcement, new booster pumping stations and new service reservoirs may often be notably less than the cost of providing new water resources, but this may not be the case where long-distance transfers of modest volumes of water are required. Water network capacity should be considered as an absolute requirement for any new development. It is therefore a threshold criterion, rather than target ambition or weighted maximisation criterion. The criterion should take account of any efficiency or on-site water reuse measures delivered as part of water neutrality/demand management measures.

Phase 1a Updates

Water network constraints cannot be modelled easily in a regional level integrated model, due to model complexity constraints. We suggest that this criteria is excluded from regional modelling.

H.2 Wastewater services

Phase 1 High-level MCA

Wastewater network and treatment are absolute requirements for any new development. Providing sufficient network and treatment should be specified as threshold criteria, taking account of any on-site provision for greywater reuse.

Wastewater treatment must take account of any determinand constraints specified on the discharge consent. In some cases, these may be close to the technically achievable limit, for example for phosphorous concentration. Any increase in discharge flow rate from new development would require tightening of permitted concentration limits to ensure overall determinand loading does not increase (a product of concentration and flow rate). Where permit constraints are already close to technically achievable limit, no increase in flow rate might be possible. In this case, wastewater would have to be transferred to a different water body.

Drainage and wastewater management plans (DWMPs) should address such issues, and take a strategic view of where wastewater transfers might be required. As with WRMP, some form of adaptability may need to be specified within DWMPs to account for uncertainty in future development.

<u>Phase 1a Updates</u>

Wastewater treatment, storm tank and sewer capacity were modelled at a high level as intervention options, with impacts on modelled criteria appraised accordingly. Any such options could be modelled for regional MCA, but it is unlikely that any criteria are required to represent wastewater services in regional MCA: wastewater services themselves will not be impacted by other interventions.

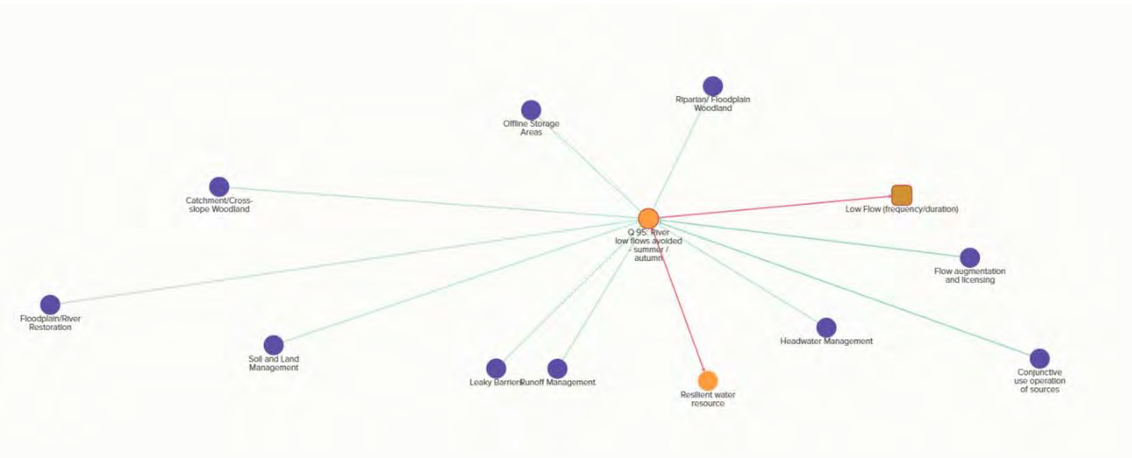
H.3 Environment

H.3.1 Environmental flows

<u>Phase 1 High-level MCA</u>

Environmental flows are water body flows required to meet the needs of the natural environment. Often low flows are of particular importance (see Figure H.1), but the loss of medium or high flows can affect fish, sediment, morphology and other WFD criteria. Some option types may directly impact environmental flows in the local water body, for example: catchment management schemes positively impacting dry weather flows through improved storage in the catchment, and slow consistent release to watercourses; rainwater harvesting having a slight negative impact by capturing summer rainfall that could otherwise run off into the catchment.

Figure H.1: System map showing key metric ‘Q95: River low flows avoided’ and the impact of different intervention options.



This criterion is related to, but distinct from the supply demand balance criterion, as a benefit to dry weather flows will only provide SDB benefit if the increase in flows raises them above a hands-off flow specified on an abstraction licence. For many options this is unlikely to be the case. We want to recognise the potentially important environmental benefits of improved environmental flows even where this provides no benefit to public water supply, for example improved flows to chalk streams.

One potential metric here is the WRGIS National Framework scenarios of surplus and deficit as means of weighting criteria between water bodies.

Phase 1a Updates

A dynamic ICM would be capable of outputting flow values at any point on the flow duration curve for each water body, or at finer spatial resolution with appropriate model refinement locally. Environmental flows can therefore be modelled directly.

H.3.2 WFD pressures (WINEP)

Phase 1 High-level MCA

Water quality is of critical importance to the ecological status of water bodies, and the status of designated sites. In Phase 1, we used the Environment Agency Catchment Challenges data on pressures and activities for not achieving good status against River Basin Management Plan objectives as the starting point for identifying water quality and other environmental criteria.

Approximately 35 pressures are listed as catchment challenges, resulting from any one or more of approximately 31 catchment activities. Activities are important in order to identify option types that can deliver a benefit against specific pressures. For example if a phosphorous pressure in a given water body is driven by sewage discharge only, i.e. agricultural nutrients are already well managed, or the land use type is such that there is no nutrient runoff, then improved agricultural nutrient management is unlikely to make much of a difference. In contrast, any activity that makes a pressure worse is relevant to a water body impacted by the pressure, irrespective of what the activity is.

To constrain the list of pressures in Phase 1, and identify those that should be included as criteria, we started by excluding pressure/activity combinations that affect fewer than 12 water bodies. We then amalgamated pressure/challenge activities to reduce down the pressures for option scoring to 10 and the activities to 16, with pressure/activity combinations as shown in Table H.1 below. Lastly, we reviewed the spatial coherence of pressures and activities to further refine the list of pressures to include as criteria for MCA. The results of this review are shown in the final column of Table H.1.

Phase 1a Updates

We have updated this table to show any conclusions resulting from Phase 1a pilot modelling.

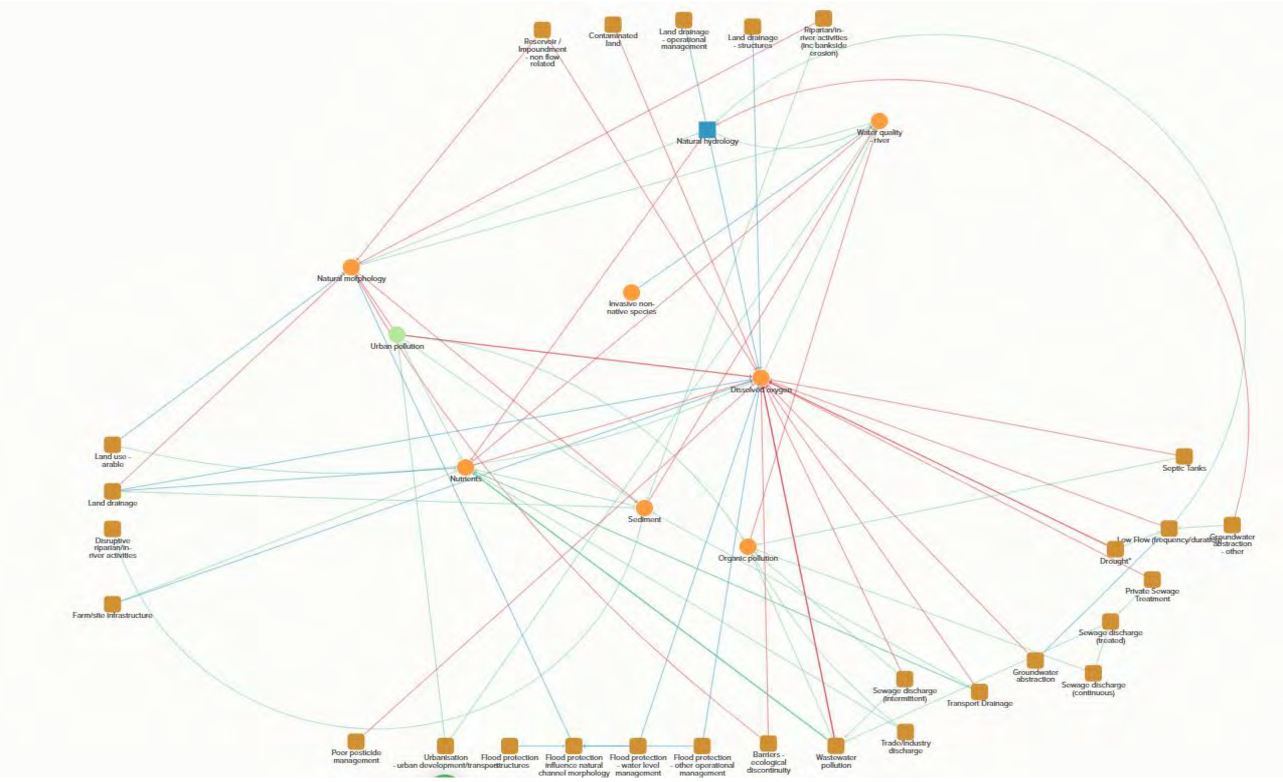
Table H.1 WFD Challenge Pressures and Activities

Option Scoring Pressure	Option Scoring Activity	Phase 1: include as MCA Criteria?	Phase 1a conclusion
Abstraction	Drought	No – WRGIS low flow surplus/deficit is more meaningful	No change from Phase 1. Address via environmental flow values
	GW/SW abstraction		
Ammonia	Sewage discharge	No – phosphorous is a sewage discharge pressure for almost all water bodies where ammonia is a sewage discharge pressure. Propose phosphorous as a proxy.	Ammonia can be modelled. Coherence between ammonia and phosphorous reasonable, but some variation. Perhaps decide

Option Scoring Pressure	Option Scoring Activity	Phase 1: include as MCA Criteria?	Phase 1a conclusion
			whether or not to include as metric at outset of specific modelling.
Dissolved oxygen	Drought Low Flow (not drought) Poor nutrient management Sewage discharge	Yes – dissolved oxygen is a fairly common pressure and quite often distinct from phosphorous	Not tested. If ammonia, nitrate and phosphorous are included as metrics, then dissolved oxygen may not be required.
Hydrology	Drought	No - WRGIS low flow surplus/deficit is more meaningful	No change. Address via environmental flow values
Invasive non-native species	North American signal crayfish	Yes – INNS affect 50 water bodies in OxCam and are distinct from all other pressures	Cannot be modelled. Best included as a generic score by option type
Morphology	Barriers - ecological discontinuity Land drainage Urbanisation - urban development	Yes – distinct pressure. No proxies possible.	Cannot be modelled but may not be affected by most option types. Potentially include as a generic score by option type
Nutrients	Poor Livestock Management Poor nutrient management Sewage discharge Urbanisation - urban development	No – Phosphorous activities match nutrient activities for almost all water bodies. Nitrogen is almost never a specified pressure contributing to non-good WFD status. Whilst it is a challenge, we suggest that measures which reduce phosphorous would also reduce nitrogen.	Nitrate can be modelled separately from phosphorous. Coherence between nitrogen and phosphorous fairly good for options tested, other than for reservoir options. Perhaps decide whether or not to include as metric at outset of specific modelling.
Organic pollution	Poor Livestock Management Sewage discharge	No – not a common pressure, and often coincides with phosphorous and/or DO. Use these instead.	No change. Address via phosphorous metric instead.
Phosphorous	Poor Livestock Management Poor nutrient management Poor soil management Private Sewage Treatment Sewage discharge Trade/Industry discharge Transport Drainage Urbanisation - urban development	Yes – the most common pressure and a good proxy for other pressures (nutrients, ammonia, organic pollution).	No change. Agree must be included as a key metric.
Recreation	Other	No – very few water bodies affected.	No change. Address social opportunities/risks via non-modelled metric
Sediment	Poor nutrient management Poor soil management Riparian/in-river activities (inc bankside erosion) Urbanisation - urban development	Yes – a distinct pressure from phosphorous and DO.	Modelling shows notable differences in behaviour from phosphorous. Agree should be modelled and included as a metric.

The system map which informed the process is shown below in Figure H.2.

Figure H.2 WFD pressures and activities system map.



H.3.3 High-flow water quality

Phase 1 High-level MCA

WFD challenge pressures are primarily based upon water quality at times of low flow. Low flow water quality is of primary importance to the ecological status of water bodies, given the challenges of eutrophication at these times.

However, water quality at times of higher flow is of considerable importance in particular for human interaction with rivers, for example swimming or bathing, and it can be driven by different pressures and activities to low flow water quality. There is no inherent coherence between water quality at times of low and high flow: a river may have good chemical status at low flow but combined storm overflows and/or storm runoff from fields could drive significantly worse quality after wet weather.

The Environment Agency's review of urban pollution management standards against WFD requirements (2012)[68] states that, "Wet weather events may affect river water quality for relatively short time periods, but these events can have a disproportionate impact on the ecosystem. Furthermore, the quality of a water body during these events may not be related in a simple way to the more general quality based on continuous discharges. With wet weather intermittent discharges, short duration, high concentration events extend the tail of the pollutant frequency distribution. The Urban Pollution Management Manual proposes 99 percentile criteria for BOD and total ammonia to limit organic loading in receiving waters."

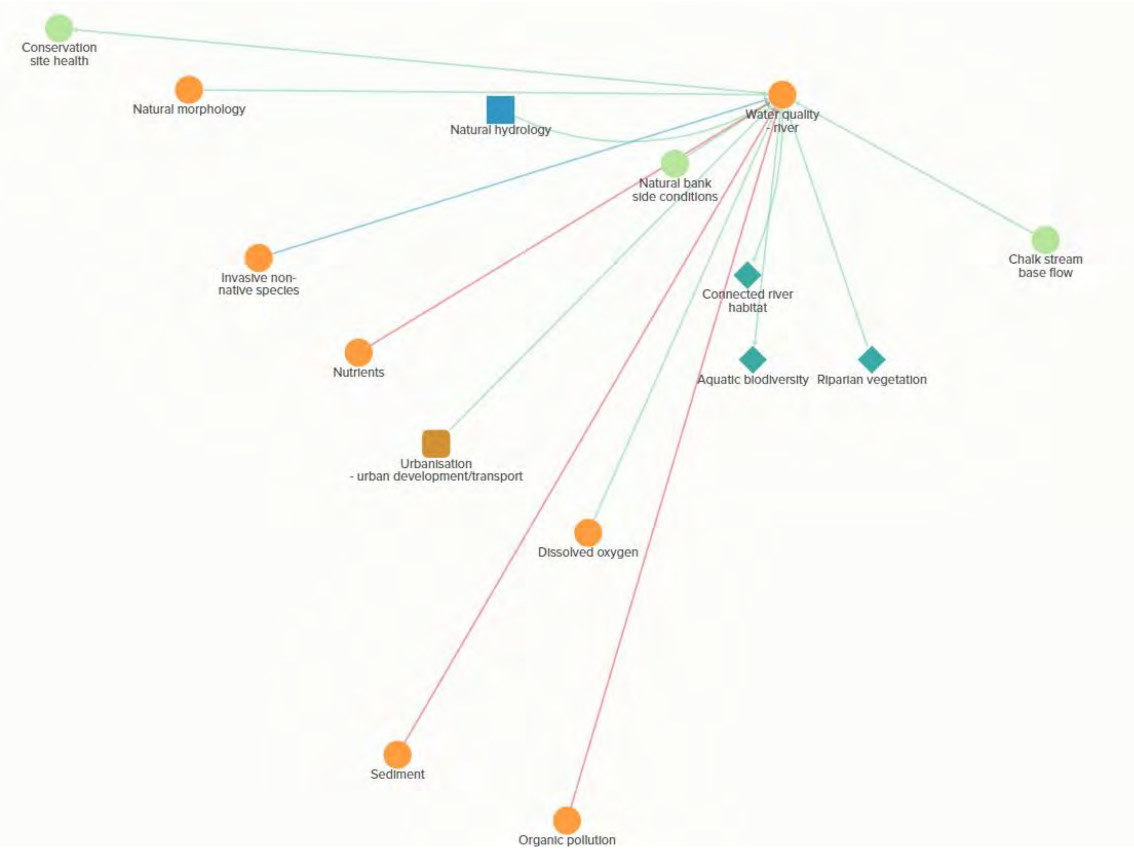
[68] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291496/LIT_7373_b2855a.pdf

There are notable gaps in data recording storm overflow impacts. We currently have access only to total hours storm overflow by WwTW for each water body, but this provides no information on the quality of that wastewater, or its impact on river water quality.

In the Phase 1 high-level MCA, we proposed 99 percentile BOD could be used as a metric for high flow water quality status.

The system map which informed the process is shown below in Figure H.3.

Figure H.3 Water quality and River health system map



Phase 1a Updates

It was not possible to test BOD in Pilot Modelling. However water quality values for phosphorous, sediment, nitrate and ammonia can be output at any flow duration curve value. Pilot modelling suggested reasonable coherence in these parameters at Q5 flow across the options tested, though with some notable differences. We propose to include all quality metrics at Q5 flow initially in any IWM regional modelling, and potentially exclude some metrics upon review of results.

H.3.4 Soil health

Phase 1 High-level MCA

Three modelled soil parameters – bulk density, organic matter content and total nitrogen concentration – have been amalgamated to provide a high-level sample of how a soil health metric could function for the catchment, as described in Section 3.5.

Phase 1a Updates

No further analysis has been undertaken in Phase 1a.

H.4 Flooding

The FCERM guidance [69]identifies four categories of option relating to flooding: protection, placemaking, recover and respond.

H.4.1 Flood protection

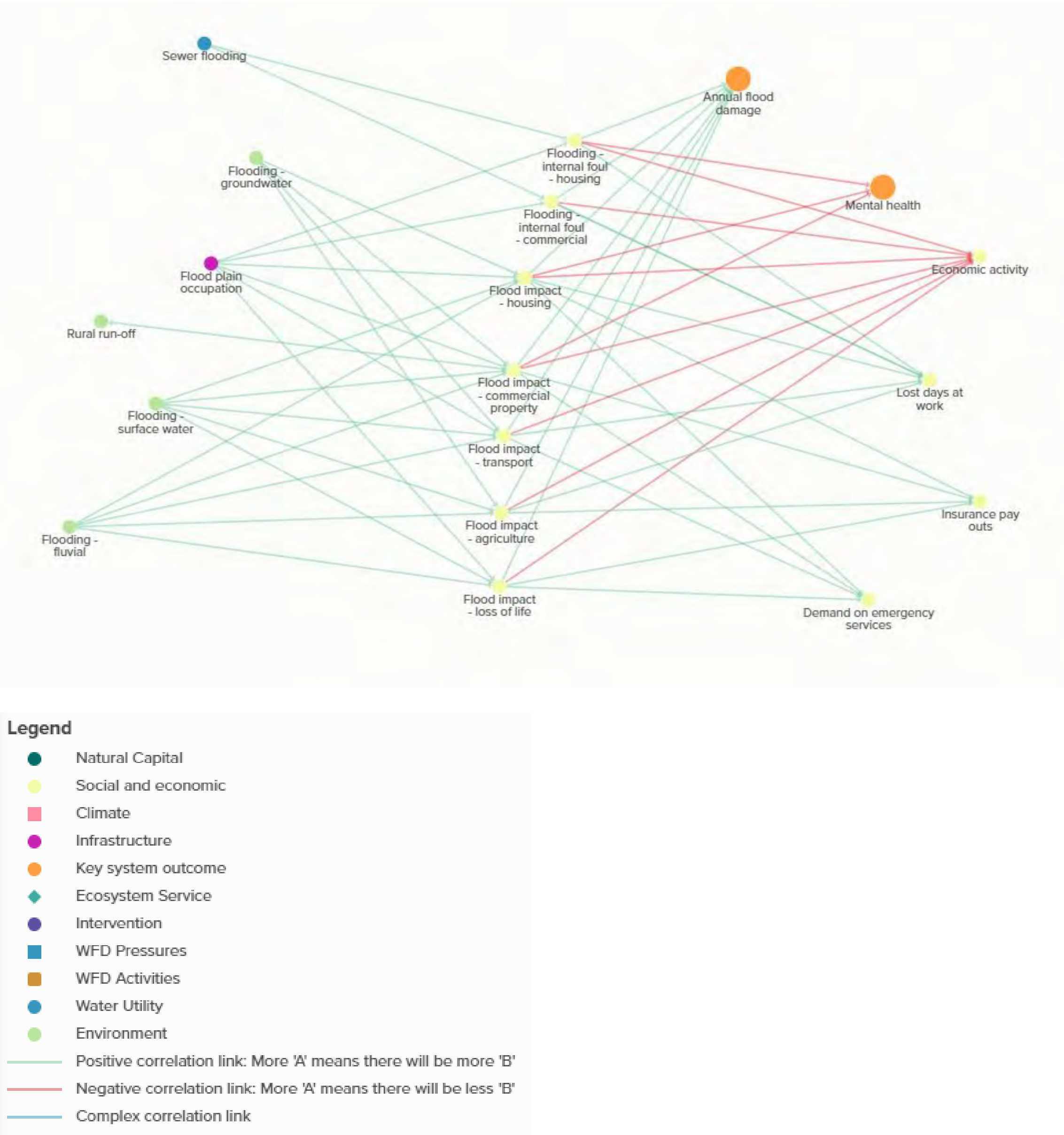
Phase 1 High-level MCA

Flood protection interventions are currently evaluated and selected based on property risk banding.

To evaluate flood risk benefits, we had proposed to use annual flood damage as a metric. System mapping showed that annual flood damage connects to all key flood baseline nodes, either directly or indirectly. It is also coherent with all flood baseline nodes in terms of benefits/disbenefits. An increase in annual flood damage is detrimental to all receptors, shown by positive-positive connections to all negative nodes (e.g. insurance pay-outs), and positive-negative connections to positive nodes (e.g. economic activity).

69 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/920944/023_15482_Environment_agency_digitalAW_Strategy.pdf

Figure H.4: System map view of key flooding criteria



Flood risk should take account of possible downstream impacts, and therefore any modelling of flooding impacts of options (positive or negative) should cover an appropriate spatial area, not limited to the local water body.

Phase 1a Updates

Flood annual average damage or property risk banding cannot be determined directly in the integrated modelling tested in Phase 1a because flood impact also requires a geospatial assessment. Options that provide benefits of protection and placemaking can be modelled with proxy indicators of impact such as Q10 and Q5 flows and the R-B index. The flood planning frameworks (FRMP) would have data relating to numbers of properties in flood risk bands, which cannot easily be recreated by integrated models.

Options that provide benefits of protection and placemaking can be modelled with proxy indicators of impact such as Q10 and Q5 flows and the R-B index. The flood planning frameworks (FRMP) would have data relating to numbers of properties in flood risk bands, which cannot easily be recreated by integrated models.

H.4.2 Flood response and recovery

Phase 1 High-level MCA

Some options will not reduce the frequency, duration or magnitude of flood water impacting land or property but will make the land/property more resilient to that flood water. For example, "build back better" measures such as raised electrics, hard flooring, waterproof plaster, and flood doors. A separate criterion is needed to measure these.

We understand that metrics for flood resilience are under development and could be used in subsequent work.

Phase 1a Updates

The new metrics produced should be reviewed for relevance. However, we note that recovery and response options may not be applicable for inclusion in the framework if they do not correspond to comparable options across the four sub-system components.

H.4.3 Flood & environmental place-making

Phase 1 High-level MCA

Flood and environmental place-making is identified as a key criterion in the system. Assigning value to flood & environmental place-making recognises the importance of green space to mental and physical health, and the importance of reduced runoff to both flood risk and water quality.

As contributions to flood and environmental place-making can take many forms, it is not possible to identify one objective metric to use for measuring this. Option types' contribution to place-making will also be location-specific. Therefore we propose to score generic option types against this criterion through stakeholder engagement, with scoring varying by location according to the outcomes of this engagement.

This criterion could be set either with a target ambition for MCA, through a concept such as urban neutrality, or as a maximisation criterion, based on stakeholder weighting.

Phase 1a Updates

Flood place-making is treated in the same way as flood protection where relevant options are presented. These may not be appropriate for modelling in the ICM, depending on the type of option presented. If necessary they should be compared on the basis of planning framework modelling.

I. Generic option type scoring and gap analysis

I.1 Common option categories

We reviewed the option types across the different planning frameworks and identified 186 generic types as shown on Table I.1 below. We used the system mapping exercise to compare the option types identifying the influence they had across the water and environmental systems of interest.

Table I.1: Generic Option Types Scored in high-level MCA

Option Category	Number of Option Types
Drainage and Wastewater Management Planning	44
Environmental Land Management Sustainable Farming Incentive Schemes ("ELMS Tier 1")	6
Environmental Land Management Local Nature Recovery Schemes ("ELMS Tier 2")	4
Environmental Land Management Landscape Recovery Schemes ("ELMS Tier 3")	3
Flood defences	20
Flood Resilience	6
Natural Flood Management	21
Sustainable Urban Drainage	19
Water Industry National Environment Programme	19
Water Resource Management Planning	44
Grand Total	**186**

I.1.1 Generic option type scoring

For the initial high-level MCA, option types were scored against each criterion on a bespoke scale from +4 to -2, as defined in Table I.2 below. We did not find any generic option types that would result in major disbenefits against any criteria, and so found no need for scores of -3 or -4 anywhere.

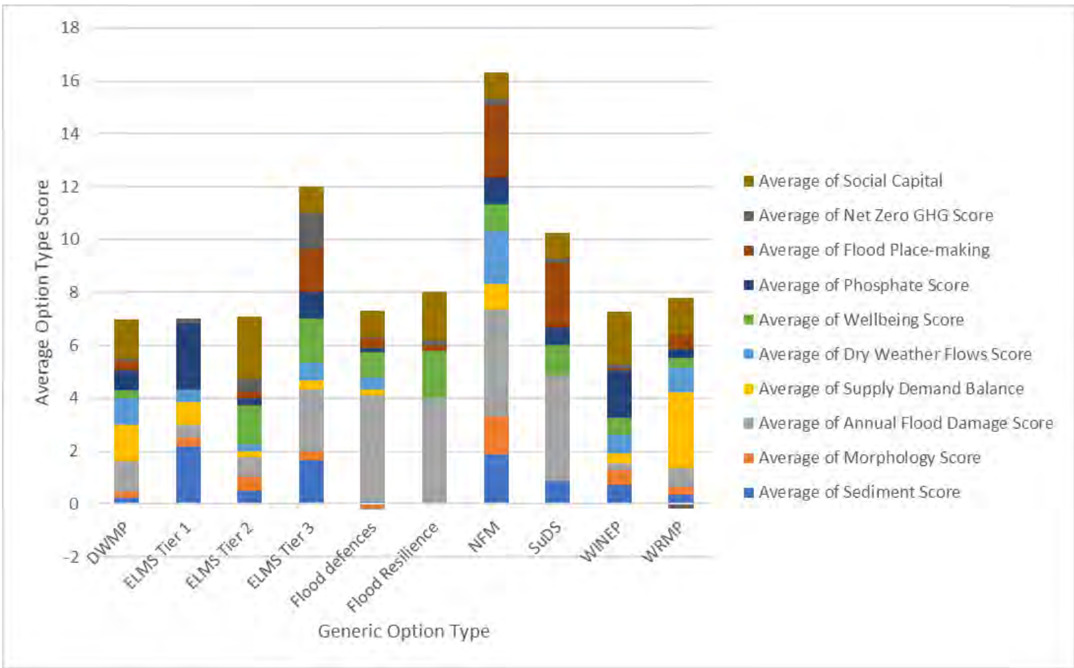
Table I.2: High-level MCA scoring definitions

Score	Definition
4	Primary purpose of the option type is to benefit this criterion
3	A major secondary benefit of the option type against this criterion
2	A moderate secondary benefit of the option type against this criterion
1	A minor secondary benefit of the option type against this criterion
0	Option type has no impact on the criterion
-1	Option type has a minor negative impact on the criterion
-2	Option type has a significant negative impact on the criterion

Scoring was undertaken by subject matter experts, checked and quality assured by other subject matter experts. For detailed MCA, more rigorous scoring could be carried out involving stakeholder experts.

The average option type scores are broken down by selected criteria and by option category in Figure I.1 below.

Figure I.1: Average score of generic option types by option category against a selection of key criteria



It is clear that considerable potential for synergies and co-benefits exist across option types. Natural flood management (NFM) options score particularly highly across most criteria, as do ELMS Tier 3 option types.

Supply demand balance benefits are mainly delivered by WRMP options, though DWMP options can also contribute, mainly through demand-side water efficiency options which would reduce demand for water as well as wastewater. NFM could provide a supply/demand benefit, through options such as offline storage, river restoration and wetland creation. ELMS Tier 1 options could all contribute in a minor way to supply/demand balance. Direct benefits to dry weather (environmental) flows would be delivered by many NFM option types, some WINEP, some WRMP, DWMP, and ELMS Tiers 1, 2 and 3.

Flood defence, flood resilience, SuDS and NFM option types contribute most to flood protection (annual flood damage). Almost all DWMP option types would make a contribution, some significantly so, such as Catchment management – flows, Increased conveyance and DWMP SuDS. Three ELMS Tier 1, two Tier 2 and three Tier 3 option types would make a minor to moderate contribution. WINEP Priority habitat creation, restoration, species recovery work could make a significant contribution. For WRMP, flood storage, integrated catchment management, habitat creation, natural water retention, new reservoirs, open water transfers, river restoration and SuDS all contribute significantly.

Flood place-making is delivered primarily by SuDS and NFM, though with notable potential contribution from ELMS Tier 3, some WRMP option types, DWMP, flood defences and ELMS Tier 2. We also identify some notable gaps in option types particularly relevant to flood place-making, as specified in Section I.1.2 below.

Phosphorous (and other nutrients) are addressed primarily by WINEP option types, but ELMS Tier 1 option types are likely to make a highly significant contribution also, through field cover, field margins, livestock, nutrient and soil management. Seven DWMP option types could also make significant contributions as well as three WRMP option types and three NFM. We note that raw water transfers could have minor negative impacts on water quality if the receiving water body quality exceeds source water quality on any important parameters, and treatment is not specified. Sediment and morphology scoring was generally similar to phosphorous, though with a greater contribution from NFM to morphology and less contribution from WINEP or ELMS.

Other best value criteria have benefits across most option types to varying degrees.

I.1.2 Option type gap analysis

The system mapping process facilitated useful discussion around potential interventions which could help to improve the water system that are not currently included in planning.

The following is a starting list of option types identified in system mapping focus groups, which do not appear to be present within the option categories currently used as a primary basis for system planning.

- Open Water Transfers, such as the Bedford Milton Keynes Waterway. The aim of this is to create a green corridor at the heart of new developments, with significant amenity value, to provide storage space for flood protection, and to enable transfer of water resources.
- Urban greening, e.g. converting existing car parks to nature reserves, converting paved gardens to green space, brownfield restoration.
- Raised buildings
- An institutional "Water Fund" platform to design and enhance financial and governance mechanisms which unite public, private and civil society stakeholders around a common goal to contribute to water security through nature-based solutions and sustainable watershed management. For example, they have been developed by cities and conservation practitioners including The Nature Conservancy, and propose to help resolve governance issues by bridging science, jurisdictional, financial and implementation gaps[70]
- Blue/green corridors: protect riverbank margins, e.g. from livestock, development, roads. Provides benefits across flood risk, water quality, and significant social benefits if combined with careful public access.
- Integrated crop-livestock management[71]
- Rewilding and keystone species reintroduction: various examples exist for where reintroductions of species such as beavers and bison have delivered considerable benefits to the water system at low cost. Important issues around perception and potential crop damage must be addressed.
- 20-minute Cities: developments where all relevant amenities are accessible by public transport, or ideally active travel, within 20 minutes of any household.
- Biofuels: Use of biofuel crops to increase resilience and long-term profit as well as a cover crop.
- Encouraging collective property management and good stewardship models for water management on new developments.
- Use of dedicated WTW and water supply networks to avoid the use orthophosphorous to prevent plumbosolvency

[70] Norfolk Water Strategy Programme - Water Resources East (wre.org.uk)
[71] https://rodaleinstitute.org/blog/10-tips-for-adding-livestock-to-your-crop-rotation/

- Biodiversity Net Gain offsetting
- Sustainable design/zero-pollution infrastructure
- Abstraction-Effluent Dilution, reducing river abstractions during high precipitation events to dilute untreated sewer spills[72]
- Brownfield remediation: benefits for soil, drainage and therefore flood risk, water quality. Potential benefits to recharge.
- Active floodplain creation from inactive floodplain (defended). NB Flood defence Grant in Aid can be used to support funding.

[72] Protecting rivers by integrating supply-wastewater infrastructure planning and coordinating operational decisions (iop.org)

J. Modelling in water planning frameworks

Table J.1: Main modelling undertaken in water sector planning frameworks

Sub-system	Modelling Activity	Example models	Model spatial resolution	Model time resolution	Model area scale	Key outputs for planning
Water Resources	Rainfall-runoff	GR6j, HYSIM, Catchmod	Sub-catchment (typically a few hundred km2)	Typically daily	River basin	Flow series under current and future conditions
	Groundwater	MODFLOW	200x200 metres	Daily?	River basin	Water availability, groundwater levels & stream flows
	Water resource simulation	PyWR, Aquator	WRZ with water body nodes	Daily?	Water company or region	System deployable output or drought resilience. Can include performance against multi-criteria (e.g. WRE)
	Investment modelling	EBSD	WRZ	Snapshot and yearly	Water company or region	Option portfolios & costs with performance against multi-criteria
Waste Water	Integrated Catchment Modelling	Infoworks ICM	Properties, sewer network, CSOs,	5 minutes to daily	Drainage area catchment	Option portfolios; Spill volume, peak flows and frequency; Water quality relevant to permits; dry weather flows
Water Environment	In river water quality modelling	SAGIS, SWAT, INCA, QUAL-2K	Sub-catchment (typically a few hundred km2)	Daily to yearly	River basin	Pollutant concentrations and source apportionment
	Fish habitat modelling	PHABSIM	A few meters	Static	River reach	Environmental flows
	Macro invertebrate modelling	LIFE	A few hundred meters	Static	River reach	Environmental flows
Flooding	Statistical analysis	WINFAP	Sub-catchment (typically a few hundred km2)	N/A	Sub-catchment	Peak flow for different AEPs
	Rainfall-runoff	ReFH2	Sub-catchment (typically a few hundred km2)	Minutes-hours	Sub-catchment	Flood hydrograph for different AEPs
	Hydraulic modelling	FMP, TUFLOW, Infoworks	From 1x1m to 20x20m	Seconds	Sub-catchment	Flood risk maps
Regional IWM (e.g. OxCam)	Integrated Water Cycle Model	WSIMOD	Water body	Daily	Catchment to Regional	Flow duration curves, water quality indicators, drought resilience indicator, flooding flow indicators

K. MCA best practice review

This section sets out a review of current practice for conducting Multi Criteria Analysis (MCA) and investment appraisal to inform our development of an integrated assessment of solutions across the four core water sub-systems (water resources, wastewater, flood risk and water environment) within the OxCam Arc.

MCA is a means of making decisions in complex systems where multiple variables need to be evaluated and compared. It is used in investment appraisal techniques. Key concepts are introduced and the following approaches to MCA reviewed:

- primary government guidance on investment appraisal
- investment appraisal in the water sector
- water company investment optimisation
- broader perspectives

Implications for the development of the OxCam Arc IWMF are then discussed in the final section.

K.1 Key concepts and terms

The creation of the IWMF comprises a synthesis of different planning processes. Each planning process has embedded assumptions about risk, valuation of benefits, cost and other variables. In this section we set out a few key concepts that will enable us to compare different planning assumptions implicit in different procedures.

The following definitions and explanations of key terms will inform our review of MCA policy and practice.

The PRINCE2 project management guidance defines a **benefit** as 'the measurable improvement resulting from an outcome that is perceived as an advantage by one or more stakeholders.'[73]

The Green Book providing UK government guidance defines **appraisal** as 'the process of defining objectives/outcomes, examining options and weighing up the relevant costs, benefits, risks and uncertainties to inform a decision.'[74]

The ability to make an informed decision is affected by **uncertainty**, which is defined by the Ministry of Transport as 'limited knowledge about past, current and future events and the systems in which these events occur'[75]. The DfT refer to **known unknowns** where information is incomplete. It may be possible to reduce these unknowns through further investigation. However, in the context of increasing uncertainty as a result of global change including climate change and the impact of pandemics, there are knowledge gaps that cannot be resolved – referred to as **unknown unknowns**. The increasing significance of these unknown unknowns is driving the need for new practices in handling uncertainty in planning.

[73] Managing Successful Projects with PRINCE2, Edition 5, The Stationery Office, Norwich, 2009. ISBN 978-0113310593

[74] The Green Book: Central Government Guidance on Appraisal and Evaluation, HM Treasury, 2018
The Green Book (publishing.service.gov.uk)

[75] TAG Uncertainty Toolkit, Department of Transport https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/983766/tag-uncertainty-toolkit.pdf

Some uncertainty in an appraisal is a function of the type of system or systems of interest. The Magenta Book[76] identifies problems (and systems) as being simple, complicated and complex. A **simple** system is straightforward and has the least uncertainty (e.g. building a wall, or following a recipe). A **complicated** system has diverse interacting components (e.g. engineered systems such as a pumping station, flood barrier or water distribution system), but is still essentially predictable. A **complex** system has non-linear and non-proportional behaviour;[77] and shows a degree of unpredictability in how the different elements interact and what the outcome will be in a given situation (e.g. socio-economic systems such a river catchment or landscape).

The key aim for this Annex is to review guidance and practice in how planning processes can handle uncertainty in complex systems and to show the context and rationale for methods proposed (and already undertaken) for the OxCam IWMF

K.2 Primary government guidance

K.2.1 Green Book

The Green Book[78] provides guidance on the use of appraisal to support decision making when spending public money.

It recommends appraisal using either Social Cost Benefit Analysis (SCBA) or Social Cost-Effectiveness Analysis (SCEA). This places a valuation on all significant costs and benefits to allow the best value-for-money option to be selected. Where possible, costs and benefits should be monetised, and when this is not possible, alternative forms of quantification should be considered to provide a common metric. For example, through approaches drawing on customer research to estimate the value that customers place on environmental services (e.g. through Willingness to Pay (WTP) analysis).

Discounting should then be used to compare interventions with different timespans and cost-benefit profiles over the appraisal horizon. This accounts for the concept of 'time preference' (people prefer to receive goods now rather than later), to ensure accurate valuation of future costs and benefits.

Within appraisal, uncertainty is accounted for in the following ways:

- **Risk management –** optimising social value through identifying and monitoring risks that may occur over the appraisal period. Mechanisms are recommended such as risk registers, assessment of contract-related risk and of risk controls.
- **Optimism Bias –** which can be applied based on an organisation's own evidence based for historic levels of over-estimates.
- **Sensitivity analysis –** used to assess how sensitive an option is to changes in key inputs. Switching values can be used to show the point at which these changes would lead to a significant change in the option evaluation – e.g. when benefits exceed costs.

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[76] Magenta Book: Central Government guidance on evaluation, March 2020
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879438/HMT_Magenta_Book.pdf

[77] Magenta book: Supplementary Guide: Handling Complexity in Policy Evaluation (2020) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879437/Magenta_Book_supplementary_guide._Handling_Complexity_in_policy_evaluation.pdf

[78] The Green Book: Central Government Guidance on Appraisal and Evaluation, HM Treasury, 2018
The Green Book (publishing.service.gov.uk)

- **Monte Carlo analysis –** using simulation-based risk modelling to run multiple scenarios, addressing the collective impact of a number of uncertainties and producing confidence intervals and expected values.
- **Decision trees and real options analysis –** used to explore alternative approaches that are available if key risks arise. Decision trees map out the expected values within complex situations and real options demonstrate choices that may become available in future.

Supplementary guidance has been issued to help appraisals account for the effects of climate change[79] through identifying climate risks during early option development and adapting options if required. Climate scenarios are then incorporated into the appraisal process to ensure that the risks and impacts on costs and benefits are accounted for. **Robust** plans can then be created to mitigate climate change related uncertainties. This supports adaptive decision-making, prioritising options with the greatest **flexibility** of benefits over those with the highest benefits. Therefore, a robust strategy has been defined as one that ‘performs well across a wide range of plausible assumptions about the future’[80].

The guidance also provides an overview of the different methods which can be used to handle uncertainty and the areas of planning they are most suited for. MCA is suggested as a suitable approach for use in water management as it enables uncertainty to be incorporated as an assessment criterion and also combines expert judgement and stakeholder preference within a structured evaluation.

K.2.2 Magenta Book

The Magenta Book[81] provides government guidance for the evaluation of interventions. Interventions include ‘anything intended to elicit change, including a programme, policy, project, regulation and changes in delivery method.’ The book describes process, impact and value-for-money evaluation. The method for impact evaluations is important to this project because of the attribution of outcomes and benefits to interventions. Value for money evaluations draw on the valuation of costs and benefits from the Green Book.

A key element to impact evaluations is the acknowledgement that there are broader influences that act between the intervention and the outcome. Therefore, the benefit may not be entirely attributable to the intervention. The book provides guidance on how best to evaluate complex systems characterised by complexity and unpredictability. In these circumstances causality is hard to prove, with problems stretching across policy domains. The book proposes a combination of system maps, logic models and stakeholder engagement to understand how systems behave. Systems mapping demonstrates causality, interlinkages, broader external influences, feedback loops and allows influential system levers to be mapped out. Participatory system mapping is a means of drawing out the collective insights on system operation from people with locally informed contextual knowledge and expert knowledge.

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[79] Accounting for the Effects of Climate Change: Supplementary Green Book Guidance
Accounting_for_the_Effects_Of_Climate_Change_-_Supplementary_Green_Book_.._.pdf (publishing.service.gov.uk)

[80] RAND – Water Planning for an Uncertain Future - Water Planning For the Uncertain Future | RAND

[81] Magenta Book: Central Government guidance on evaluation, March 2020
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879438/HMT_Magenta_Book.pdf

K.2.3 Other government guidance

The UK Transport Appraisal Guidance (TAG)[82] provides specific guidance on the treatment of uncertainty within transport planning, with these principles also applicable to other areas of public spending. This focuses on the need for appraisals to be consistent in their treatment of uncertainty. For the transport sector, use of Common Analytical Scenarios (CAS) ensures that a common set of 6 scenarios can be selected for appraisal purposes. This allows different versions of the future to be selected, accounting for possible changes to drivers such as transport demand, population growth and decarbonisation. These scenarios can then be modelled to test the robustness of different options.

However, other methods to treat uncertainty are also suggested within the UK TAG. For example, expert knowledge can also be incorporated when Judgement Based Approaches are shown to be feasible. Although this method of uncertainty analysis is subjective, it can be a much quicker way of identifying key uncertainties early in a project. The guidance also emphasises a proportionate approach to addressing uncertainty, with some evaluations requiring use of multiple methods in combination.

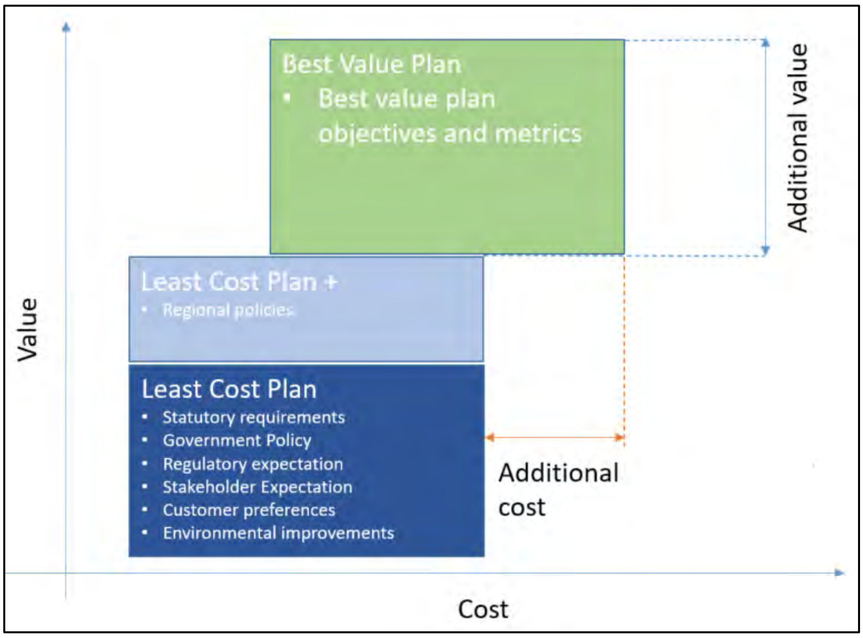
K.3 Water sector methods

This section explores methods used for appraisal and strategic planning across the water sector.

K.3.1 Best value

The concept of best value reflects the fact that water resource interventions commonly bring co-benefits beyond water resources. A Best Value Plan is defined within the WRPGs as '*one that considers factors alongside economic cost and seeks to achieve an outcome that increases the overall benefit to customers, the wider environment and overall society'.*

Figure K.1 Least cost and best value planning (WRSE)



[82] TAG Uncertainty Toolkit, Department of Transport https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/983766/tag-uncertainty-toolkit.pdf

Figure K.1 shows the conceptual link between least cost and best value plans. The least cost plan is the most cost-effective way of meeting the requirements of the plan. The 'best value plan' can be understood as answering the question, 'assuming the least cost plan is to be implemented, what additional interventions could be added for a marginal additional cost that would improve the overall cost-effectiveness of the plan'. An example would be a river restoration plan that meets water quality objectives which might be included in the least cost plan; and if public access to the river is added at a marginal additional cost, then significant additional social benefits are realised from the river restoration activity, meaning that the overall cost-effectiveness of the scheme is enhanced.

K.3.2 System mapping

System mapping is a method to identify the interconnected nature of systems. Is a method that:

- Draws on expert judgement for complex system linkages
- Clarifies detail of systems such as categories of intervention and their benefits
- To validate the selection of metrics used in an appraisal process.
- Takes a broad perspective on describing a system that enables targeting of effort for more detailed analysis.

As such system mapping can be used to assess how well a schedule of metrics reflects system benefits or attributes used in an appraisal.

WRSE used system mapping to understand what to measure to assess the resilience of the water sector. A system map for the public water supply identified how soft and hard system functions contributed to resilience of the water sector and therefore should be included in the resilience framework. The mapping was used in conjunction with a consultation which highlighted, among other things, the need to reflect a broader perspective than the engineered PWS, including the foundational significance of the environmental system in underpinning water system resilience. The system map was annotated to show how the resilience metrics reflected functions that contribute to water system resilience. As a result of the system mapping metrics were added for soil health, customer relations and collaborative landscape management all of which enhance system resilience when in place.

K.3.3 Consultation and engagement

Both the WRPG and UKWIR guidance recommend that consultation and stakeholder engagement take place throughout the planning process. Consultation and engagement help handle uncertainty because they allow for collective judgement and perception of a problem to inform problems that cannot be addressed by the availability of data alone (either the data isn't available or cannot be connected economically; or because the system is complex, and its behaviour may be nonlinear or in some way unpredictable).

Early engagement ensures that the objectives used to define 'best value' are in line with customer views. This can be provided through existing customer research and the involvement of Customer Challenge Groups (CCGs). Engagement and consultation also regulators to provide feedback throughout the process and to ensure that the appropriate constraints are considered within the best value framework and least cost plan.

Consultation takes place within both the WRMP and regional planning processes. This occurs with customers and other stakeholders during early stages to identify the best value framework. Further consultation then takes place with the public and Ofwat after the publication of draft plans.

K.3.4 Expert judgement

Expert judgement is required where impacts are uncertain and there is insufficient time or resource available to fully determine them. For example, the impact of severe drought or climate change on the deployable output of supply options that are only approximately defined. Assumptions have to be made, and allowances for uncertainty may be specified using simplified models of how the supply option will behave under certain climate conditions, based on previous experience of similar options.

K.3.5 Investment modelling

Investment modelling tools are also used by water companies for portfolio optimisation, identifying the best value combination of projects that could be selected. This improves the efficiency of the project appraisal process by embedding benefits and appraisal frameworks within these planning tools and strategies. It also enables in-combination effects to be taken account of, for example, where a deficit in one supply area is best resolved by delivering new water resources in a different supply area and transferring the water to the area in deficit. This requires modelling to take account of supply demand balance across the model area, the cost of interventions everywhere and the cost of transferring water. More sophisticated modelling may also take account of wider criteria representing other costs and benefits associated with different supply options and transfers.

An example of an investment prioritisation tool used within the water industry is Copperleaf C55. This is used by several companies including Anglian Water[83], which incorporates its own Service Measures Framework into the Copperleaf system as a basis for portfolio evaluation. Advanced cost estimation capability means that two alternatives can be costed for each project to help identify the best combination of projects within a portfolio. Similarly, Thames Water uses the APS (Asset Planning System) which includes embedded cost and carbon estimating tools, as well as risk and benefit frameworks. Price Review data and monetised benefits (cost of failure and willingness to pay data) can then be used to determine the optimum balance between service (performance commitments), risk and cost according to a number of user defined constraints. This enables prioritisation within investment areas and across the whole investment programme to determine the size of the overall investment plan for a Price Review.

Different Regional Water Resource Groups also use different types of investment model. For example, WRSE uses a regional investment model in which costs and benefits are specified up front, and options selected to meet alternative supply/demand scenarios across the region. In contrast, WRE uses an investment simulator, in which supply-side modelling of options is carried out within the investment model, and cost curves are specified for different components of the options to enable more flexibility in option sizing. Due to the additional computational demand, smaller options are excluded from this modelling and must be appraised separately by companies, with reconciliation then required with the regional plan.

K.4 Water sector planning

Ofwat[84] has also set out the need for water companies to develop their strategic planning frameworks through alignment with those of other stakeholders. This includes river basin management plans (RBMPs), flood risk management plans (FRMPs), the flood and coastal erosion risk management strategy (FCERM), and flood risk activity permits. Recommendations are also related to programme optimisation over the long term and the need to support

[83] Copperleaf – Continuous Investment Optimisation and Planning at Anglian Water
Copperleaf ESG Spotlight Anglian Water

[84] PR24 and beyond: Final guidance on long term delivery strategies, Ofwat. April 2022.
PR24-and-beyond-Final-guidance-on-long-term-delivery-strategies_Pr24.pdf (ofwat.gov.uk)

decisions by using common scenarios and sensitivity testing. The Environment Agency's National Framework for Water Resources (NFWR)[85] also calls for integration, requiring water resource planning to consider flood plans. There are habitat and Strategic Environmental Assessment (SEA) requirements) in WRMP planning that address environmental systems.

As such, there is increasing emphasis on the need for each system to consider interlinkages with the others, but while they reflect the presence of the other systems, this does not comprise a fully integrated approach.

K.4.1 Water resource planning

The approach to water resources planning in the UK is set out within the NFWR and emphasises the interaction between the planning processes of the 5 regional groups and the 17 water companies and other water users. This sets out the requirements for regional plans (Figure K.2), emphasising the need to take a multi-sector approach and reflect the WRMPs.

These are grouped as:

- Must Dos - absolute requirements and constraints for planning purposes for inclusion within any least cost plan
- Should Dos) present the absolute requirements and constraints for planning purposes for inclusion within any least cost plan, whilst Could Dos can form part of the value criteria to be included above this level

[85] Summary of the NFWR

Figure K.2: Scope for regional plans set out by the NFWR

MUST
- take account of the National Framework and set out its potential contribution to the national need
- be reflected in Water Resource Management Plans
- forecast supply and demand over at least 25 years and set out solutions to any deficits
- be a single strategic plan with a preferred adaptive solution
- take a multi-sector approach
- look beyond regional boundaries and use technical approaches compatible with other regions
- include enhanced environmental improvements and demand management
- take a catchment-based approach
- consider wider resilience benefits, including reducing flood risk, when developing options
- be open to market mechanisms
- take into account growth ambition
- comply with Strategic Environmental Assessment (SEA) and Habitats Regulations Assessment (HRA) legislation

SHOULD
- engage widely with interested groups
- set out how the region will respond to drought and agree common scenarios for drought actions
- join up with drainage and wastewater management plans
- seek to improve resilience to events other than drought, particularly floods
- look ahead 50 years or more

COULD
- contain all the detailed information required for Water Resource Management Plans
- contain all the detailed information required for Drought Plans

Methods used for water resources planning in the UK are informed by the Water Resources Planning Guidelines (WRPG)[86] and UKWIR guidance[87] on best value planning.

K.4.2 Water Resource Management Plans

At the water company level, statutory requirements are also set out within the WRPG and cover a greater range of inputs than for the regional plans. These guidelines can then inform the development and weighting of value criteria included within the MCA. Supply and demand forecasts should also be conducted to identify customer requirements over a minimum 25 year period. If deficits are identified, then options to reduce supply or demand must be considered to ensure a sustainable approach.

UKWIR guidance[88] also recommends that MCA is included within the best value planning process for producing water resource management plans.

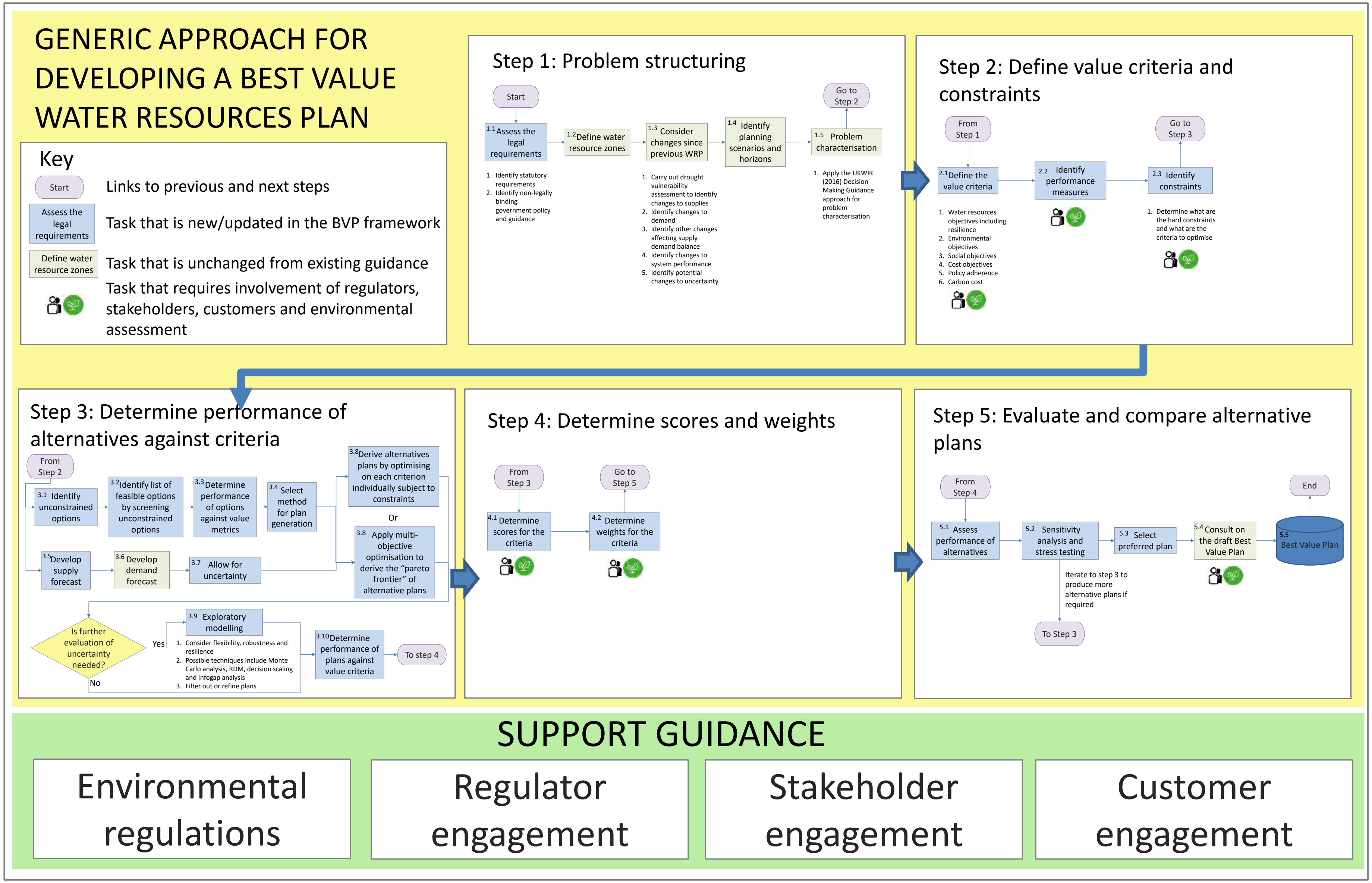
The five step process (Figure K.3) is recommended as a way to develop a BVP incorporating MCA to inform the decision-making process.

[86] Water Resources Planning Guideline - Water resources planning guideline - GOV.UK (www.gov.uk)

[87] Deriving a Best Value Water Resources Management Plan - Deriving a Best Value Water Resources Management Plan (ukwir.org)

[88] Deriving a Best Value Water Resources Management Plan - Deriving a Best Value Water Resources Management Plan (ukwir.org)

Figure K.3: Generic approach for developing a best value water resources plan (UKWIR)



Best value metrics cover areas such as water resource usage and efficiency, as well as drought resilience. Natural capital and environmental value should also be measured through use of BNG and the results of SEAs and Habitats Regulations Assessments (HRAs).

This approach to best value planning ensures that plans not only cover water companies' statutory obligations but also deliver greater overall benefits to customers and the environment. These can then be aligned with regional planning.

K.4.3 Regional planning

This approach to planning has been adopted at the regional level within the UK, within the Water Resources South East (WRSE)[89] and Water Resources East (WRE) programmes. Both produce BVPs which account for significant complexity, with adaptive plans produced after multiple rounds of iteration and portfolio simulation to account for uncertainty from varying climatic and developmental pathways.

Setting the objectives for the BVP includes a high level of customer and stakeholder engagement from water company research as well as a risk-based planning method to work out the severity and complexity of problems at the Water Resource Zone (WRZ) level. This validates the metrics and ensures that 'must do' criteria are developed in addition to other value criteria which can be included within the optimised BVP.

Within the WRSE approach, the following table provides an example of BVP objectives and criteria with metrics then used to measure success against each objective.

Figure K.4: WRSE BVP objectives and criteria

Our best value objectives and criteria

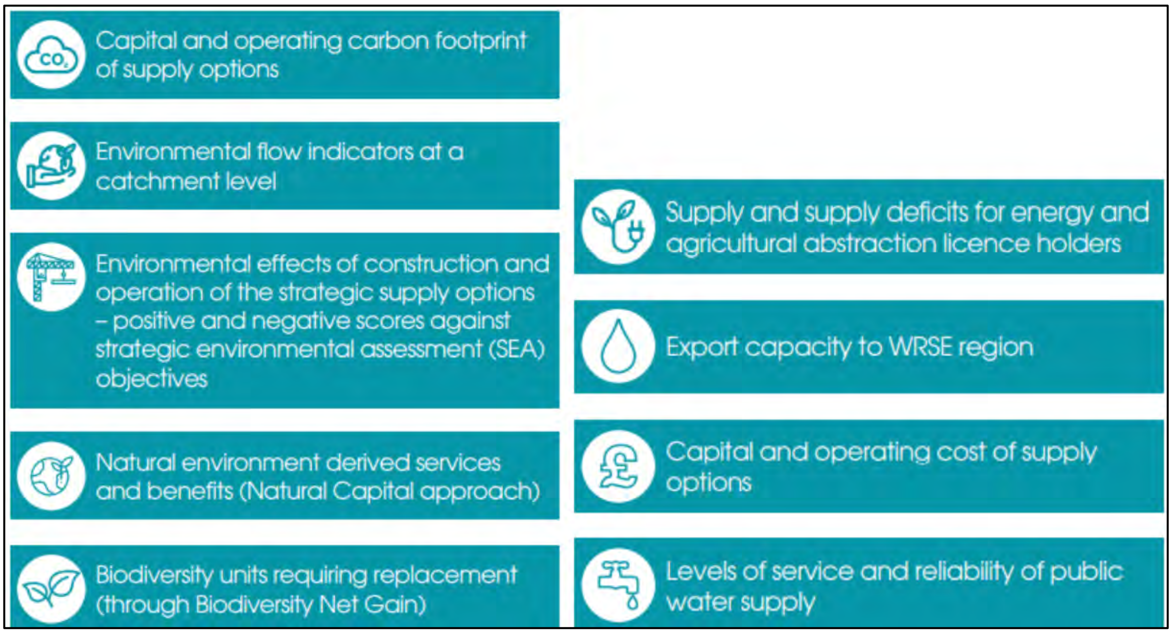
Objective	Criteria
Deliver a secure and wholesome supply of water to customers and other sectors to 2100	Meet the supply demand balance – provide enough water for public water supply and other sectors by 2100
	Halve leakage by 2050 and reduce it further beyond 2050
	Reduce how much water is put into supply by water companies
	Options that customers prefer (using customer preference score from customer insight)
Deliver environmental improvement and social benefit	Reduce how much water is abstracted from identified sites and by when
	Environmental disbenefits of the programme (assessed by the Strategic Environmental Assessment)
	Environmental benefits of the programme (assessed by the Strategic Environmental Assessment)
	Enhance natural capital
	Improve biodiversity (biodiversity net-gain score)
	The cost associated with offsetting carbon emissions
Increase the resilience of the region's water systems	Achieve 1 in 500-year drought resilience (date achieved)
	Reliability - how well the water system can cope with short-term shocks without changing how it performs
	Adaptability - how well the water system can adapt so it can accommodate short-term shocks
	Evolvability - how well the system can be modified to cope with long term trends
Deliverable at a cost that is acceptable to customers	Total cost of the programme (using the Social Time Preference Rate)
	Spread the total cost of the programme across present and future generations (using the Long Term Discount Rate)

Modelling takes place first through the Integrated Risk Model (IRM) to determine the water resources supply demand balance over the period, and then through into the Investment Model which produces investment programmes for comparison and shortlisting. This identifies a programme of options which is optimised against both single and multiple future situations. Through this process, branched pathways are established which provide the opportunity for adaptive planning.

The WRE programme follows a similar approach, with a set of best value criteria defined along with associated metrics.

[89] WRSE Method Statement: Best Value Planning, January 2022 (Updated July 2022) method-statement-best-value-planning.pdf (wrse.org.uk)

Figure K.5: WRE vest value performance metrics



To account for uncertainty, the WRE programme also demonstrates a highly innovative decision-making framework through combining robust decision-making (RDM) and multi-criteria Robust Decision Making (MO RDM) process. This makes use of a system simulator which functions as an integrated computer model that implements the robust decision-making under uncertainty framework. The simulator is then run under multiple future scenarios to identify promising portfolios and their trade-offs. This varies the interactions between supply and demand based on climate, hydrological and socio-economic modelling and the outcome for each variation is ranked against performance metrics agreed by the project stakeholders. Detailed least cost optimisation and option scheduling then takes place through Economic Balance of Supply and Demand (EBSD) modelling, and Systematic Conservation Planning (SCP) is used to evaluate the costs and benefits of alternative land use management options and ensure that environmental ambitions are achieved within the WRMP. This enables a multi sector approach exploring the links between land, water and nature which can develop multiple benefits and increase cost efficiencies.

K.5 Other areas of water sector planning

Beyond the area of water resources planning, appraisal of options is also undertaken across all areas of water sector planning such as in water environment, wastewater and flood risk management planning. Stakeholder engagement and consultation is common to all processes.

Many of these approaches to appraisal in other areas of water sector planning also draw on guidance from the Green Book, following a standard CBA where possible. However, the Green Book also summarises their different approaches to the valuation of benefits and unmonetisable values, detailing how this varies between the water resources and flooding sectors.

K.5.1 Wastewater planning

Wastewater planning follows a similar approach to water resources and draws on a set of guiding principles[90] and the Water UK framework[91] which set out the expectations and legal requirements for a DWMP. Similarly to WRMP planning, this requires:

- Meeting environmental obligations – such as the 1991 Urban Wastewater Treatment Directive (UWWTD), 1992 Habitats Directive, 2000 Water Framework Directive and the 2006 Bathing Water Directive.
- Strong linkages to be demonstrated with the WINEP, FRMPs, RBMPs and Local Plans.
- Stakeholder engagement to identify risks and opportunities within early planning, including relevant RMAs.
- Customer engagement as part of best value planning and benefits assessment.

It is worth noting that as DWMP planning is still in its first cycle, companies are still developing their approaches and therefore programme appraisals can be varied. However, the main elements of appraisal are consistent and an example approach[92] would include:

- Early Baseline Risk and Vulnerability Assessment (BRAVA) to determine catchment risks and inform option development
- Option evaluation through identification of costs and benefits, with option risks monetised in accordance with Green Book guidance
- Benefits assessment undertaken with key wastewater metrics such as treatment compliance/capacity, network capacity and internal/external flooding, as well as for environmental and social metrics through natural capital and strategic habitats regulation assessments.
- Best value framework developed with clear objectives or value criteria, along with the metrics for the objectives.
- MCA undertaken to compare the difference in performance between programmes.
- Identification of least cost plans for comparison against the BVP.

K.5.2 Water environment planning

Planning for the water environment focuses on the ability of RBMP programmes of measures to meet environmental objectives as determined by the WFD.

- Measures are based on programmes of investigations to understand why some water bodies are not meeting the default objective of good status or potential.
- These measures are costed in water company business plans, individual project appraisals, government published figures and the Environment Agency's business plans.
- Costs associated with rural land management sector are produced using the Environment Agency's Cost of Agricultural Measures (CAM) tool. In all catchments, the most cost-effective measures are selected, for example, low cost measures were preferred against higher cost land use change.

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[90] Guiding principles for drainage and wastewater management plans - GOV.UK (www.gov.uk)

[91] Atkins – A framework for the production of Drainage and Wastewater Management Plans. Appendix D: Options development and appraisal.

Water_UK_DWMP_Framework_Appendices_September-2019-D.pdf

[92] Thames Water DWMP programme appraisal approach programme-appraisal-briefing-note.pdf (thameswater.co.uk)

An impact assessment was carried out by the Environment Agency in 2015[93] to specify environmental objectives and actions in a set of updated RBMPs, based on cost/benefit appraisal. The following methods were used for benefits valuation:

- For surface water appraisals, the Environment Agency used the National Water Environment Benefit Survey (NWEBS) willingness to pay values to allow for the monetisation of ecosystem services and wider social benefits. NWEBS provides benefits from WFD status improvements (bad to poor, poor to moderate etc.) per km (or km2) of river, lake, estuary or coastal water affected, based on willingness to pay values which capture aesthetic, recreational and existence benefits.
- For groundwater appraisals, values were transferred from previous peer-reviewed economic assessments to monetise some ecosystem service benefits. Where benefits cannot be monetised they were captured qualitatively for each catchment to record whether benefits or disbenefits to ecosystems services are 'significant', 'noticeable but not significant' or have 'no net change'. This is based on the ecosystem services framework to assessing benefits, as specified in the Treasury's 'Green Book supplementary guidance: environment'. Benefits are only appraised sufficiently to decide whether or not the benefit/cost ratio is greater than or less than 1.

The methodology for undertaking WINEP appraisals is currently being updated. However, it is expected that companies will be required to use a best value approach delivering wider benefits. For example, increasing flood resilience and amenity value for communities in addition to achieving environmental goals[94].

K.5.3 Flood Risk Management Planning

Planning in the flooding sector revolves around the delivery of the national FCERM strategy. This determines how much flood defence is required nationally, with the total funding available informed by the Long Term Investment Scenarios (LTIS (published every 5 years)) which provide an economic assessment of the optimum level of investment for FCERM. Flooding schemes identified are then required to apply for DEFRA Grant in Aid (GiA) and go through an appraisal process to demonstrate how managing flood risk will provide benefits at the national level in addition to the local level. Benefits at a national level are those demonstrated to have a net positive impact to the national economy, environment or society. Local level impacts should also be included within appraisal but are not viewed as having a net impact on the nation as a whole, as these changes are likely to be cancelled out by projects in other locations.

The FCERM appraisal process[95] largely follows Green Book guidance and uses either CBA or CEA for benefits valuation depending on project type.

- Appraisals use a series of outcome measures for each scheme to determine the amount of benefit provided, with emphasis on the number and value of houses protected by flooding or erosion.
- Benefits are primarily determined by the number of properties moved from one flood risk band to another.
- Other methods to estimate the changing risk of flooding and coastal erosion over time, include the use of Annual Average Damages (AAD) as a metric. This is the probability-

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[93] Impact_assessment_update_to_the_RBMPs_for_England_s_water_environment__2015_.pdf (publishing.service.gov.uk)

[94] Draft water industry national environment programme methodology July 2021 draft-water-industry-national-environment-programme-methodology.pdf (environment-agency.gov.uk)

[95] FCERM appraisal technical guidance – March 2022, Environment Agency external corporate report template (publishing.service.gov.uk)

weighted resource cost of flood damage to property and infrastructure, plus adverse health impacts and the resource costs of disruption.

- Valuation of wider social and environmental benefits (including net carbon impacts) also takes place, with monetisation in accordance with Green Book guidance.

K.5.4 Summary

Table K.1 summarises the different metrics and methods used across water environment planning processes.

Table K.1: Use of metrics across planning processes

Metrics	WRMP	Regional plans	DWMP	RBMP/WFD	FCERM/FRMP	WINEP*
SEA	Yes	Yes	Yes	Yes	Yes	
Selection criteria	MCA	MCA	MCA	Objectives & CBA	Objectives & CBA	CBA
Resilience	Yes	Yes	Yes	Yes – Climate Change	Yes	No
Best value	Yes	Yes	Yes			Yes
BNG	Yes	Yes	Yes			Yes
NC	Yes	Yes	Yes	Yes – ES valuation	Yes	Yes
Modelling	Yes	Yes	Yes		Yes	
Carbon	Yes	Yes	Yes		Yes	
NWEBS?				Yes		Yes

*Based on proposed updates to WINEP methodology

K.6 Global best practice

Global approaches to water sector planning have focused on developing robust and adaptive water management. This addresses the challenge of decision-making under uncertainty (DMUU), due to uncertain futures caused by climate change and supply-demand imbalances. Plans which adopt these principles can then be incorporated into IWMFs to ensure all potential co-benefits are appraised across multiple systems.

K.6.1 Robust Decision Making

Water resource planning globally has increasingly adopted strategies such as Robust Decision-Making (RDM), a common method used to produce a set of robust (not necessarily optimal) strategies which meet or exceed a set of minimum criteria across a range of plausible futures. This takes place through stress testing investment plans to identify which scenarios will produce failure. This can then be coupled with multi-objective optimisation to connect a search algorithm to a simulator to identify trade-offs between different portfolios of schemes.

Examples of this approach have been developed in Western USA[96] to manage water scarcity and address the planning needs of multiple sectors within an uncertain future. This has enabled the vulnerability of the Colorado River system to drought, climate change and growth to be assessed through a multi-criteria evaluation of the performance of future management strategies. These are based on increasing supplies, managing demand and modifying the operation of existing assets. The multi-criteria evaluation is then completed using metrics for water supply, hydropower, flood control, water quality, recreation and the environment. Optimisation then takes place through connection to a simulator to identify the possible trade-offs between different portfolios. These approaches have influenced regional water resource planning within the UK, such as WRE.

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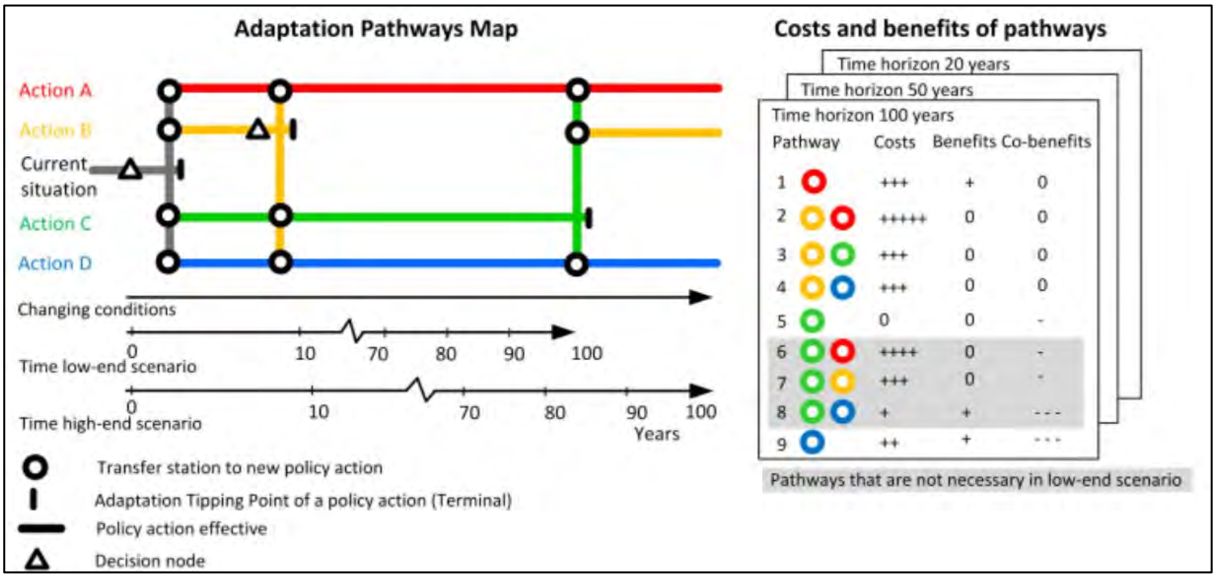
96 Moncaster S Report 2015 Final Winston Churchill Fellowship.pdf (sharepoint.com)

K.6.2 Adaptive planning

Beyond water resources planning, other approaches have been adopted globally[97] to consider how whole regions (e.g. deltas with freshwater and flooding needs) can adapt to climate change. This is achieved through the use of Dynamic Adaptive Policy Pathways (DAPP) [98]. This ensures that plans are adaptive through mapping alternative policy choices (Figure K.6) that can be taken at key decision points within a planning scenario. The costs and benefits of different pathways can then be compared, and trigger points defined where alternative interventions and pathways may become preferrable.

Figure K.6: Example of adaptation pathways (Deltares)[99]



Adaptive planning has successfully informed decision making under uncertainty in complex systems such as the Rhine Delta in Holland, to ensure that plans are able to meet both water resource and flood risk management needs into the future. These principles have then also been used to inform water resource regional planning in the UK and are also being used in the development of the FCERM strategy[100].

K.6.3 Integrated Water Management Frameworks

Integrated planning approaches can then be applied at the regional scale, to incorporate the outputs of individual planning strategies and improve the efficiency of benefits appraisal across the whole water sector.

In Australia, the IWMF[101] for the state of Victoria utilises the knowledge and experience of water sector organisations, applying an integrated approach to water cycle planning by providing a forum for collaboration on projects which will deliver cross-sectoral benefits. Robust economic analysis is applied to compare options and includes recognition of avoided costs which could

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[97] Literature review on an adaptive approach to flood and coastal risk management, Environment Agency Heading 1 (publishing.service.gov.uk)

[98] Haasnoot, M., et al., Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environ. Change (2013)

[99] Deltares: Adaptive Delta Management Brochure-Adaptive-Delta-Management.pdf (understandrisk.org)

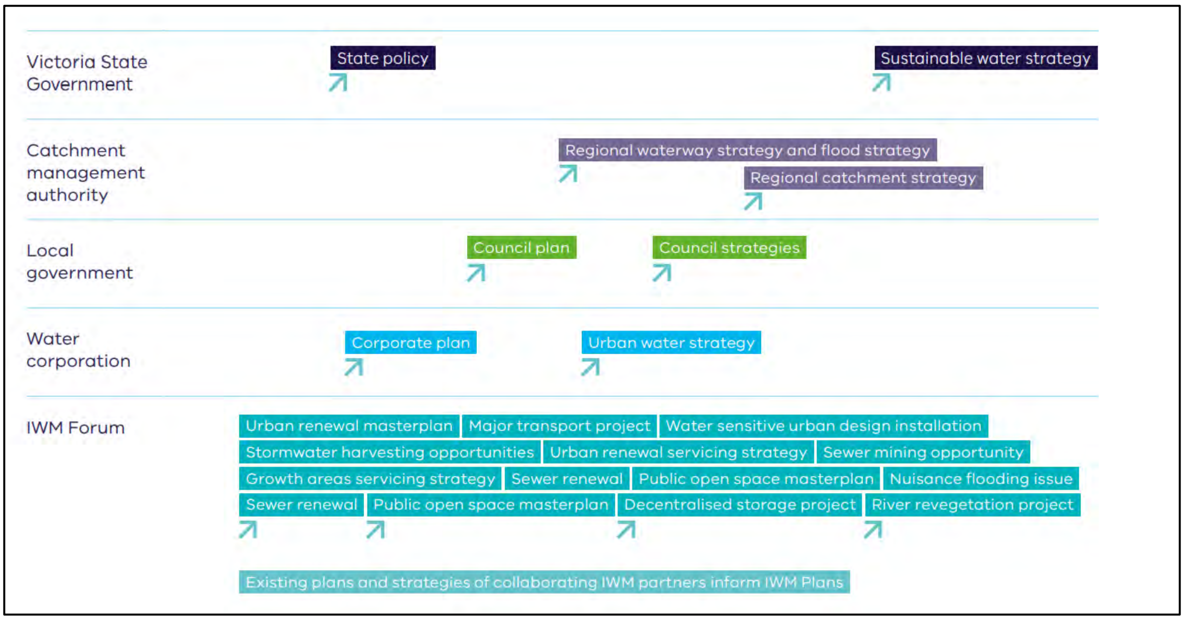
[100] Literature review on an adaptive approach to flood and coastal risk management, Environment Agency Heading 1 (publishing.service.gov.uk)

[101] Integrated Water Management Framework for Victoria: DELWP-IWM-Framework-FINAL-FOR-WEB.pdf (water.vic.gov.au)

result from a solution and be classed as benefits. Integrated planning is particularly valuable for the region, given that urban areas such as Melbourne suffer from significant stormwater related issues. Addressing these challenges requires co-ordination between water resources, wastewater management, flooding policy and urban planning to explore solutions which deliver multiple benefits. For example, a proposed blue-green infrastructure water recycling project which has the potential to both reduce stormwater flooding and provide a water resource through the use of rainwater collection tanks, whilst green infrastructure can also improve water quality outcomes and urban cooling.

Therefore, a key part of developing the IWMF has been to recognise the interface between the different organisations which are responsible for managing the urban water cycle – such as Melbourne Water, the Victorian Planning Authority, the Environment Protection Agency, property owners and Catchment Management Authorities. A flow of information between planning strategies (Figure K.7) can then be created to ensure organisations are aware of planned activities in neighbouring sectors.

Figure K.7: Water Management Planning flow of information (Victoria IWMF)



Thus, the IWMF has demonstrated the value of data sharing and collaboration to support more efficient investment and include options which were previously disregarded but are now recognised as best value. This takes place through recognising the additional co-benefits that are provided to the community and environment beyond the aims of one sector alone. Shared investment is then incentivised across organisations, allowing high-cost high-value schemes to be realised. Implementation and governance of the IWMF is then facilitated through the use of IWM Forums to include stakeholders and develop place-based IWM plans.

Analysis of the policy interface governing the water sector has formed a key part of the OxCam project so far and could provide a similar forum to identify opportunities for more integrated solutions.

K.7 Implications for IWMF

- The MCA undertaken by water sub-system investment planning varies considerably, both between sub-systems and between regions within sub-systems.
- The optimisation of WRMP is complex and must be undertaken over a regional spatial scale to account for the ability to transfer water long distances. Therefore, MCA at an OxCam (or other sub-regional) scale cannot be used to attempt to optimise water resource planning.
- MCA of water resource planning is already complex, and it is generally not possible to monetise all benefits/costs, nor to find a single optimised solution across all criteria. Adding more criteria, such as flood benefit or WFD status benefit to WRMP planning would therefore be challenging.
- To make an IWM MCA achievable, it therefore is necessary to set boundaries for the IWM MCA. This could be done by running portfolios of solutions obtained in existing planning processes through an integrated catchment model, and identifying thresholds for key indicators generated by the model representative of criteria that are assessed in existing sub-system MCA. Then using the ICM MCA to test the effects of sub-system interventions operating in combination, and to find portfolios of options in combination that meet the thresholds specified whilst maximising performance against other criteria not fully appraised in individual sub-system optimisation.
- An example approach is described as follows:
  - Assuming regional WRP outputs 10 portfolios of options, which are all potentially viable solutions to the WRMP problem in 2030, 2040, etc, each of these portfolios could be run through an IWM model and performance compared across low flows at key rivers in the model, as well as in drought resilience (“Ml/d deficit”) for key parts of the supply system. From this review, key performance thresholds for flow and resilience could be specified in the IWM model.
  - Assuming DWMP specifies one or more portfolio of options to meet certain WFD and flooding objectives, these portfolios could also be run through the IWM model and performance compared across water quality and high-flow indicators for key rivers in the model, again in order to specify key performance thresholds for water quality and high flow.
  - The same could be done for FRMP to identify any further high flow thresholds necessary to meet for specific flood defence schemes to meet their desired objectives. And for WINEP to identify key water quality and environmental flow thresholds required to meet RBMP objectives.
  - WRMP, DWMP, WINEP and FRMP portfolios could then be run in different combinations to assess performance of the system as a whole against the key performance thresholds identified. Any performance deficits or surpluses could be identified, and portfolios adjusted to attempt to optimise around the thresholds.
  - Additional MCA criteria could be added at this point to form part of optimisation, for example health/wellbeing benefits of certain option types, carbon emissions and sequestration potential, and impacts on biodiversity or natural capital.
  - New, innovative options, especially nature-based solutions, could also be tested against these performance thresholds to seek out integrated solutions which meet the thresholds needed for each individual sub-system objectives, but at lower cost and/or greater overall environmental and social performance.
- Given the scale over which water resource optimisation is undertaken, the scale for IWM may need to be similarly large. However the use of performance thresholds could enable only a part of the wider sub-system to be tested in MCA at any one time.

L. Demonstration modelling using Water Systems Integration (WSIMOD) Framework – Imperial College CSEI

OxCam Arc phase 1a:
Demonstration modelling using Water Systems Integration (WSIMOD) framework

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May 2022

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Executive Summary

Background

This report focuses on the application of integrated modelling to a case study within the OxCam Arc. The work was commissioned by the Mott Macdonald consultancy under the Phase 1a Integrated Water Management Framework project led by the Environment Agency. The work was focused on the application of integrated modelling software WSIMOD, developed at the Imperial College London, to evaluate how the tool could be used to assess impacts of development (population and climate) scenarios and effectiveness of selected interventions across four core systems of interest (water resources, wastewater, water quality/environment, and flooding). The WSIMOD developed for the selected case study integrates 27 water bodies (sub-catchments) in the region and implements 5 development and 10 options scenarios. Results are presented for 12 indicators and three selected locations at the outlets of Granta, Rhee (DS Wendy), and Cam sub-catchments. We discuss results from development scenarios' impact evaluation and four selected interventions:

- Reservoir
- Wetland
- Tree planting
- Per Capita reduction.

We categorise the findings in the context of:

- Water availability
- Water quality
- Flood behaviour.

We give an overview of the integrated modelling usefulness for integrated planning and how modelling could be linked with Multi Criteria Assessment (MCA) framework developed by the consultant in Phase 1. Finally, we summarise recommendations for future modelling of the OxCam Arc.

Key findings

Water availability. Climate change together with increased groundwater abstractions decrease groundwater storage in all catchments, while both climate change and population growth will significantly increase freshwater treatment deficit, which endangers future water security. Reservoir operation slightly decreases groundwater storage in Granta and Rhee (DS Wendy), with potential negative impacts on dry periods baseflow; however, new reservoir decreases freshwater treatment deficit under all scenarios, adding to water security in the region. Wetland in Granta contributes to groundwater recharge, leading to increased baseflow to rivers in dry period and attenuation of river flow peaks in wet period. Tree planting in Granta increases evapotranspiration, resulting in a decrease in groundwater storage, lower low flows, and the slight increase in water deficit. Less per capita demand has positive impact on groundwater storage, however, causing less wastewater effluent to be discharged into rivers during the low-flow period, potentially impacting downstream dilution capacity of rivers.

Water quality. We see effects of both climate and population scenarios, with negative impact on rivers dilution capacity during drier climates and increase in wastewater effluent discharge into rivers due to population growth. A new reservoir generally increases river pollutants concentration, especially nitrate and to a lesser extent phosphate. Wetland affects water quality through increased baseflow providing more dilution, which will decrease ammonia and SRP concentration in Granta. Through storing rural runoffs, wetland will also sediment solids and enhance denitrification that removes nitrates. Per capita reduction reduces urban pollutants (ammonia and phosphate) but nitrate and solids concentrations are increased because the reduction in effluent causes reduced dilution of these pollutants.

Flood behaviour. Both climate change and population growth have very little effect on high flows and flashiness of flows, which is because the flashiness of large rivers is dominated by contributions from rural runoff. The new reservoir seems to have minimal effects on flood behaviour because it is only impacting river flows at lower flows, and not changing the generation of runoff. Wetland significantly reduces flood peaks by storing surface runoffs on site in Granta. The trees significantly reduce flooding metrics, due to less surface runoffs that are the major cause of hydrograph peaks in rivers, while per capita reduction has minor effects.

Summary and recommendations

The results highlight the need for adopting integrated modelling approaches to understand key interdependences in the system, including reduced rural baseflow that lowers river dilution effects needed to manage urban wastewater effluent, how options implemented in one catchment will have impacts on not only downstream catchment but also other catchments that do not share direct hydrological connections and how interventions create co-benefits and trade-offs in water availability, water quality and flood behaviour. Analysing results with a range of indicators can provide multiple perspectives and thus can be used to support MCA. Given different stakeholders may have specific interests, such information can potentially be used in combination with tools such as participatory modelling for multi-stakeholder decision-making. We propose a 3-step process in order to expand the generic

MCA and include integrated modelling analysis. Finally, future work could significantly bolster sensitivity analysis to vary intervention location/timing, compare options in combination and test different spatial scales of appraisal. The current model could be scaled up to the whole of the OxCam Arc, with improved process representations, detailed calibration and a wider range of targets and options, including physical, policy and operational interventions.

Introduction

This document is a draft of the design work undertaken in Phase 1a of the OxCam Integrated Water Management Framework (IWMF) project.

Phase 1a takes place between the initial work in Phase 1 and the consultation at the end of the Phase. Phase 1a therefore allows additional information to be added to the work done so far so that the consultation creates a strong platform to progress to the more detailed work on the design of the IWMF in Phase 2.

The focus of Phase 1a, which is the scope of this report, was to model a sample area of the Arc to demonstrate what can be achieved through the integrated modelling. This was done to show the potential value of the IWMF programme to third parties and inform the design of Phase 2. The modelling was undertaken in partnership with The Centre for Systems Engineering and Innovation (CSEI) at Imperial College London. In addition, the consultant (Mott MacDonald) undertook review of concurrent planning processes with which the IWMF interface was made.

This report covers the Task 1 of the Phase 1a. Task 1 aims to demonstrate the potential benefits for integrated modelling, by showing what can be achieved with proposed interventions over a selected geographical area within the OxCam Arc. The modelling aims to showcase how intervention options can produce multiple benefits in areas with multiple problems across the four core systems of interest: water resources, wastewater, water quality/environment and flooding.

Ultimately, this will provide input to develop a method for Phase 2 by understanding the capability of the integrated modelling on a selected area and to inform how modelling the whole Arc could be used in the design of the IWMF in Phase 2.

Context

- What is Water Systems Integration Modelling Framework?

The Water Systems Integration Modelling Framework (WSIMOD) is a self-contained software package developed at the Imperial College London as part of the CAMELLIA NERC funding[1]. The tool contains modelled representations of all key elements of the water cycle (urban and rural) – each type of modelled element (e.g., reservoir, hydrological catchment) is generically described as a component. Components are written in such a way that any component can interact with any other component. This enables a flexible

[1] https://www.camelliawater.org

representation of the water cycle that is needed to accommodate the wide variety of different built/natural infrastructure configurations. Components can be parameterised with publicly available data and, in theory, set up for any area that these data cover. We note that we currently expect to publish this software package, including automatic parameterisation for anywhere in England, as open source for non-commercial use in late summer 2022.

- How can it add value to integrated regional water management planning?

The key motivation for using WSIMOD is to reveal potential impacts (positive or negative) that result from interactions across the different parts of the water cycle (Table 1). The development of the WSIMOD is focused on the capability to assess, in an integrated way, impacts of planning, development and intervention scenarios on a range of environmental indicators, including water flow and quality. This is particularly important for future integration of planning as benefits / trade-offs of selected interventions can be quantified across water resources, drainage and wastewater, river basin and flood management plans.

A further reason for the development of the WSIMOD is to understand how the water system changes because of implementing nature-based solutions (NBS), which have historically been difficult to predict (Kail et al., 2015). The detailed modelling and study to support the NBS itself often fails to appropriately consider the wider water cycle context of the intervention, thus missing or mischaracterising unforeseen impacts. Our work has shown that this is true for both NBS and conventional engineering options.

Table 1. The summary of integrated modelling added value to address challenges of fragmented water planning

Integrated modelling using WSIMOD	**Added value**
We can simulate both water flow and quality at a range of scales (water body to regional)	We can compare development scenarios and management options across a range of indicators and scales relevant for multiple plans and organisations
We can simulate both urban and rural systems, natural processes, and blue, green, and grey infrastructure	We can account for urban-rural interactions (link between abstractions, discharges, and pollution) and compare Blue Green (urban and/or rural) and Grey (infrastructure) options to analyse trade-offs and co-benefits arising from their implementation
We can simulate urban planning (housing development and water demand), infrastructure operation (abstractions, discharges, fertiliser use) and policy (abstraction licences) decisions	We can explicitly link urban planning with water management decisions and include behavioural, operational or policy options in the portfolio of interventions for future planning, which enables analysis of the value of interventions for multiple stakeholders (LPAs, water companies, Environment Agency, Natural England....)

- Current examples of the work – short description of published case studies

We have demonstrated the WSIMOD methodology in a variety of case studies which highlight the added value of an integrated systems view:

  - An integrated view of London's urban water cycle demonstrated how reducing abstractions on days when CSOs were likely could dilute the spills and improve water quality by amounts that would require >£200 million worth of infrastructure to otherwise mitigate (Dobson and Mijic, 2020). By strategically doing this only on days when reservoir levels were high, we showed that there were negligible impacts on the reliability of water resources.
  - By analysing commuter flows we were able to project how the COVID-19 lockdown impacted the generation of wastewater, thus the influent to wastewater treatment works (WWTWs) and ultimately in-river pollution concentrations (Dobson, Jovanovic et al., 2021). Our findings showed a reduction in influent at Beckton WWTW (Wastewater Treatment Works) of around 25% and significant increases in the concentration of pollutants in the River Wandle and Lee (the two modelled inner-London tributaries) due to the cessation of commuting. Although Thames Water could not provide timely data for this study, they have anecdotally confirmed our findings and suggested that our approach is the only way to untangle hydrological/climate variability with the changes seen at WWTWs.
  - Simulating urban-rural integrated water cycle in Cherwell Catchment shows that rural water dominates river flows in wet periods, while urban water dominates river flows in dry periods (Liu et al., 2021). Based on such insights, an integrated water quality management strategy is developed, where fertiliser application is reduced during wet periods and enhanced wastewater treatment is conducted during dry periods. This strategy is demonstrated to be more efficient in improving river water quality via simulation.

Methods

Sub catchments/layout

We selected the Cam rivers as a case study for this work. This region is part of the OxCam Arc, contains a mix of urban and rural areas, a variety of hydrological characteristics, displays existing water quality issues, and has a more self-contained water resources systems than the rest of the Arc. The region is shown in Figure 1 below and was selected in collaboration with Environment Agency stakeholders.

The whole study region is delineated into 27 sub-catchments (SC) based on WFD River Water Bodies Cycle 2 (Environment Agency, 2021). The study area is 1,035 km^2. The land cover is predominantly rural, with 75% categorised as arable and 13% as grassland in 2015 (LCM 2020). Approximately 8% is populated urban or suburban areas, dominantly surrounding Cambridge. The average annual rainfall is recorded as 576 mm (Cam) (Marsh and Hannaford, 2008). Hydrogeological conditions are defined by highly permeable chalk in the east of River Cam, driving significant baseflow, and less permeable loamy and clayed soil in the west (Cranfield Soil and Agrifood Institute, n.d.). The gauged mean flow for the River Cam is 2.8 m^3/s (UK Centre for Ecology and Hydrology, 2020).

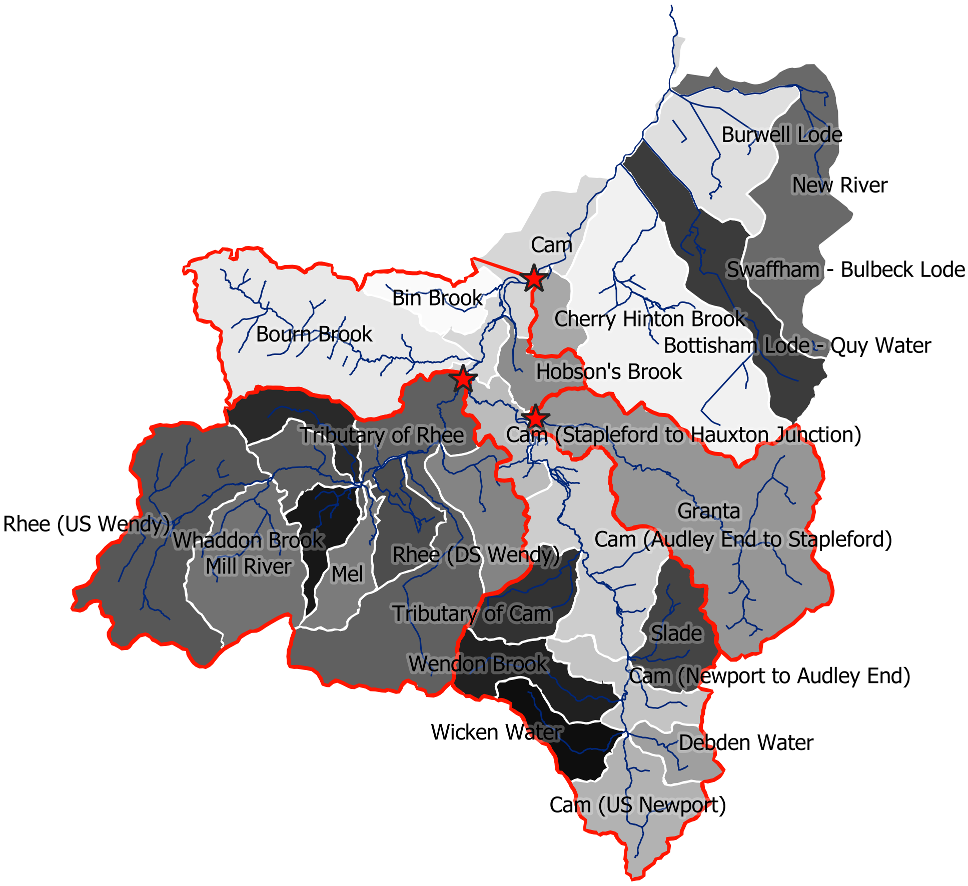

Figure 1: WFD water bodies used in study. Red outlines indicate the catchments for the three locations that results focus on. Stars indicate the specific points where in-river indicators or monitoring comparisons are calculated.

In Figure 2, we depict the WFD classifications that were available for most water bodies. It is clear from these maps that the region is struggling most from phosphate concentrations.

Thus, in this report we will primarily refer to water quality in terms of phosphate concentration, although we note that other pollutants (dissolved inorganic nitrogen, total suspended solids, and ammonia) were also modelled.

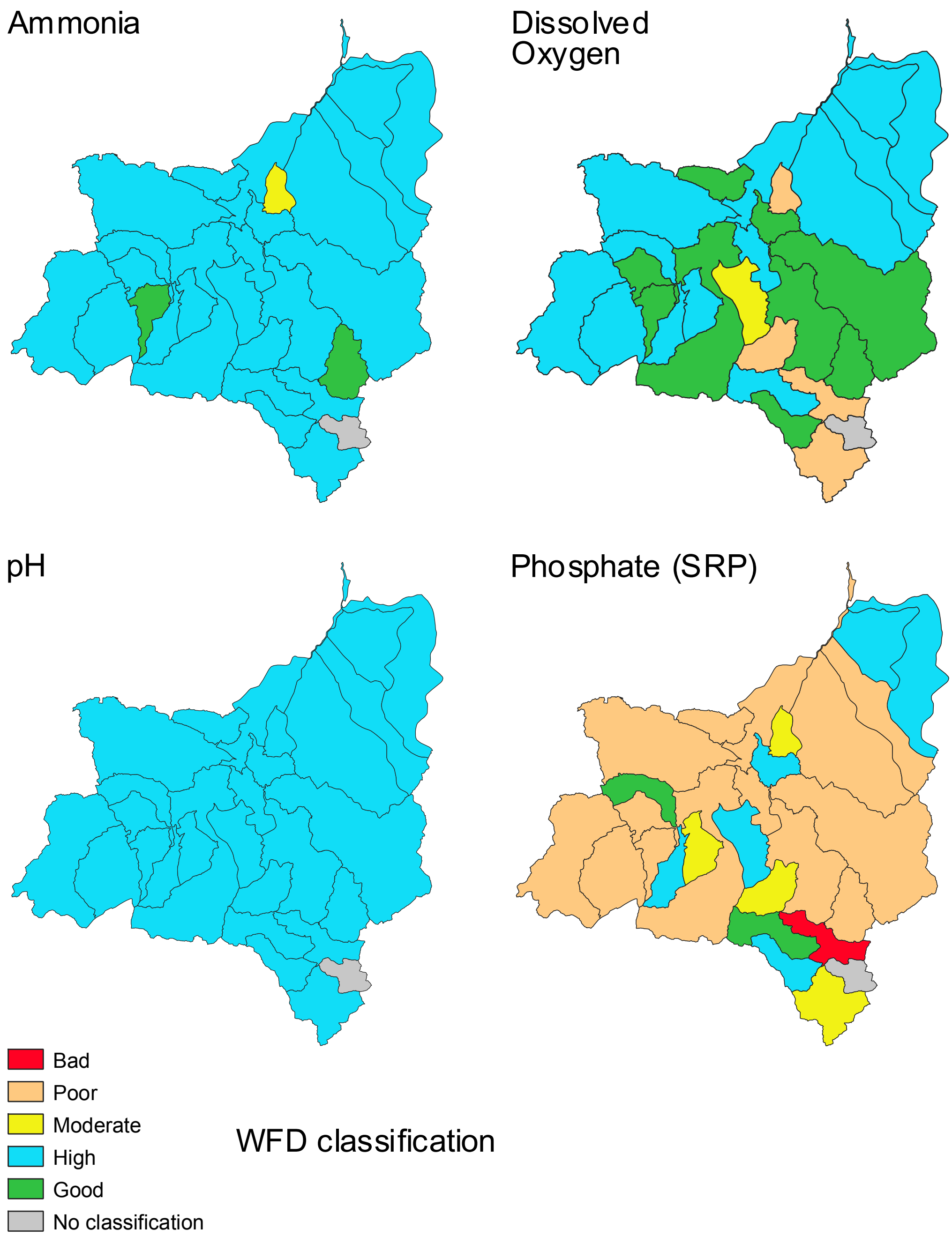

Figure 2: WFD classifications for different pollutants in different water bodies. Other pollutants (e.g., inorganic nitrogen) are sampled in the region but not given a classification.

Model structure/Key assumptions

WSIMOD provides parameterised aggregated components that can be arranged in a variety of ways. For this study we primarily model components at the water body scale, connecting each catchment outlet to its downstream catchment outlet according to the river network (see Figure 1). We provide a high-level summary of the component configuration used in this study in Figure 3.

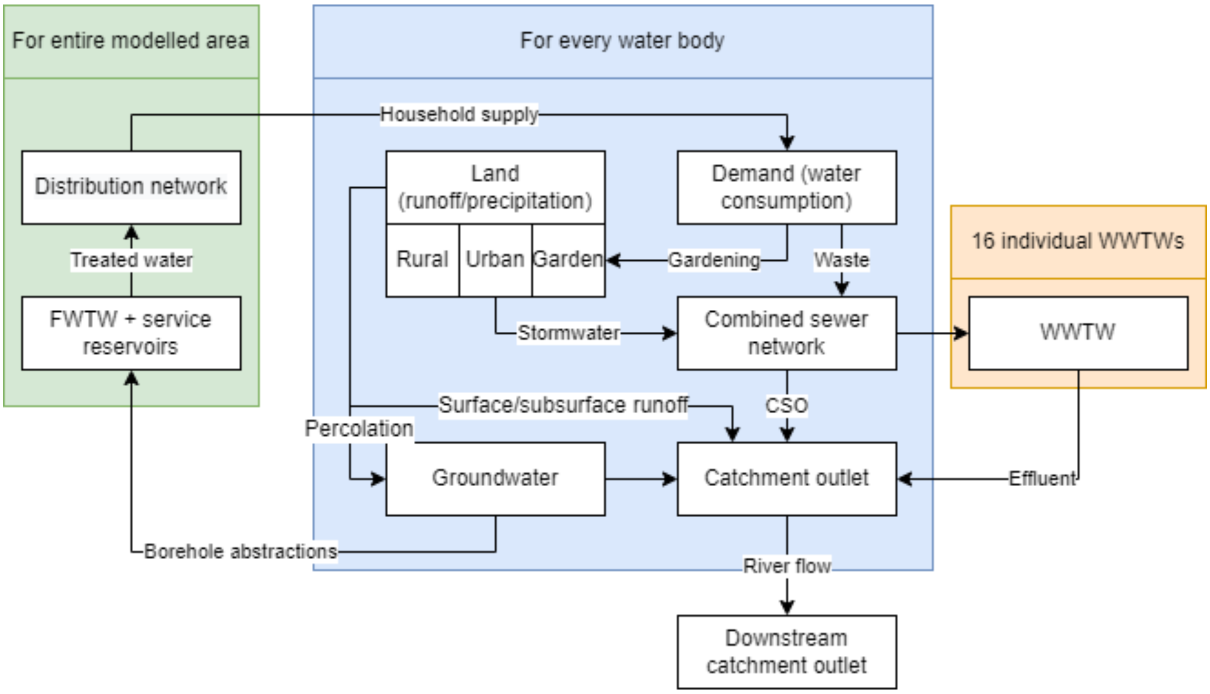

Figure 3: A high level overview of the model structure. Flows are given along arcs while components are given in boxes.

Urban water cycle

Because Cambridge Water describe their water resource supply system as a grid, and because detailed water resources information is not available without data sharing agreements that timeliness did not allow, we assume that households in the entire study region can be supplied by abstractions across the entire study region. Thus, in the model, all abstractions from groundwater nodes supply a single conceptual freshwater treatment works (FWTW). Groundwater abstraction locations/quantities have been informed by the Cambridge Water WMRP and are limited to ensure that licences are not exceeded (Cambridge Water, 2018). The FWTW removes pollutants from abstracted water (sending the sludge to all wastewater treatment works) and sends treated water to service reservoirs, that contain an assumed 2 days of water supply. The service reservoir then supplies a distribution network that can supply all demand nodes. We note that, besides agricultural irrigation abstractions (see Rural Water Cycle), all other non-public water abstractions were assumed negligible and not modelled in this Phase.

Demand nodes (at water body scale) are assumed to have a constant indoor per capita water demand of 120l/d. This omits non-household water consumption, however openly available data on this is not available – but could easily be modelled if provided. Outdoor water demand depends on the soil moisture deficit of gardens in the adjoining land node.

Demand nodes satisfy soil moisture deficit (i.e., simulating gardening) with an efficiency of 0.6 (Mayer et al., 2011). Indoor water use produces foul waste assumed to have constant pollutant concentrations, derived from (Dobson et al., 2021). Foul waste is then sent to the combined sewer nodes at water body scale.

Urban land nodes contain two key surfaces, ‘mixed urban’ and ‘gardens’. Mixed urban includes the urban and suburban classification from Rowland et al. (2017). Gardens are derived from Office for National Statistics (2020). Because mixed urban land cover is not entirely impervious, it is treated as a shallow (2.5mm) soil tank. Water that exceeds the soil tank storage drains to the combined sewer nodes. Water in the soil tank can either evaporate (at a rate of 10% of PET, assuming minimal transpiration), percolate to groundwater nodes (up to 4% of soil tank volume) or subsurface flow to rivers (up to 16% of soil tank volume). Gardens are conceptualised the same, but with a larger soil tank (200mm), higher evaporation (50% of PET), higher percolation (up to 45% of soil tank volume) and lower subsurface flow to rivers (up to 5%). Pollutant decays processes are active in both soil tanks. A daily pollutant deposition accumulates on both surfaces; we have assumed these to be the same for both mixed urban and garden surfaces due to data limitations. We assume, 0.5e-7kg/m2/day ammonia, 0.5e-7kg/m2/day nitrate, 0.5e-7kg/m2/day phosphate and 100e-7kg/m2/day solids.

Due to the number of spill locations described in two publicly available datasets (Environment Agency, 2022a; Environment Agency, 2022b) for nearly every water body in the case study, and with lack of any better data, we have assumed all sewer networks in the study region to be combined networks. Parameterising sewer networks in the absence of any data is not customarily done, and so there is little literature to advise us on this. Thus, we have assumed that the networks can drain 1.5x the Dry Weather Flow (DWF) plus 5mm/d precipitation over impervious surfaces. The sewer networks reach WWTWs according to the catchments set out in Figure 4. Although these catchments would ideally be informed by data, this information is not publicly available. Instead, we have manually matched LSOAs to their nearest logical WWTW until the population that the WWTW serves is fully accounted for by the catchment. Cambridge WWTW was then allocated all remaining LSOAs because it is by far the largest WWTW in the study region.

Figure 4: Wastewater treatment works, WWTWs, (Circles) used in study. Wastewater is allocated to WWTWs according to the manually delineated catchments (Polygons).

WWTWs receive water from combined sewers and reduce the pollutant concentrations before releasing treated effluent to rivers. The conceptualisation and parameterisation of this treatment process is described in Dobson et al. (2021). WWTWs are sized to treat a throughput of 2.5xDWF of the wastewater catchments shown in Figure 4. WWTWs also have storm tanks that can hold 2.5xDWF. If no additional throughput capacity is available and storm tanks are full, combined sewer overflows (CSOs) spill untreated effluent to river nodes.

Rural water cycle

Rural land node calculates rural water cycle processes for both water quantity and quality, which are conceptualised and quantified by CatchWat (Liu et al., 2021). The rural land area is classified into hydrological response units (HRU) based on the vegetation. With different land cover and soil characteristics, these HRUs have different performance in generating groundwater recharge, surface, and subsurface runoffs. Both runoffs route into storage tanks and experience different residence time before they are discharged into their respective river node. The generation, transport and decay processes are also simulated along with the rural water cycle. Irrigation is simulated based on the soil moisture deficit, which is abstracted from river node and groundwater node and applied to the HRUs.

The equations for the rural water cycle are adopted from multiple existing models and are modified to be consistent with each other in the integrated modelling framework. Among these functions, irrigation demand adopts equations mainly from FAO 56 method (Allen et al., 1998); atmospheric deposition, fertilisers, soil pool transformation, potential crop uptake, soil erosion, soil denitrification, phosphorus adsorption/desorption, in-river water quality mostly adopt equations from HYPE model documentation[2]; soil water and routing functions adopts equation mainly from a conceptual hydrological model (O'Keeffe et al., 2018).

Groundwater is conceptually modelled as a storage tank that receives recharge from rural land node (Knoben, 2019). In a similar way to runoff routing tanks in rural land node, groundwater experiences a much longer residence time before being discharged into river nodes. Water abstraction is applied before the baseflow is generated and discharged.

River node accepts surface and subsurface runoffs from rural land node and baseflow from groundwater node as natural river flow. Water supply for domestic use and irrigation is abstracted from the river node. It then accepts wastewater effluent discharge from urban water cycle. All the components are mixed and experience bio-chemical processes such as phytoplankton/macrophyte uptake. The river outflow will then be generated and discharged to downstream river node.

Explanation of indicators

This study adopts 11 indicators that cover water availability, flood behaviour and water quality to holistically evaluate the options' performance in water management. In a baseline scenario, indicators are calculated over the model's dynamic simulation using climate data from the historic period 2000-2020. This period was selected based on data availability.

For water availability, both surface water and groundwater are evaluated.

- For surface water, river flow Q70 and Q90 are adopted. Both evaluate river low flow conditions which may be crucial for agriculture irrigation surface water abstractions. Q70 is defined as the flow in cubic metres per day which was equalled or exceeded

[2] http://www.smhi.net/hype/wiki/doku.php?id=start:hype_model_description

for 70% of the flow record; Q90 is defined as the flow in cubic metres per day which was equalled or exceeded for 90% of the flow record (UK CEH, 2022). Q90 is also a critical indicator for environmental purposes.

- For groundwater, mean daily groundwater storage across the entire simulation period (in cubic meters) for each sub-catchment is evaluated. This is an important indicator because Cambridge Water supplies all water through borehole abstractions (Cambridge Water, 2018).

To create a metric that most closely matches water company formulations, we also record the maximum additional quantity required to alleviate any shortfall during the driest 365-day period in the simulation. This 'Water Supply Deficit' can be thought of as the additional Ml/d supply required for drought resilience. From an historic perspective, this dry 365-day period typically occurs during the 2005/6 drought. This drought is one of the critical hydrological periods used by Cambridge Water in their drought planning (Cambridge Water, 2018).

For flood behaviour, both flood peaks and hydrograph flashiness are evaluated.

- For flood peaks, Q5 and QMED are adopted, both of which assess high values of daily river flows series. Q5 is defined as the flow in cubic metres per day which was equalled or exceeded for 5% of the flow record; QMED is defined as the median of the annual maxima of river flows during the simulation period (Kjeldsen, 2015).
- R-B index is calculated to represent the flashiness of the catchment. It is calculated as accumulative absolute differences of daily river flow divided by the sum of daily river flow. High value representing 'flashy' catchment with significant peaks and low value representing flat pattern of hydrographs. A low R-B index value is thus preferred to reduce the flood risks.

$$R - B = \frac{\sum_{i}^{ndays} |q_i - q_{i-1}|}{\sum_{i}^{ndays} q_i}$$

For water quality, the mean concentration of river pollutants over the simulation period, including ammonia, nitrate, phosphate and solid, are adopted. Using this indicator complies with the current surface water quality regulation standards, which are also based on mean concentrations (DEFRA, 2014).

Explanation of scenarios

To understand how a range of plausible futures may impact the OxCam development in the study region, we test multiple climate and population scenarios. Scenario data was provided by Mott MacDonald. All combinations of all scenarios described below were simulated. In total this was 18, from 3 climates (2 scenarios described below and the no climate change baseline) and 6 populations (5 scenarios described below and the no growth baseline).

Climate scenarios

The two climate scenarios we tested were RCP4.5 (carbon emissions peak in 2040 due to aggressive adoption of renewables) and RCP8.5 (business as usual). Due to time constraints, these scenarios were modelled using monthly multiplication factors on the baseline climate. While a common approach, this technique assumes that, e.g., all Julys are drier than the historic record, and all Decembers are wetter. WSIMOD can use any continuous climate data, and detailed daily or hourly climate simulations (e.g., from UKCP18's Convective Permitting Modelling scenarios) can be included with sufficient time to prepare data.

Population scenarios

Five population scenarios were tested. These consisted of the local authority projections, expanded existing settlements with both 23,000 and 30,000 more people than the local authority projections, and new settlements both 23,000 and 30,000 more people than the local authority projections.

Baseline

The historic 2000-2020 period was used as a baseline to compare simulated indicators against. It is also the period that we had the most complete validation data for.

Explanation of options

All options were selected based on the Mott MacDonald high level multi-criteria appraisal. We selected options that: scored highly overall, scored highly across multiple different criteria, could be evaluated with reasonable ease and confidence considering the modelling assumptions. Options were generally located only in the Granta catchment, to examine the spatial sensitivity of the integrated water system to options. All options were simulated for all scenarios, resulting in 198 simulations (from 10 options below and a no options baseline and 18 climate scenarios).

We have formulated the behaviour of all options based on our best understanding of available evidence in the academic literature. However, these formulations are flexible and can be changed, provided an evidence-based specification is given for how they should behave. For example, the tree planting option below does not increase percolation to groundwater, because we could not find any published evidence that this is the case, however the option could be formulated otherwise.

Water Resources Options

- Supply Reservoir

A new supply reservoir option was modelled adjudging it to be a standard benchmark for comparison of water resources options. Because the water supply network is aggregated across the entire study region, and because the Granta catchment does not have suitable geology for a supply reservoir, we opted to model a supply reservoir at study-region scale. Lacking further information about Cambridge Water's water resources operations and considering that their Water Resource Zone is listed as a supply grid, we enable all public water supply groundwater abstractions in the study region to reach the supply reservoir. We selected a small reservoir of 1500Ml, sized based on simulation-iteration to alleviate additional water supply deficits under various study scenarios. We force the groundwater abstractions that supply the reservoir to operate under existing licences, meaning that the reservoir is topped up during non-drought years when licences are not maximised, and the reservoir is drawn down during drought years when licences are being maximised elsewhere to meet demand.

- Per Capita Reductions

Per capita reductions were modelled to represent a range of possible Multi Criteria Assessment (MCA) options, including: domestic re-use, greywater re-use, and water efficient appliances. Under Per Capita Reduction option we decrease per-capita consumption from 120l/person/d to 100l/person/d in the Granta catchment. For context, these are about the reductions we would expect from retrofitting all households in the Granta catchment, and fitting any additional households, with water efficient showers and toilets (Blokker et al., 2010).

- Groundwater Licence Reductions

Because the Environment Agency is considering reducing groundwater licences in the area, we evaluated the impact of these licence reductions. We modelled this as a 35% reduction in public water supply abstractions and a 5% reduction in agricultural irrigation abstractions. These reductions were made across the entire study region because the water supply is at this scale.

Urban Water Options

Because pluvial flooding was not considered in the MCA, we adjudged that large sizes were needed for DWMP options to cause impacts visible at water body scale and thus investigate the integrated impacts of the option.

- Attenuation tanks

These were modelled as a 10% increase in the size of the mixed-urban soil tank in the Granta catchment (equivalent to about 4000m3).

- WWTW capacity, Storm tanks

These were modelled as a doubling of Linton, Sawston and Cambridge's WWTW throughput capacity or storm tank volumes (these plants' catchments serve most of the Granta's population). These options effectively model the complete removal of CSOs from these plants by two quite different methods. Although this may seem like a large increase, Linton and Sawston plants already experience frequent CSOs, while the Cambridge plant is key plant in the region, and the population increase under most scenarios is disproportionately located in the Granta catchment.

- Sewer capacity

This option was modelled as an increase in the runoff replacement of the Granta catchment by 2mm. Effectively applied over the entire mixed-urban surface type and any additional mixed-urban surface created by population growth.

Rural Options

- Runoff attenuation features

Farm wetlands can store runoffs during rainfall events. We conceptualise it as a type of HRU that has a soil water storage tank, which has characteristics including wilting point, field capacity and total pore volume. It has three additional features compared with the HRUs in rural land node: firstly, it receives runoffs from rural lands, which will infiltrate into the soil tank; secondly, when the soil moisture is above total pore volume, the excess water will form the standing water on the surface. Additional nutrients processes will happen in the standing water, including more enhanced denitrification, suspended solids sedimentation, and macroplant nutrients uptake; thirdly, the evapotranspiration on the total area is the sum of evaporation of water surface and transpiration of land surface with vegetation; finally, the standing water has a threshold depth, above which standing water flowing downstream to river nodes will happen. Detailed equations that describe these additional features are adopted from HYPE model (HYPE Model Documentation, 2021). We implement 0.3 km2 farm wetlands that represent the aggregated farm wetlands widely distributed over the

Granta catchment. 50% of the total runoffs generated on the rural land node is assumed to flow into the wetlands, while the other half is assumed to pass by the wetlands and directly discharged into rivers.

- Trees planting

Trees planting is one of the major measures for rewilding. This is modelled as increasing the area of trees by 30 km^2 in Granta whose total rural land area is 112 km^2 and decrease the other crops areas proportionately. Increased trees area is expected to intercept more rainfall than before given its larger canopy. It also has higher evapotranspiration than the other vegetation and deeper rooting system that connects deeper soil water to the atmosphere (Robinson et al., 2006). These will generate fewer runoffs and consequently decrease soil erosion.

- Regenerative farming

Regenerative farming techniques have been widely reported to help loosen the structure of the compacted soil (Jan et al., 2020). It can increase the ability for soil to hold more water than before, which is conceptualised by increasing the filed capacity from 0.35 in Granta (baseline) to 0.4 (Houšková, 2016). It is also reported to increase the infiltration and groundwater recharge generated by around 50% (Basche and DeLonge, 2019). This percentage is adopted to increase the percolation coefficient from 0.2 to 0.3 in Granta, with surface and subsurface runoff coefficients decreasing proportionately. We implement regenerative farming techniques on the 50% of the rural land area. The values of the field capacity and coefficients over Granta rural land are weighted by areas with and without regenerative farming.

Results

Summary of presented results

This section includes results from our 198 simulations described previously (10 options and a no options, in combination with 2 climate scenarios and a no climate change scenario, in combination with 5 population scenarios and a no growth population scenario). Total of 12 indicators is calculated (4 for each of water quality, water resources and flooding) at the three locations highlighted in Figure 1 (these catchments were selected to provide a balance of up/middle/downstream). We note that every water body and every option is modelled, however due to the high resulting number it is not feasible to include all results in the report, thus we highlight a selection to illustrate the usefulness of integrated modelling in the OxCam context.

We first provide validation plots to demonstrate potential model performance in selected areas. We note that no formal calibration has taken place due to time and resources limitation, and the same parameters are used for every catchment, thus these must be treated as indicative. However, detailed calibration and validation could be refined in Phase 2 of the work.

We then look at the impact of climate change and population growth scenarios on the indicators without any options in place.

Following this we show the impact of four selected options (reservoir, wetlands, tree planting and per capita reductions) across all climate change and population growth scenarios.

We then provide a detailed examination of three selected indicators (water supply deficit, Q5 for flooding and phosphate for water quality), demonstrating how these values change under all options, climates, populations, and locations.

Finally, we provide a table to show how indicators change based on the option size, to give an idea of the sensitivity to differently sized options.

Demonstration of key results figure

Because results are aggregating a great deal of information across many potential futures (i.e., the climate and population scenarios), locations (i.e., the three focussed catchments), and options, we present them in boxplot format. In Figure 5 we provide a breakdown of the information contained in these.

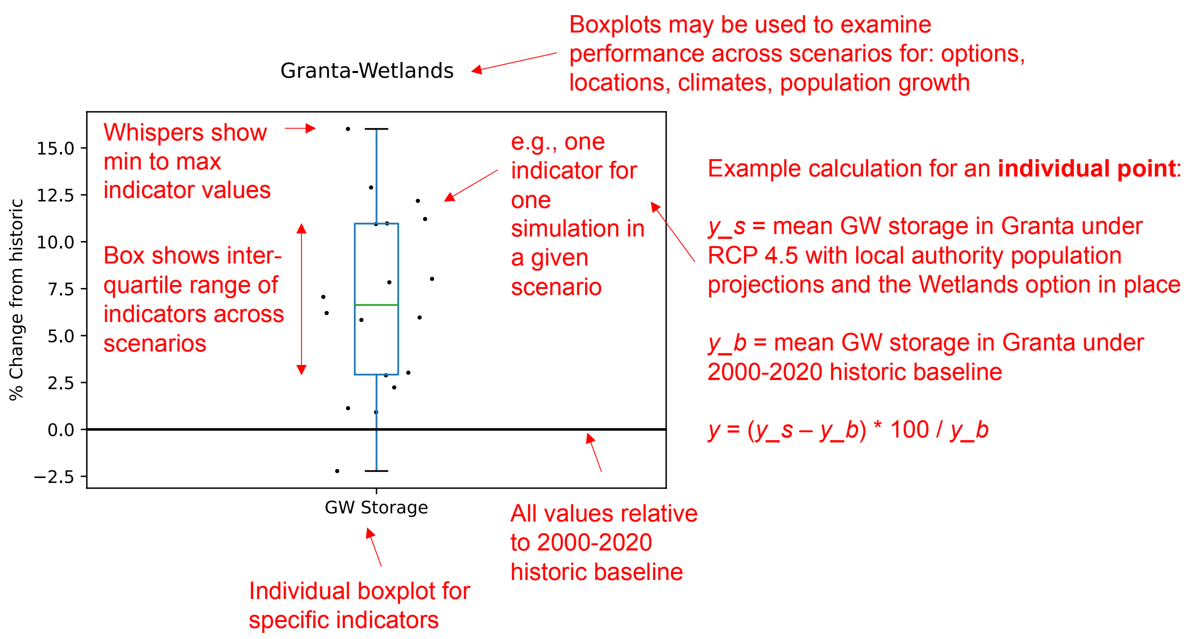

Figure 5: Example boxplot that is the main method to present results.

Validation

In Figures 6 and 7 we provide two sub-selections of timeseries for flow and phosphate (SRP) at the Granta and Rhee outlets. These locations were selected based on data availability. The performance of the flow in the Rhee catchment is 0.8NSE and 0.2NSE in the Granta. This highlights the variability in performance that results from trying to capture hydrologically different catchments with the same parameter set. It does, however, show that the CatchWat hydrological model can achieve high simulation performance in the region.

The match against phosphate is worse than for flow, although this is primarily during periods when WSIMOD is significantly under/over-estimating flow. Temporally the phosphate pattern is well captured. The performance metrics are lower at 0.1NSE, however we note that these are comparable to other uncalibrated catchment scale water quality simulation models (Hankin et al., 2019). We also note that water quality is significantly under-sampled with only monthly samples, and that pollution concentration can vary hugely throughout a day, so comparison against the mean daily concentration (WSIMOD - blue) against spot samples (WIMS - red).

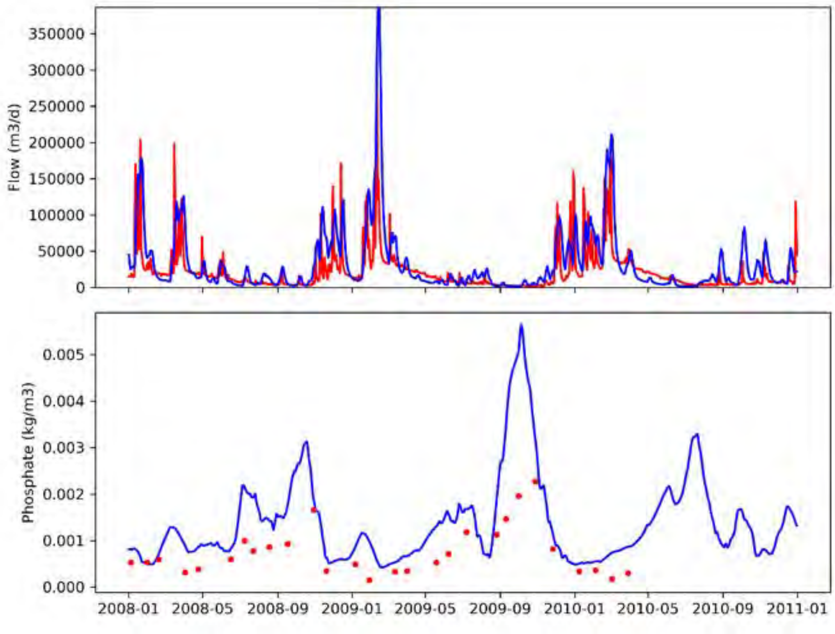

Figure 6: Red is NRFA gauged daily flow (top) and WIMS samples (bottom), blue is WSIMOD simulations for the outlet of the Granta catchment.

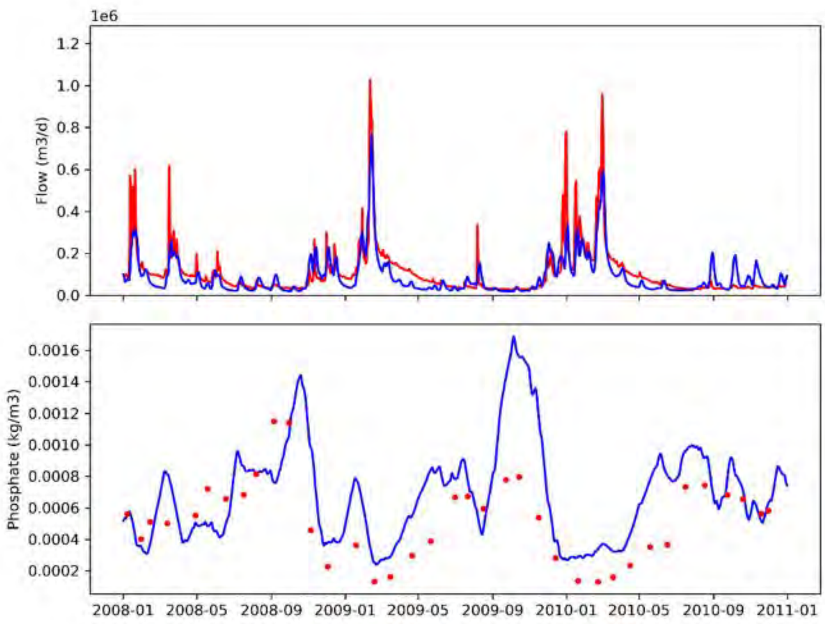

Figure 7: Red is NRFA gauged daily flow (top) and WIMS samples (bottom), blue is WSIMOD simulations for the outlet of the Rhee catchment.

Baseline + Impact of scenarios

In Figure 8 we provide an overview of how the different indicators respond to the different climate and population scenarios (captured in terms of a boxplot, see Figure 5 for instructions to read).

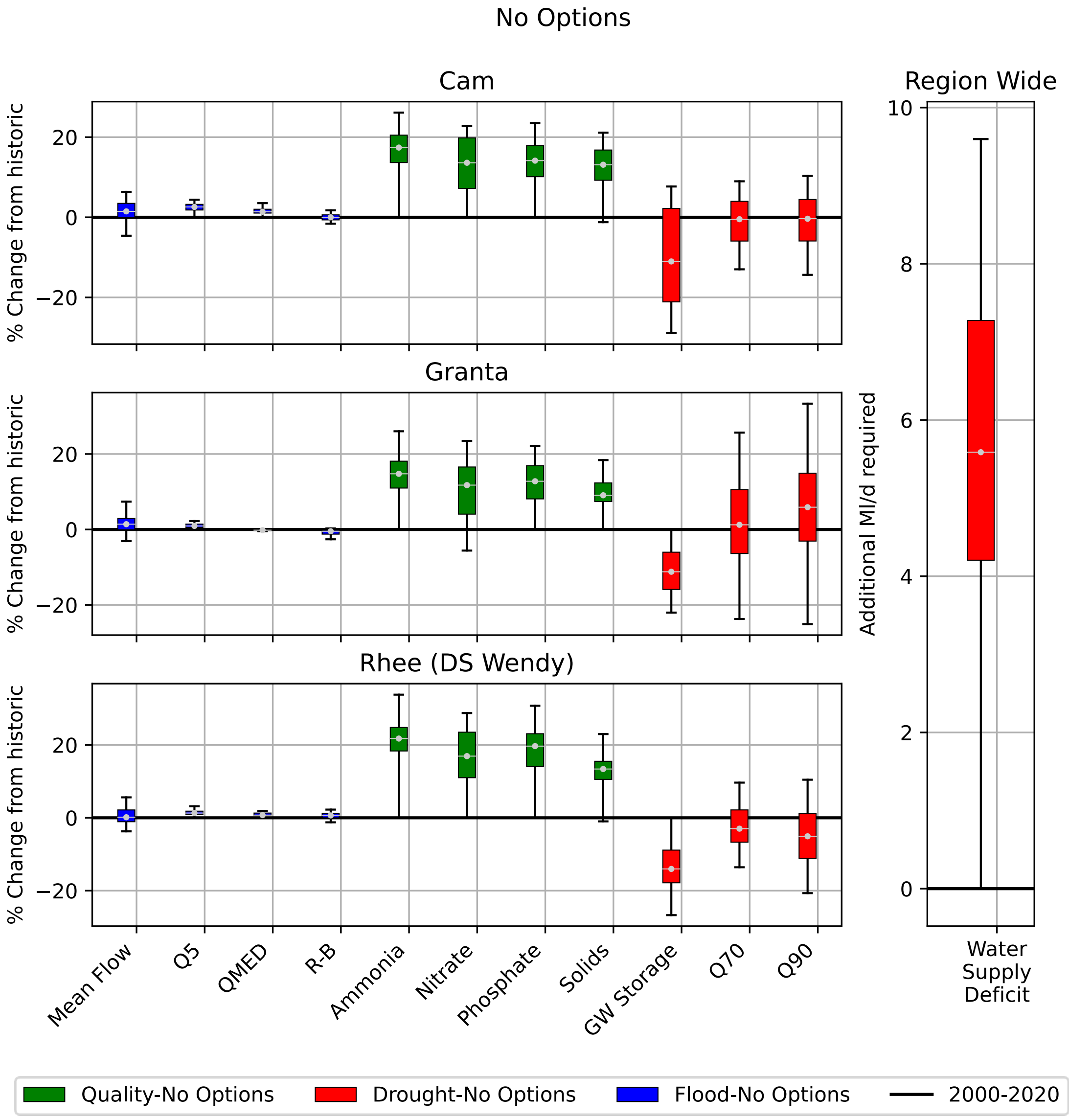

Figure 8: % change from baseline in the climate change and population growth scenarios, in 11 indicators classified as drought, flood and water quality; and the region-wide additional water supply required (Ml/d).

For water availability:

- Climate change with drier hydroclimatic conditions and increased groundwater abstractions decrease groundwater storage in all catchments.
- The low river flows (Q70, Q90), which are significantly driven by treated effluent, are redistributed via public water supply abstractions, primarily away from Rhee towards the Granta because of the uneven population growth across the regions. This growth will increase the WWTW effluent discharge into rivers, which will increase Granta flow (Q70, Q90) in dry periods.

- Both climate change and population growth will significantly increase freshwater treatment deficit, which endangers future water security.

For water quality, both climate change and population growth increase river pollutants concentration (mean ammonia, nitrate, phosphate and solids).

- Drier climates will decrease river flows from rural runoffs and baseflow, which will decrease river flow dilution effects to wastewater.
- Population growth will increase wastewater effluent discharge into rivers.

For flood behaviour:

- Climate change has very little effect on high flows (Q5, QMED) and flashiness of flows (R-B index). This is due to the nature of the monthly UKCP18 multiplication factors that were used. A daily or sub-daily timeseries to capture climate change (e.g., using the CPM simulations) may produce a different trend.
- OxCam growth similarly has little effect on high flows/flashiness (flood risk). Though urban area is still increasing quite a bit, but the flashiness of large rivers is dominated by contributions from rural runoff.

Selected options across indicators

Reservoir

In Figure 9 we plot the boxes from Figure 8 in hatching alongside boxes showing the distribution of indicators when simulated using the Reservoir option.

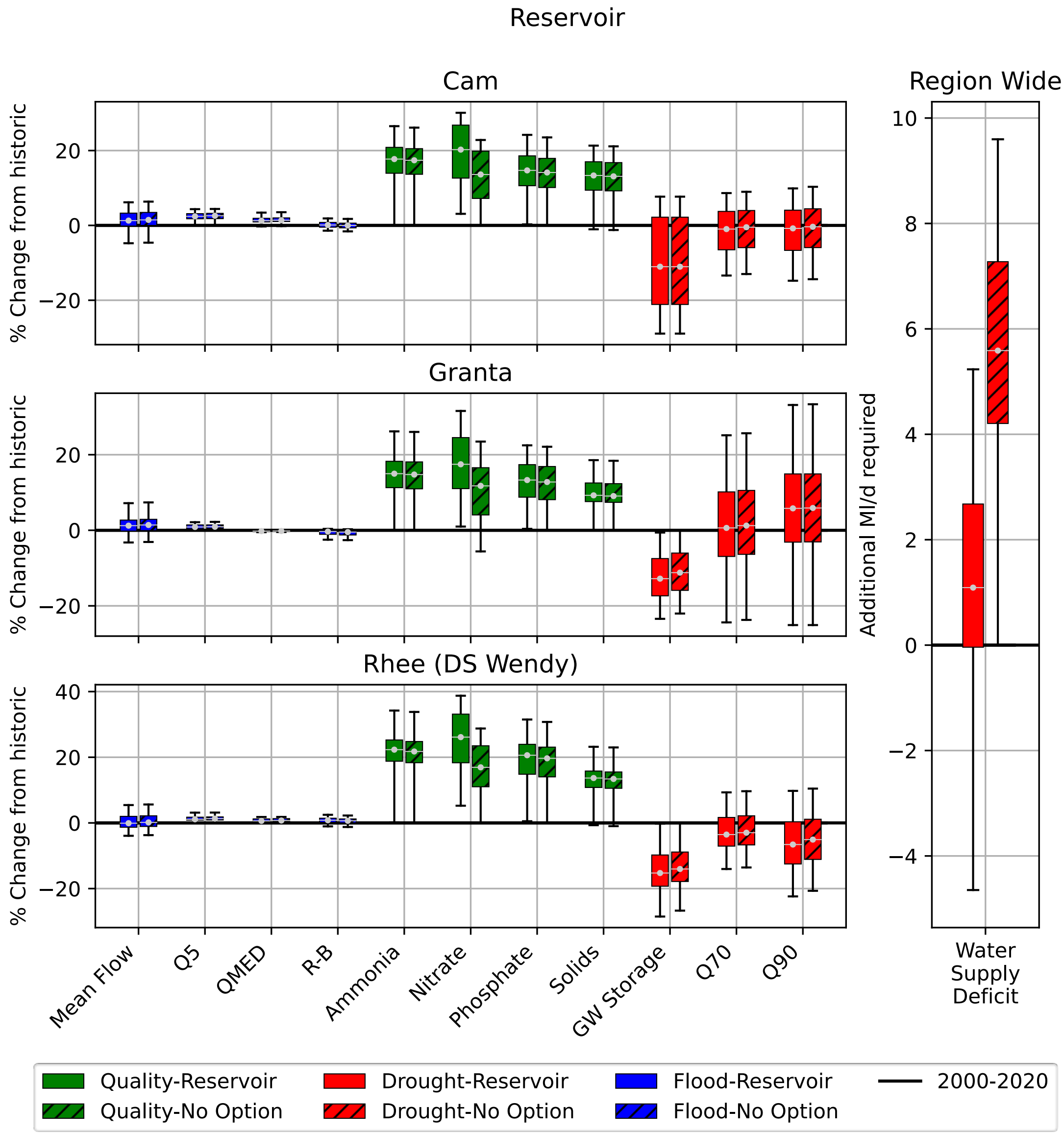

Figure 9: % change in drought, flood and water quality indicators and additional water supply required (Ml/d) by reservoir building, compared with the no-option scenario (shaded).

For water availability:

- Reservoir operation means abstracting more groundwater and storing it, which slightly decreases groundwater storage in Granta and Rhee (DS Wendy).
- Less groundwater storage means less baseflow into rivers, especially during dry periods. This decreases river Q70 and Q90 flows, albeit to a very slight degree.
- Building reservoir decreases freshwater treatment deficit, which in turn increases water use security under future climate change and population growth scenarios.

For water quality, a general increase in river pollutants concentration is caused by reservoir operation, especially in nitrate and to a lesser extent phosphate. This is caused by the smoothing of FWTW sludge production, enabling high pollutant concentrations in sludge to line up with lower river flows with weakened dilution. This is most pronounced in nitrate because nitrate concentrations typically increase during the treatment process due to de-ammonification.

For flood behaviour, reservoir seems to have minimal effects because it is only impacting river flows at lower flows, and not changing the generation of runoff.

Wetlands

In Figure 10 we show the impact of the Wetlands option.

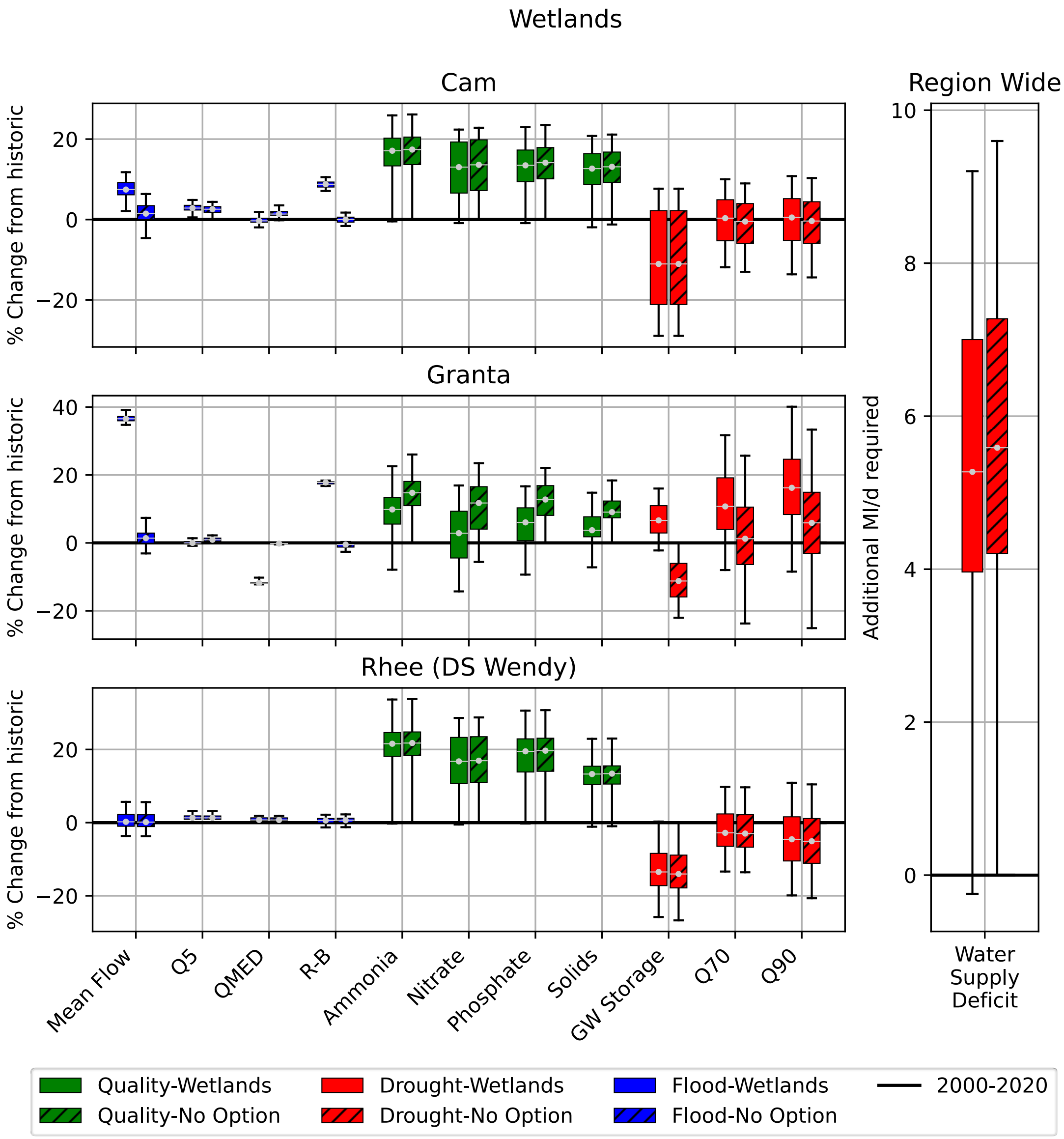

Figure 10: % change in drought, flood and water quality indicators and additional water supply required (Ml/d) by farm wetlands implementation, compared with the no-option scenario (shaded).

For water quantity, implementing wetland in Granta can divert runoffs into groundwater recharge, which increases groundwater storage. This will increase the baseflow to rivers in dry period (Q70, Q90) and attenuate river flow peaks in wet period (QMED, R-B index, Q5). The increase in baseflows is less than the increase in mean flows because a large portion of the baseflows consist of treated effluent, which is not impacted by the wetlands option.

For water quality,

- given ammonia and SRP are all foul generated pollutants, more baseflow provides more dilution, which will decrease pollutants concentration in Granta.
- Solids and nitrate mainly are generated from rural land by soil erosion and fertilisers application, respectively, and are carried by rural runoffs. Apart from retaining these two pollutants by storing rural runoffs, wetlands also sediment solids and enhance denitrification that removes nitrates, respectively.

However, other catchments will also be affected.

- Rhee (DS Wendy) has very slight increase in groundwater storage and dry-period river flow, which is induced by the increased Granta groundwater abstractions enabled by more storage from the wetland, meaning that less needs to be abstracted from the Rhee.
- Cam, as the downstream catchment of Granta and Rhee (DS Wendy), is impacted by both catchments.

Tree planting

In Figure 11 we show the impact of the tree planting option.

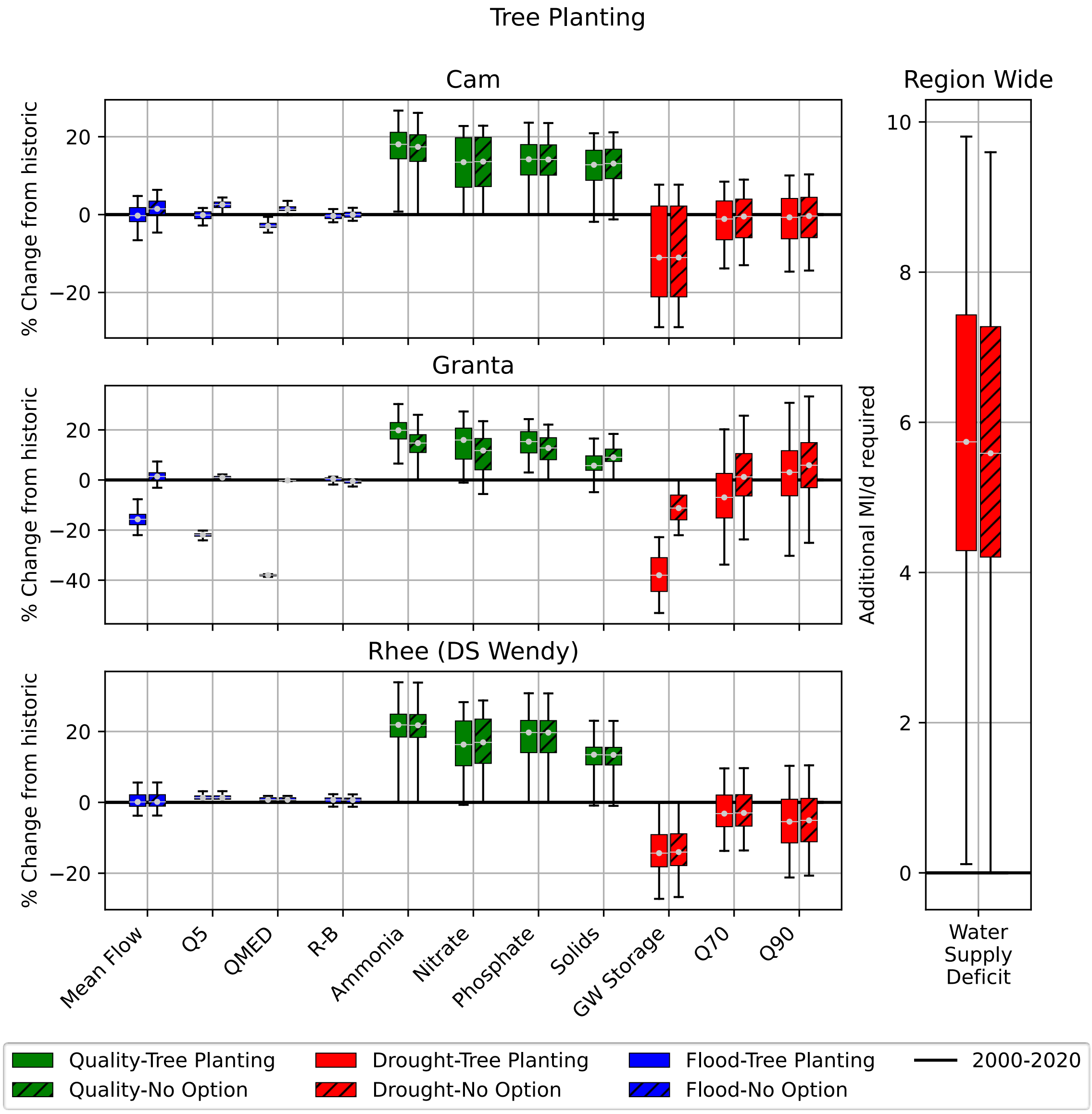

Figure 11: % change in drought, flood and water quality indicators and additional water supply required (Ml/d) by farm wetlands implementation, compared with the no-option scenario (shaded).

For water resources we see a decrease in groundwater storage in the Granta catchment (where the trees are planted) that is the result of increased evapotranspiration, more soil water storage and more interception by canopy. This causes lower low flows and reduces possible groundwater abstractions from the Granta, resulting in the slight increase in deficit.

These lower flows also have an impact on water quality, increasing it in all pollutants except for solids. Solids are decreased due to less soil erosion on rural land, which is caused by less surface runoffs generated.

The trees significantly reduce flooding metrics Q5 and QMED, due to less surface runoffs that are the major cause of hydrograph peaks in rivers.

In Figure 12 we show the impact of the per capita reductions option.

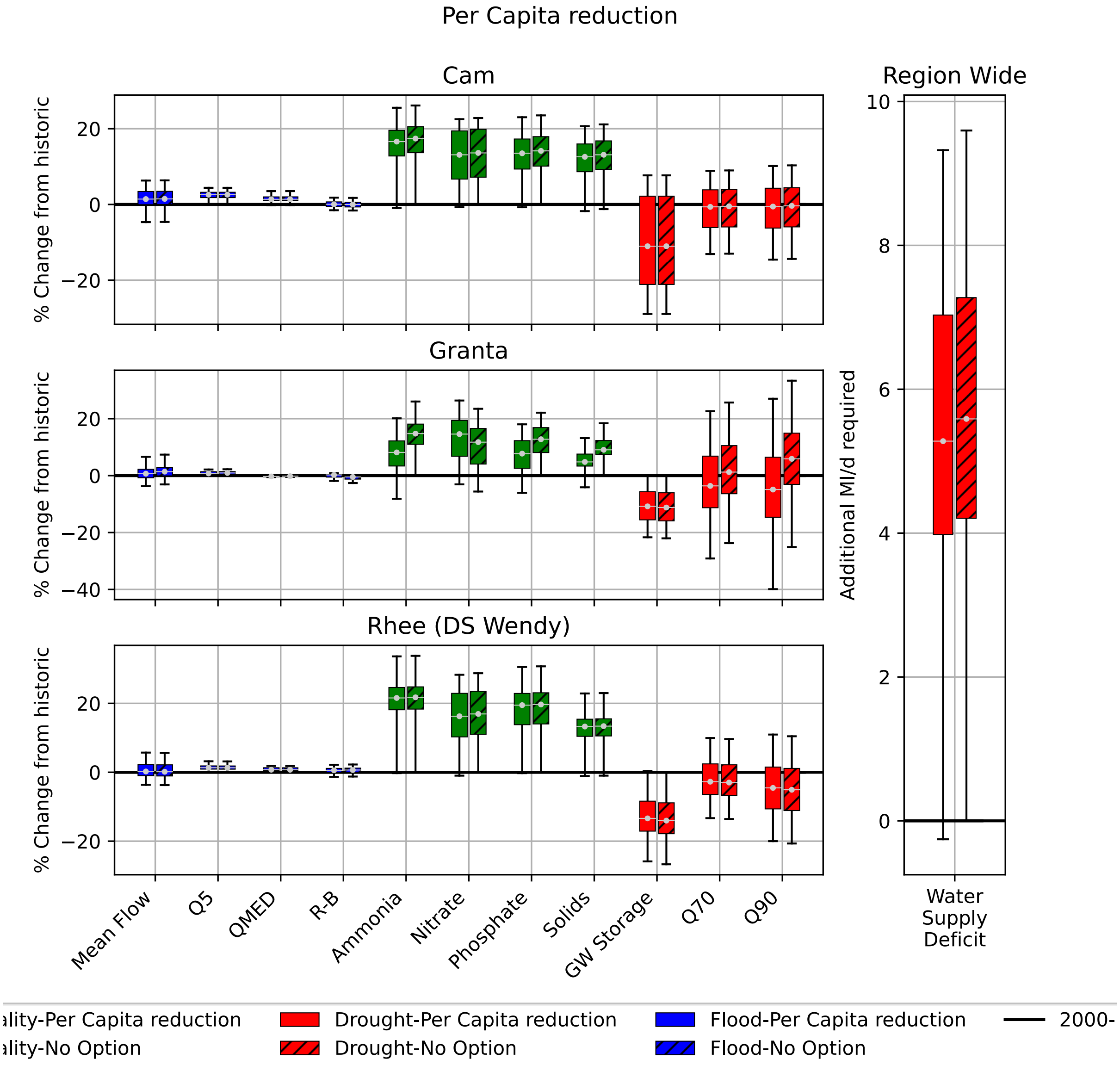

Figure 12: % change in drought, flood and water quality indicators and additional water supply required (Ml/d) by per capita water demand reduction, compared with the no-option scenario (shaded).

For water availability:

- Less per capita demand requires less groundwater abstraction, which slightly increases groundwater storage in both Granta and Rhee (i.e., the catchments with GW borehole abstractions).
- However, this means less wastewater effluent will be discharged into rivers during the low-flow period. This decreases Q70 and Q90 in Granta as urban wastewater effluent comprises a significant percentage of the river flow during this period.

- Slight increases in groundwater storage, Q70 and Q90 in Rhee (DS Wendy) due to reduced abstractions needed across the study region.

For water quality:

- Ammonia and phosphate, mainly coming from wastewater, decrease due to less wastewater effluent discharged in Granta.
- Meanwhile, rural pollutant (nitrate and solids) concentrations are increased because the reduction in effluent causes reduced dilution of these pollutants.

For flood behaviour, per capita reduction has minor effects due to high flow peaks being mainly induced by rural surface runoffs.

Options summary

These results highlight the need for adopting integrated modelling approaches:

- Integrated urban-rural water cycle simulation: reduced rural baseflow reduces river dilution effects needed to manage urban wastewater effluent.
- Integrated multi-catchment interactions: implementing options in one catchment will have impacts on not only downstream catchment but also other catchments that do not share direct hydrological connections because of the shift in groundwater abstractions.
- Integrated water management objectives – co-benefits and trade-offs: wetlands generate co-benefits in water availability, water quality and flood mitigation; reservoirs improve water availability but might decrease river water quality in dry periods.

These results test the performance of options in water availability, water quality and flood behaviour. Such sensitivity tests provide insights on the mechanisms of options intervening the system and how the system reacts. The performance is useful information to frame the potential optimisation problem that searches the optimal combinations of options at different implementation scale to achieve the maximum improvement in integrated water management objectives (i.e., Phase 2).

Selected indicators across options/scenarios

Water supply

In Figure 13 we show the distribution of changes in water supply deficit across multiple options, locations, climate scenarios and population growth scenarios.

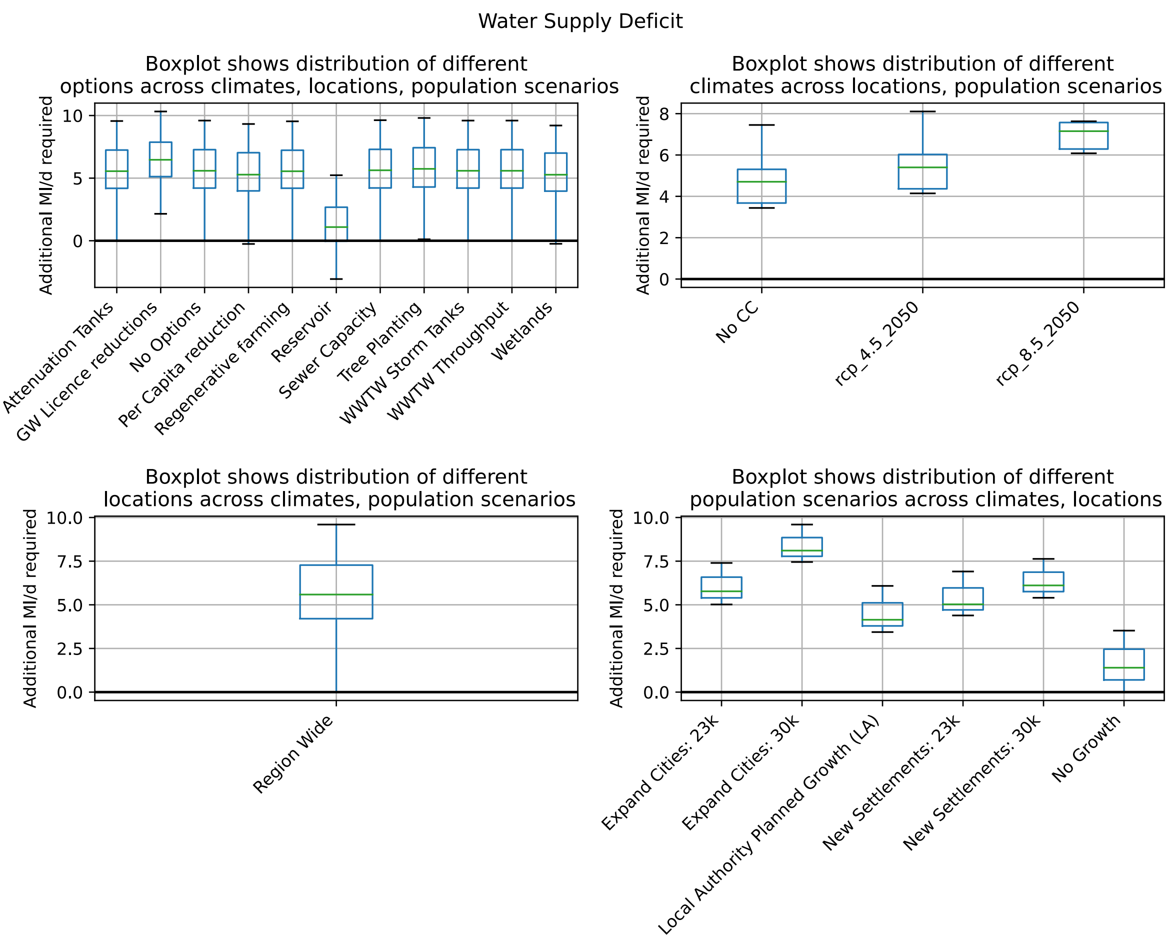

Figure 13: Changes in water supply deficit by options, climate change and population growths.

Water supply deficit is an indicator for water availability: high deficit indicates low water availability and vice versa.

- Both climate change and population growth increase water supply deficit. The sensitivity to population growth is however more significant than to climate (bottom right showing climate change with no population growth shows up to 1-3Ml/d required, while top right no climate change over population growth scenarios shows 4-6Ml/d required).
- Only the reservoir can fully mitigate such increasing water supply deficit to a very large extent, with the remaining options being less effective.
- Other options, such as wetlands and per capita reductions, can still have a small positive impact (as described in the previous section).
- Some options, such as tree planting, can have a small negative impact (as described in the previous section).
- Groundwater licence reductions have a significant negative impact. However, they are not as significant as the 35% reduction in licence may lead one to expect, this is

because the main driver of deficits in our water resources model is groundwater yield rather than licence constraint. Groundwater yield drops due to reduced precipitation and increased demand in antecedent conditions, reducing the storage in the groundwater tank and limiting abstractions. We note that this interpretation is highly dependent on our formulation of the water resources system, and would likely change with further information on the operation and behaviour of boreholes in the area.

Flood behaviour

In Figure 14 we show the distribution of changes in the Q5 metric across multiple options, locations, climate scenarios and population growth scenarios.

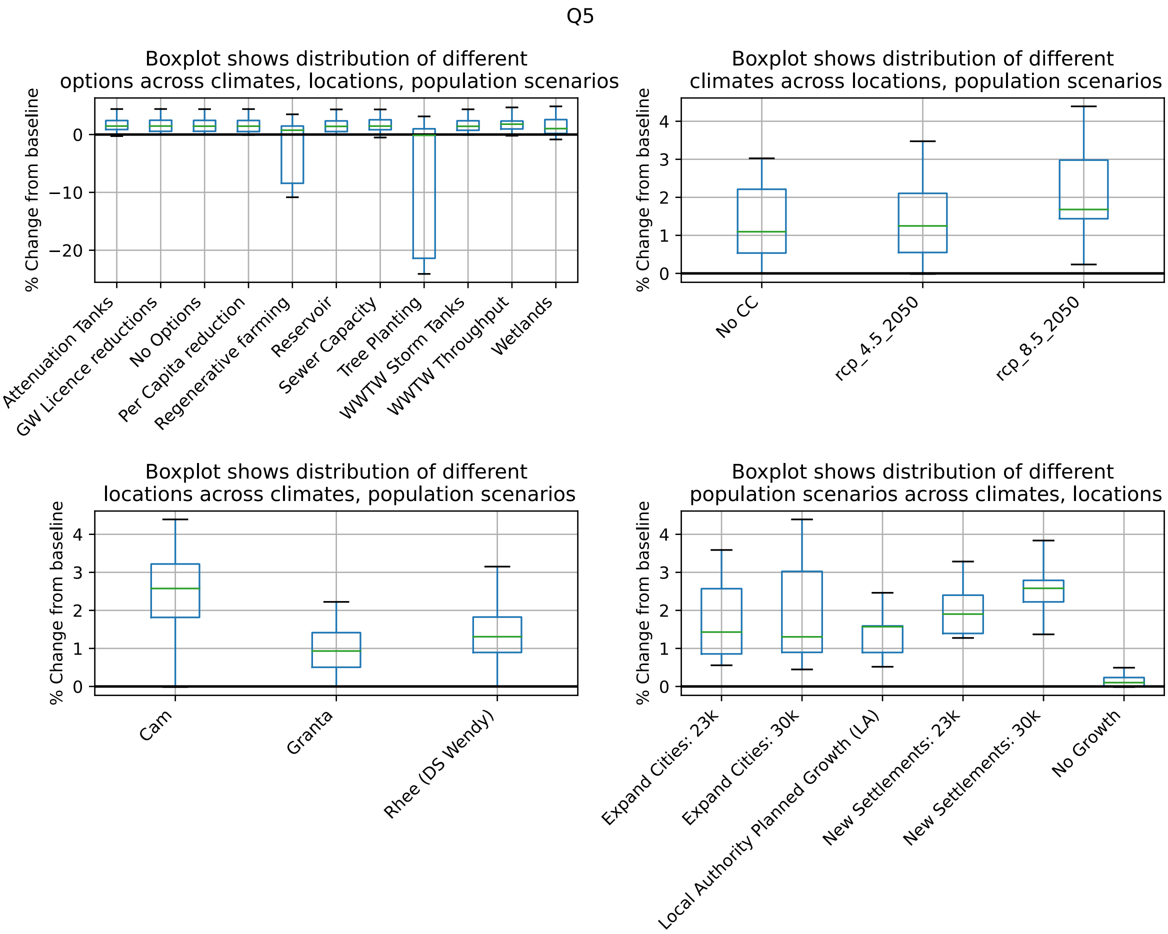

Figure 14: Changes in river flow Q5 by options, climate change and population growths at different locations.

River flow Q5 indicates flood behaviour: high river flow Q5 indicates high flood risks and vice versa.

- Climate change slightly increases river flow Q5 due to more extreme rainfall events. Population growth also increases rivers flow Q5 by expanding impervious areas, which is more impactful than climate change.
- Such river flow Q5 increase can be significantly mitigated by regenerative farming and trees planting. Regenerative farming enables more soil water storage and more groundwater recharge, while trees planting intercepts more rainfall. Both measures decrease surface runoff generation and river flow peaks.
- Wetland can attenuate flow peaks by storing surface runoffs before they reach to rivers, but less significantly than regenerative farming and trees planting. Sizes and implementation scales may be the dominant factors that cause such differences of impacts. The remaining options are not very effective in mitigating river flood peaks.
- Improvements are primarily seen in Granta catchment, with smaller impacts propagating downstream to the Cam.

Water quality

In Figure 15 we show the distribution of changes in mean phosphate across multiple options, locations, climate scenarios and population growth scenarios.

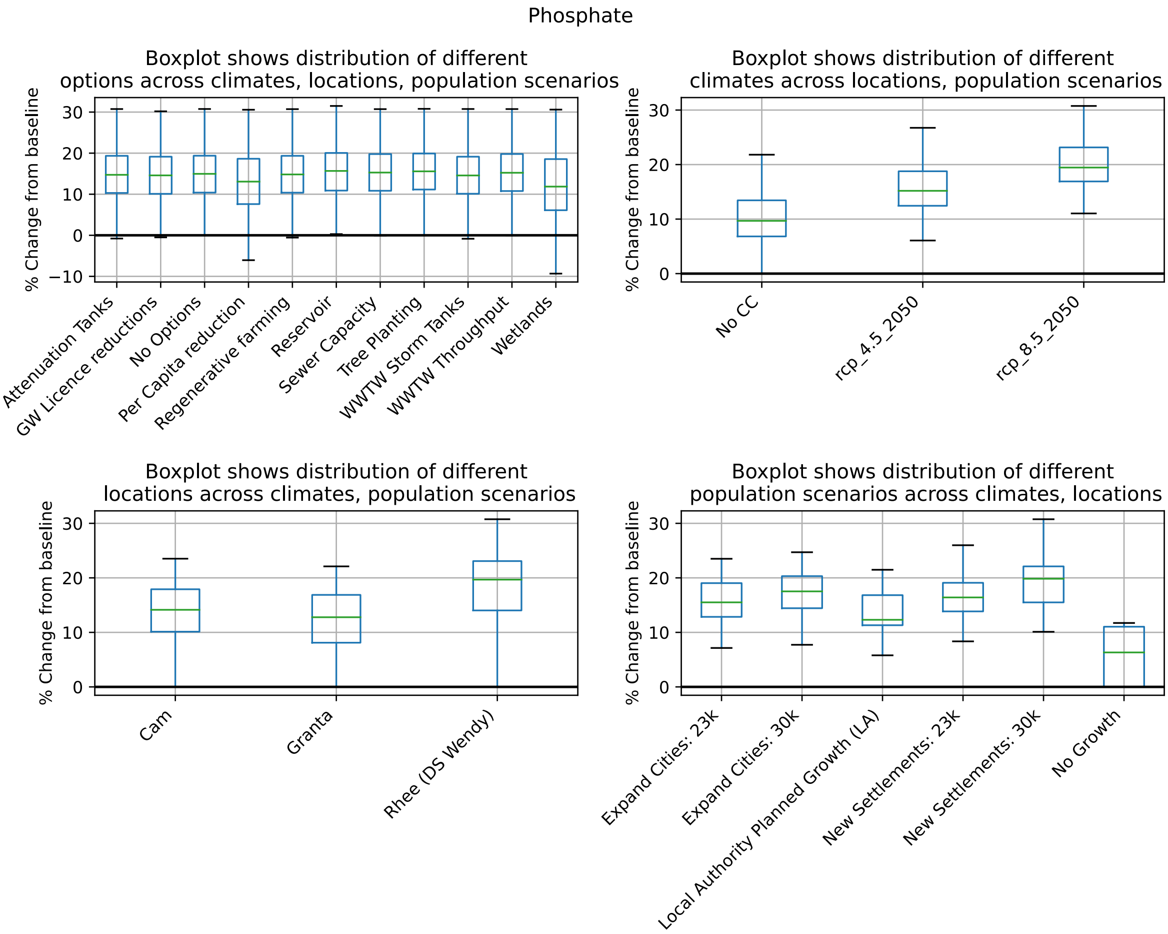

Figure 15: Changes in river phosphate by options, climate change and population growths at different locations.

River phosphate indicates river water quality as in nutrients situations: high river SRP indicates worse river water nutrients conditions and vice versa.

- Phosphate source is mainly wastewater. Population growth increases river phosphate by increasing wastewater discharge. Climate change also increases river phosphate via reducing river flows that come from rural water cycle and dilutes wastewater.
- Among the options, per capita reduction and wetlands seem to be more effective in reducing such increase in river phosphate.
    - Wetlands can divert more rainfall into groundwater recharge, which in turn increases the dilution effects of baseflow, especially in dry periods.
    - Per capita reduction decreases wastewater generation and thus decreases phosphate loads into rivers.
- Improvements are primarily seen in Granta catchment which is the implementation location, with smaller improvements in Cam that is downstream of Granta. Minimal changes in a different upstream catchment (Rhee).

Indicators summary

These figures directly compare different options performance in mitigating potential deteriorating situations caused by climate change and future development.

- Such performance is quantified and illustrated in multiple perspectives of water availability, water quality and flood behaviour and thus can be used to support multi-criteria assessment (MCA).
- Given different stakeholders may have interests in specific indicators as their focus of decision-making, such information can be potentially used in combination with tools such as participatory modelling for multi-stakeholder decision-making.

Sensitivity tests

Finally, to demonstrate how the sensitivity of different options can be examined in the WSIMOD framework, we show how different sizing can impact the indicators. This is useful to identify cost effectiveness and threshold behaviour. Results are shown in Table 2. The key parameter of each option (e.g., size or area) is varied between -20% to +20%. We note that in cases where an existing parameter is being changed (e.g., WWTW Throughput), the % refers to the size of the change, rather than the parameter itself. For example, a 5Ml/d throughput with a 2Ml/d increase would be tested with 5 + 2 * 0.8 = 6.6Ml/d, 5 + 2 * 1 = 7Ml/d and 5 + 2 * 1.2 = 7.4Ml/d under this sensitivity analysis.

Table 2: Sensitivity of indicators to differently sized options. Each row is an option where the key parameter (e.g., size or area) is set to -20%/+0%/+20%. Columns show average indicator change from 2000-2020 historic baseline over all scenarios.

	Water Supply Deficit	GW Storage	Nitrate	Solids	Phosphate	Ammonia	Q5	Q90	Q70	QMED	R-B	Mean Flow
Unit	Ml/d	%	%	%	%	%	%	%	%	%	%	
No Options-0.8	5.4	-11.6	13.4	11.2	14.7	17	1.6	0.3	-0.2	0.7	-0.1	1.3
No Options-1.0	5.4	-11.6	13.4	11.2	14.7	17	1.6	0.3	-0.2	0.7	-0.1	1.3
No Options-1.2	5.4	-11.6	13.4	11.2	14.7	17	1.6	0.3	-0.2	0.7	-0.1	1.3
Attenuation Tanks-0.8	5.4	-11.4	13.3	10.6	14.5	16.4	1.6	0.6	0.1	0.7	-0.3	1.3
Attenuation Tanks-1.0	5.4	-11.4	13.3	10.4	14.5	16.2	1.6	0.7	0.2	0.7	-0.3	1.3
Attenuation Tanks-1.2	5.4	-11.4	13.2	10.2	14.4	16.1	1.6	0.7	0.2	0.8	-0.4	1.3
GW Licence reductions-0.8	6	-11.4	11.2	11.1	14.4	16.8	1.6	0.7	-0.1	0.7	-0.1	1.3
GW Licence reductions-1.0	6.2	-11.4	10.4	11.1	14.3	16.7	1.6	0.8	0	0.7	-0.1	1.3
GW Licence reductions-1.2	6.4	-11.3	9.4	11	14.2	16.6	1.6	1	0.1	0.7	-0.2	1.4
Per Capita reduction-0.8	5.2	-11.3	13.8	9.9	13.1	15	1.6	-2.3	-1.4	0.7	0.1	1.1
Per Capita reduction-1.0	5.1	-11.2	13.9	9.5	12.7	14.4	1.6	-3	-1.7	0.7	0.2	1
Per Capita reduction-1.2	5.1	-11.1	14.1	9.2	12.3	13.8	1.5	-3.7	-2	0.7	0.2	1
Regenerative farming-0.8	5.4	-7.2	13.4	10.7	14.6	17.1	-1.3	0.8	0	-3.6	-1.2	-0.8
Regenerative farming-1.0	5.4	-6.3	13.4	10.6	14.6	17.1	-2.1	0.9	0.1	-5	-1.5	-1.3
Regenerative farming-1.2	5.4	-5.5	13.4	10.5	14.5	17.2	-2.9	1	0.1	-5.7	-1.8	-1.7
Reservoir-0.8	1.5	-12.3	20.3	11.4	15.2	17.3	1.5	-0.2	-0.7	0.7	0.1	1.1
Reservoir-1.0	1	-12.4	20.7	11.5	15.3	17.3	1.5	-0.3	-0.7	0.7	0.1	1.1
Reservoir-1.2	0.4	-12.6	21.1	11.5	15.3	17.3	1.5	-0.3	-0.8	0.6	0.1	1.1
Sewer Capacity-0.8	5.4	-11.8	18.1	11.1	15	17	1.6	0.1	-0.6	1.2	1.3	1.3
Sewer Capacity-1.0	5.4	-11.9	19	11	15.1	17	1.7	0	-0.7	1.3	1.6	1.3
Sewer Capacity-1.2	5.4	-11.9	19.8	11	15.2	17	1.6	0	-0.8	1.5	1.9	1.3
Tree Planting-0.8	5.5	-18.5	14.3	10.2	15.3	18.6	-5	-0.7	-2.5	-9.8	0.1	-3.6
Tree Planting-1.0	5.5	-20.6	14.6	10.1	15.6	19	-7	-1	-3.2	-13.3	0.2	-5
Tree Planting-1.2	5.6	-22.9	14.9	9.9	15.8	19.4	-9.3	-1.3	-3.9	-16.1	0.2	-6.5
WWTW Storm Tanks-0.8	5.4	-11.6	13.3	9.5	14.5	15.8	1.6	0.4	0.9	0.7	-1.1	1.3
WWTW Storm Tanks-1.0	5.4	-11.6	13.2	8.5	14.3	15.1	1.6	0.6	1.6	0.7	-1.8	1.3
WWTW Storm Tanks-1.2	5.4	-11.6	13.1	7.5	14.2	14.3	1.5	0.8	2.2	0.7	-2.5	1.3
WWTW Throughput-0.8	5.4	-11.6	14	3.6	14.9	12.3	1.7	0.3	-1.3	0.7	0.2	1.5
WWTW Throughput-1.0	5.4	-11.6	14.2	0.2	15	10.4	1.8	0.3	-1.3	0.7	0.2	1.6
WWTW Throughput-1.2	5.4	-11.6	14.3	-2.2	15	9	1.8	0.3	-1.4	1	0.5	1.6
Wetlands-0.8	5.2	-6.2	10.8	9.5	12.4	15.4	1.8	3.8	2.7	-3.1	9.2	15
Wetlands-1.0	5.1	-5.4	10.4	9.3	12	15.1	1.4	4.3	3.3	-3.7	9	15
Wetlands-1.2	5.1	-4.7	10	9	11.7	14.8	1.1	4.6	3.8	-4.3	8.8	14.9

Although this is a limited sensitivity analysis, with essentially 3 data points per option (because we are aggregating over all scenarios), some examples of non-linear behaviour have been identified.

- Solids and Ammonia vary non-linearly between the three WWTW throughput sizes; we see that the reduction in concentrations from a -20% and 0% (3.4% for solids and 1.9% for ammonia) is less than the reduction between 0% and 20% (2.4% for solids and 1.4% for ammonia). This is because ammonia and solids have high concentration in spilled effluent during a CSO. Increasing WWTW throughput significantly reduces CSO, however once these are largely alleviated, we would see diminishing returns in increasing throughput.

- QMED varies non-linearly between the three regenerative farming areas; we see a larger reduction between -20% and 0% (1.4% for QMED) than between 0% and 20% (0.7% for QMED). Because QMED is based on such extreme flows, we would not necessarily expect it to react linearly to the hydrograph smoothing that tree planting causes.

We expect that a more expansive sensitivity analysis would stress the system under a wider variety of option behaviours and thus reveal more non-linearities. However, even in a linear system, such a sensitivity analysis is useful because it can quantify the expected change in an indicator that is likely to result from a unit change in an option's size. For example, we can see that a 20% increase in reservoir volume is likely to result in a 0.5Ml/d reduction in deficit, which is far larger than the 0.05Ml/d day reductions resulting from the wetland or per capita reductions in the Granta catchment.

Usefulness of integrated modelling in OxCam Arc

Foremost, this case study demonstrates both the feasibility and utility of performing integrated modelling for the OxCam Arc. Total of 196x20-year daily simulations were performed across 27 water bodies capturing all key sub-systems within the water cycle. Validation plots were encouraging and would likely be more than satisfactory with a devoted calibration. Results clearly highlight the impacts of both the population growth and climate change scenarios on 12 indicators spanning flooding, drought, and water quality. By inspecting different options, we reveal potential unanticipated costs and benefits that may result from a variety of water resources, urban water, and nature-based solution options.

A key observation from doing the work is how difficult it is to offset future impacts. For example, a regenerative farming scheme applied to half of the entire studied Granta catchment ($30km^2$), while completely offsetting flooding impacts, would have minimal impacts on water quality and water supply. Even the most effective integrated option of wetlands that capture 50% of the Granta's runoff offsets water quality impacts in less than half of plausible future scenarios.

However, we believe that these results are ultimately encouraging because they provide firm evidence for the integrated impacts of various options. Even if the wetlands only provide 0.5Ml/d water supply resilience during a drought, they are not primarily a water supply option, and so this non-trivial amount of water can be used to shape evaluations of future wetland options. Additionally, knowing when integrated benefits may not occur is just as important a part of integrated water management planning as knowing when they do.

In contrast to benefits, the integrated modelling revealed a variety of integrated costs. We see that new population will bring new effluent, and ultimately new in-river pollutants to the region. Meanwhile, climate change will reduce flows and increase in-river pollutant concentrations, worsened by the additional groundwater abstractions required. Options such as tree-planting, although achieving their primary objective of reducing flooding, tend to increase evapotranspiration, reducing groundwater levels, impacting water supply, and leaving less water in rivers that increases pollutant concentrations.

Conceptual framework for linking MCA with integrated modelling

Based on the modelling work undertaken in Phase 1a, we provide an overview of the potential expansion of the generic MCA framework. Proposed 3-step process is shown in Figure 16.

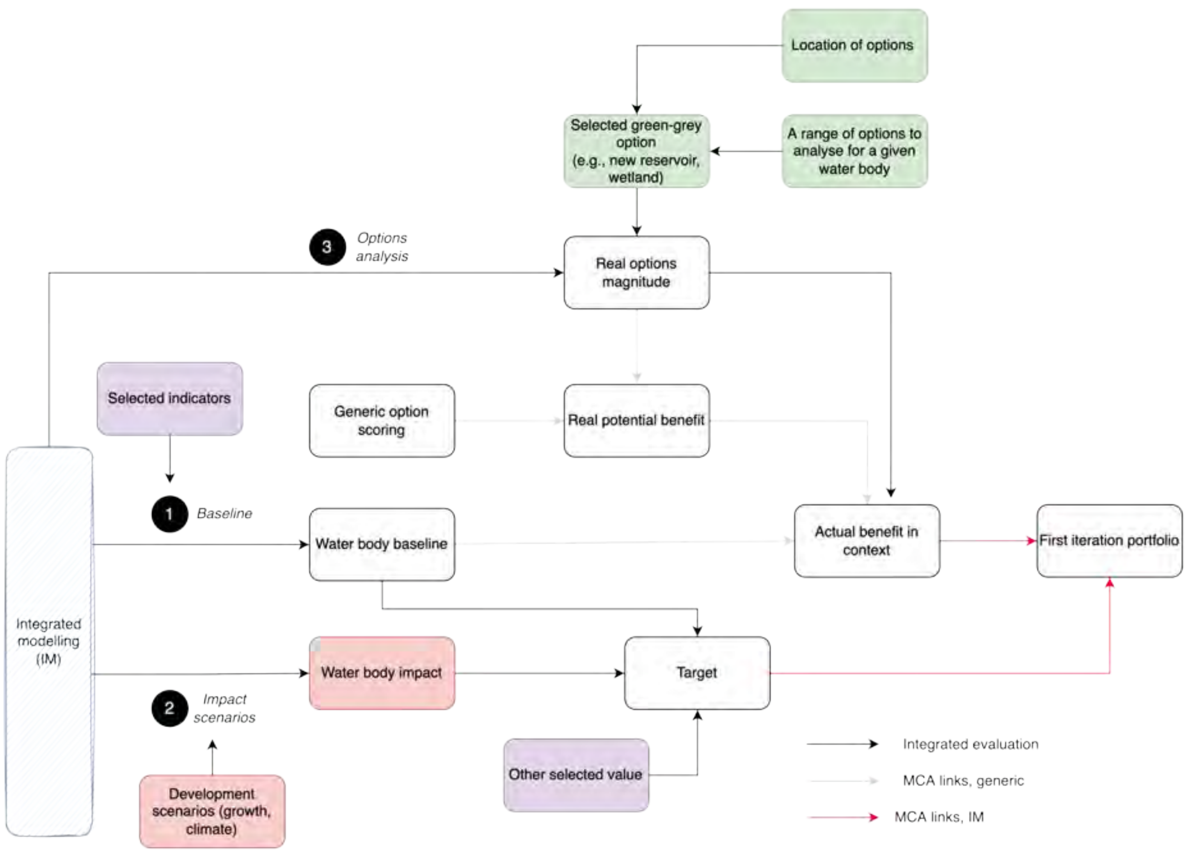

Figure 16. Proposed MCA and links with integrated modelling analysis. The figure maps links that are applicable if used with the integrated modelling, as well a as range of decisions that need to be agreed as an input to integrated modelling.

Integrated modelling enables evaluation of indicators for a range of impact scenarios and intervention options, and hence provides additional information to the Generic option scoring. Once the analysis indicators are selected then the Water body baseline analysis could be done as proposed by the original MCA (Step 1). By defining development scenarios, the model can be then used to evaluate Water body impact; that is, the change of the value of indicators for a given development scenario. This information can then be used in multiple ways (Step 2): to define the management Targets using the concept of neutrality, where options would be designed to offset additional impacts of development scenarios compared to the baseline evaluation; or to define Targets based on any predefined value for a given indicator (e.g., based on the regulation requirements). Finally, to assess the Actual benefit of an option, a range of decisions needs to be made (Step 3): selection, location, and size of an option. Once the management objectives and constraints are defined, this could be done using the multi-criteria optimisation. The options impact on the system can be then evaluated using the integrated modelling. It should be noted that any options benefit would need to be interpreted with Step 3 information considered, as well as considering interdependences effects both spatially (upstream – downstream) and options-wise (change in management rules) across the system.

Recommendations for future work

We summarise some key activities that were not possible in this study due to the large number of catchments/options/scenarios that were included and the limited resources, which can be done with the model developed in Phase 1a.

- Sensitivity testing, varying intervention location/timing. While we performed a small investigation into differently-sized options, we did not examine any spatial or temporal elements around this. Interventions in different catchments may be differently successful than in the Granta catchment that we focussed on, primarily due to the different make-up of land covers, populations and WWTWs that ultimately drive the catchment's water cycle. In practice, different options take different amount of time to implement, thus causing a significant lag between a decision being made and the option functioning as designed – decision pathway analysis would be needed to map out how best to stagger a portfolio of options to achieve specified objectives.
- Sensitivity test to compare including options individually and in combination. In this work, each option was tested in isolation due to the limited resources of the project.

In the best case, optimisation would be used to leverage beneficial interactions between different options in different locations to create a variety of option portfolios that best achieve the multiple competing objectives (water quality, flooding, water supply).

- Sensitivity test to different spatial scales of appraisal: catchment v water bodies, etc. A fixed resolution of modelling was used in this study (WFD water body scale). There may be some options or scenarios that are highly beneficial or damaging on smaller scales than can be seen at water body scale. Although the primary purpose of this modelling should be high level scoping that can direct more detailed assessments, our research has shown that both the hydrological and sewer drainage representations can perform well at far smaller scales than water body. Thus, some level of 'zooming in' may be possible before detailed assessment is required.

Implications for Phase 2

- The work also highlighted a variety of data requirements that are not publicly available but would improve the robustness of the results. This is primarily water company information on both water resources, urban drainage, and wastewater systems. This would also enable a more devoted calibration to take place for individual sub-catchments.
- Options formulations are currently based on our interpretation of the best available evidence/literature. In addition, for phase 2, by utilising expertise in water management interventions and supported with detailed physical modelling, a more functional specification of how an option should behave could be created. This would enable a trusted implementation of such an option and the question of how that option impacts the wider water cycle can be investigated with a greater level of confidence.
- Although WSIMOD cannot necessarily be used to directly create 2D flood inundation maps, it can be used to create representative boundary conditions (i.e., peak flows) under the wide range of scenarios/options that could be used in conjunction with a 2D flood model.
- Wastewater systems have been modelled in a high-level way for this work, however more detailed hydraulic representations (e.g., as in InfoWorks) are typically required for evaluation of urban drainage. Recent work using WSIMOD has demonstrated that this is possible, and with speeds up to 1,000 times quicker than InfoWorks, thus making it better suited for high-level scenario/option exploration (Dobson, Watson-

Hill et al., 2021). Although, our recommendation is that this would still only be performed on selected areas of interest.

- Finally, in Phase 2 the current model could be expanded to the whole of the OxCam Arc, with improved process representations (e.g., additional pollutants), detailed calibration and a wider range of targets (e.g., water and nutrient neutrality) and options, including physical, policy and operational interventions.

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