SYSTEMS APPROACH TO REGIONAL WATER PLANNING

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MOTT MACDONALD

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Introduction

Challenges of current water planning in the UK

Multiple plans are currently produced as part of, or relating to, the water management regime in England, as shown in Figure 1. From a systems perspective, this poses a significant challenge connected to the plans' integration for analysis and design of multifunctional water management options (WMO).

Furthermore, the current planning regime is likely to lead to some contrary action, unintended consequences across plans, operational inefficiencies across siloes and the proliferation of weak or shallow leverage interventions. We define multifunctional WMO as any intervention in the system that can provide co-benefits measured by improvement in water resources, water quality and flood management quality indicators, ultimately having positive impact on ecosystem temporal dynamics.

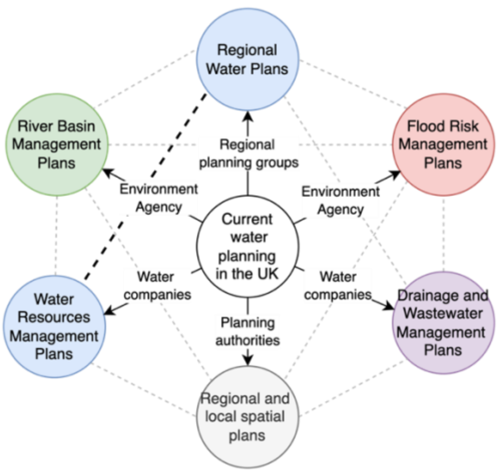

Figure 1. Overview of key plans and organisations in the current UK water planning, adapted from [1]

The need for systems approach to water management defined through integration between physical, environmental, and socio-economic components of the system has been discussed in the scientific literature summarised in [2]. From a practical perspective, multiple water plans are designed with a focus on a regional scale (Figure 1). In 2020, the Environment Agency published 'A National Framework for Water Resources' [3], which sets requirements for the development of regional plans to inform water companies' water resource management planning. The purpose of these plans is to "*identify how best to provide an efficient, sustainable and resilient supply of water for all water users in the region until at least 2050*", with a specific focus on reducing water demand, halving leakage rates, developing new water supplies including water transfers and reducing the use of drought measures. Primarily focused on water resources, current regional water planning (RWP) is only taking a wider perspective on water quality and flood management where possible. Further, there has been

Three key aspects linked to how current plans are developed are relevant in this context. Firstly, multiple plans are produced by a range of organisations across different time planning horizons covering the same spatial regions (see p.25 in [1]); as a result, a range of WMO are designed and implemented without fully understanding what the system-wide implications are (both benefits and disbenefits) for the water system as a whole and how their performance could be compared across concurrent plans. Secondly, plans are developed using multiple simulation models for specific infrastructure systems and planning objectives (see p.178 in [1]), which cannot be easily integrated to enable results comparison and cross-plans evidence for co-benefits and/or trade-off of proposed WMO. Finally, plans are designed to target specific water management aspects (water resources, flooding, water quality) and are separate from local planning (see p. 24 in [1]), which results in WMO being designed and evaluated without maximising their multifunctionally.

The need for systems approach to regional water planning

considerable discussion and attempts at more integrated water planning as part of the River Basin Management [4]. Nonetheless, a full coordination with RWP is missing. From an integrated water management perspective, however, RWP should intrinsically include assessment of water resources, quality, and flood management perspectives because of the co-dependencies inherent across the water cycle, thus enabling a fully integrated, systems approach to water management. Indeed, there may be significant efficiencies in doing so, for example by designing WMO for synergistic benefits from the outset.

A systems approach to water management (CASYWat hereafter) has been developed by the research group at Imperial College London (ICL) in collaboration with the Environment Agency as part of a NERC Innovation Placement [2]. The work aimed to start to address the UK government's 25 Year Environment Plan (25 YEP) ambition to apply systems thinking to environmental management [5]. To achieve this, the CASYWat framework and systems meta-model were produced to conceptually integrate development, infrastructure and environmental perspectives that define how our land use decisions change the water environment and impact long-term sustainability. Although this work used 'catchment' in its title it is relevant at any scale. Indeed, the work used the systems meta-model to develop both regional and catchment scale case studies. While providing new insights on how the water system can be qualitatively analysed using systems mapping to understand the potential effectiveness of different interventions available for water system management, the framework also enabled the authors to inform and scope further work on quantitative assessment through integrated modelling and participatory engagement necessary for water planning decisions.

To address the need for quantitative analysis and integrated simulations of water systems within a single modelling framework, the ICL's research group has developed the Water Systems Integration Modelling Framework (WSIMOD) initially as part of the NERC-funded CAMELLIA project[1]. WSIMOD allows for the representation of demands and impacts of multiple sectors and actors' decisions within a single tool which is considered beneficial to increasing a shared understanding of system performance and for more collaborative and coherent decisions on integrated water resources, water quality and flood management. The WSIMOD is a self-contained software package that includes modelled representations of key physical and infrastructure 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 representation of a water system that is needed to accommodate the wide variety of different built/natural infrastructure configurations and scales. Components can be parameterised with publicly available data and, in theory, set up for any area that these data cover. The tool has been developed and successfully tested through a range of applications, including integrated analysis of urban water systems [6–9], catchment water management [10,11] and urban water neutrality [12].

At the same time, the Water Consultancy Division in Mott MacDonald has been pioneering the application of participatory system mapping (PSM) as a means of portraying the operation of complex systems [1,13–15]. PSM records how, from multiple actor perspectives, different systems function and how they interact. This method facilitates co-development of system descriptions and expert judgement on the selection of metrics for the function of a system. This method was used in 2021 for Water Resources South East (WRSE) to develop the schedule of resilience metrics that included soft system functions, such as customer relations, in addition to conventional engineering resilience

[1] https://www.camelliawater.org

indicators such as network connectivity [13].

In September 2021, the opportunity arose to further develop the CASYWat work through collaboration between the ICL's Centre for Systems Engineering and Innovation (CSEI), Mott MacDonald and the Environment Agency. The project's aim was to develop a vision for a systems approach to regional water planning as an operational version of the CASYWat framework that integrates water resources, water quality and flood management. This document outlines the vision (Figure 2) and a 3-step process (Figure 3) that would enable its implementation. The proposed approach was shaped by our complementary systems-related work done so far (system and management conceptualisations, qualitative systems mapping and modelling, participatory systems mapping, quantitative dynamic systems modelling and systems-based planning piloting), extensive discussions over 2021-22 and insights gained from our first collaborative proof-of-concept study of the Integrated Water Management Framework for the Oxford-Cambridge (OxCam) Arc [1]. To provide examples for the concepts we are proposing we use the OxCam case study; therefore, we recommend reading the project report before or in parallel to this paper. The text will, however, provide references to pages in the electronic version[2] with content most relevant for this Working Paper.

In setting the proposal to move towards systems-level integration of water resources, water quality and flood management, we are fully aware of the scale of changes that the approach may require. With this Working Paper we want to open discussions and invite wider collaboration for refining a proposed approach and co-developing a transition process to achieve it. The proposed systems approach can be implemented to enhance current RWP by adding an integrational layer that will fundamentally improve both water services and the water environment as demonstrated in [1], but also for discussing and shaping a radically new planning process that will enable maximal integration, efficiency and sustainability of long-term water planning in the UK.

From the current to a systems approach to regional water planning

Our vision is to create a water planning approach that provides an explicit link between water management, regional and local planning decisions and supports the transition towards a paradigm of environment-positive (regenerative) interventions that enable development while maintaining and/or improving the future state of the water environment through co-benefits assessment of WMO (Figure 2). Design of such systems requires testing different planning scenarios including alternative developments, infrastructure paradigms and climate projections with respect to defined water planning indicators, which must be agreed by the relevant decision makers. Our proposal represents a major step forward in the context of this vision in relation to the current water management paradigm and will deliver significantly improved decisions and outcomes, if and until we transform to an alternative paradigm of regenerative socio-technical systems (e.g., zero-pollution wastewater and urban systems) in the long-term. It will implement a systems approach which can be a foundational step towards the new paradigm which can support more integrated, multifunctional planning across not just the water sector. This is an aspiration that has existed for many decades in organisations such as the Environment Agency.

[2] https://tinyurl.com/246xcbj7

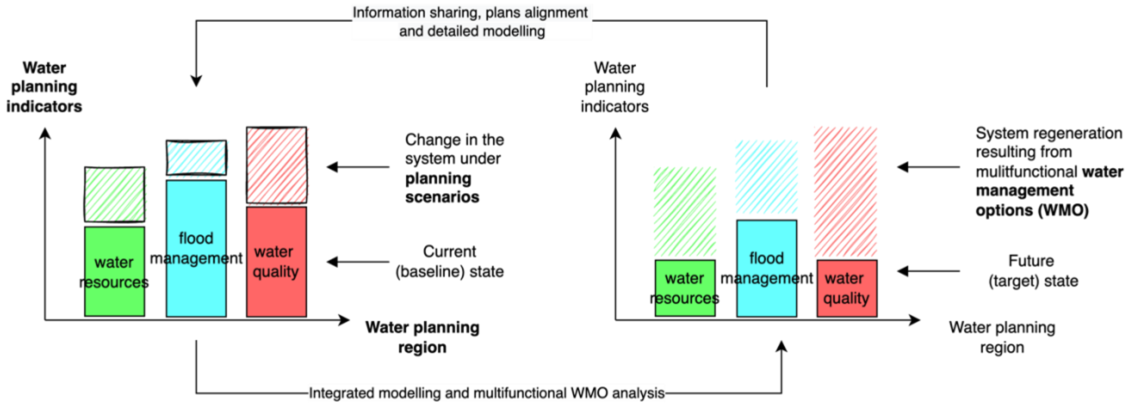

Figure 2. Vision of regional water planning for designing multifunctional water management options

The 3-step process for regional water planning

To this end, we propose a systems approach that is based on a 3-step process (Figure 3). As a first step, participatory processes such as PSM are suggested to enable decision-makers to agree on criteria necessary to start the process of system-based RWP. In the next step, evidence on WMO co-benefits and trade-offs is created using an integrated water system model such as WSIMOD. Finally, in Step 3, through a blended approach, quantitative, systems-level evidence can be used to support discussions and collaborative decisions around cross-plan multifunctional WMO design and evaluation based on qualitative system analysis, leading to maximising funding opportunities based on shared benefits [16]. Proposed steps are further explained in more detail below.

	Step 1. Agreeing	Step 2. Creating evidence	Step 3. Identifying opportunities
Benefits of systems approach	Framework to discuss WMO interactions across plans	Cross-plans evidence of WMO performance	Co-funding opportunities based on WMO co-benefits
From current …	Multiple organisations that are making separate decisions on a range of WMO	Multiple simulation models for scenario planning and WMO evaluations	Multiple plans primarily focused on a single outcome (resources, flooding, water quality)
… to systems	Organisations that make decisions on WMO using shared systems-level evidence	Modelling using an integrated tool that captures key water system interactions	Coordinated plans that incorporate evidence on WMO multifunctional performance
How to transform	Agree on common scope, evaluation criteria and planning assumptions to be able to compare performance of WMO across plans; e.g., using PSM	Develop an integrated water systems model based on the criteria defined in Step 1; e.g., using WSIMOD	Introduce a blended approach (Steps 1+2) to key organisations and create process for WMO evidence sharing across plans; e.g., using Multi-Criteria Assessment

Figure 3. A 3-step process for a blended systems approach to regional water planning

Step 1. Agreeing on common scope, evaluation criteria and planning assumptions

In this step, relevant decision-makers need to agree on the spatial boundary of the analysis and the components that define the scope of the quantitative model and its use (Figure 2). The proposed approach supports coordinated decisions on WMO design and evaluation within a defined spatial domain (hereafter water planning region) so that options co-benefits can be maximised, and potential unintended consequences identified. The PSM can be used at the outset to identify system boundaries and interconnections and then create the schedule of metrics in agreement with project stakeholders. Within a selected region, coordination is achieved by organisations involved in the water planning process agreeing on four key aspects:

(1) The selection of critical checkpoints. A water planning region is not a fixed spatial unit – its size will depend on the selection of critical checkpoints (CC), which are defined as locations where the evaluation of the water planning indicators will be used to support decision-making. This will define the size of the region that should be included in the analysis to capture the physical (e.g., upstream-downstream) and management (e.g., water abstractions) connectivity and propagation of impact (Figure 4A). We propose the Environment Agency water body catchments as a basic spatial unit for defining a water planning region. It should be noted that if WSIMOD is used as a tool for integrated water systems modelling in Step 2, there is an assumption that groundwater catchments follow the surface water system, which needs to be addressed in future work, especially for modelling groundwater-dominated regions. For some catchments, a higher density of checkpoints will be required than water bodies, e.g., upstream reaches of chalk streams. Equally, in places, a lower resolution may be acceptable, and useful to improve model run times.

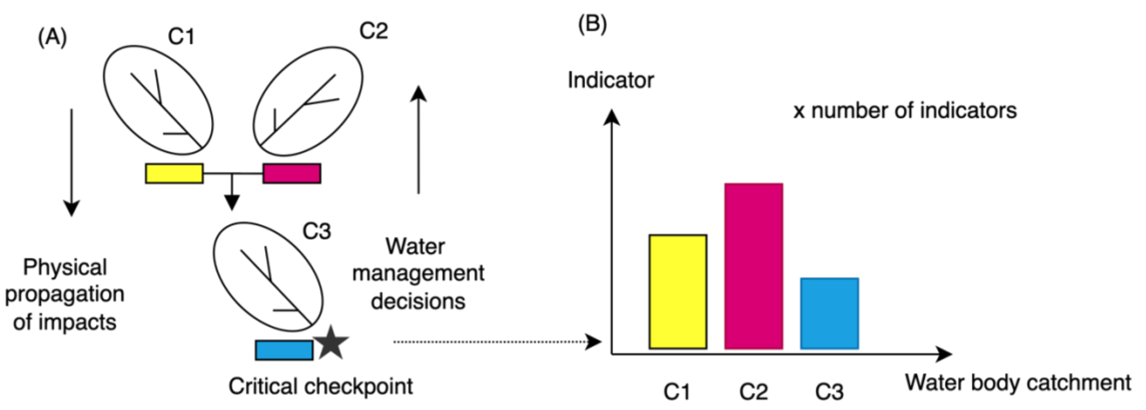

Figure 4. Illustration of a water planning region and coordination requirements for a hypothetical 3-unit system. Basic spatial units C1-C3 represent water body catchments that fall within hydrological and management boundaries for selected critical checkpoint at the C3 outlet (A). Depending on the modelling setup, a range of indicators is assessed at catchment outlets, including the critical checkpoint (B).

(2) The selection of water planning indicators is relevant for both water quantity (supply and flood) and water quality (pollution) management, which enables the evaluation of the multifunctional performance of WMO. Indicators are assessed at critical checkpoints at minimum and, ideally, at the outlets of each water body catchment within the defined region (Figure 1B). It should be noted that selection of indicators is an iterative process as shown in Figure 3. In the OxCam study PSM was used for original metrics and then revised as modelling progressed (see Section 4, 5.1 and Annex H in [1]).

(3) The selection of planning scenarios and assumptions. Decision-making organisations need to agree on the scenarios under which their decisions will be tested. Two key scenarios need to be provided as an input for integrated modelling: (i) development and population and (ii) climate change. Development and population scenarios should come from local authority projections, while climate change projections can come from a range of sources (e.g., UKCP18's Convective Permitting Modelling scenarios). At this stage common planning assumptions such as optimism bias and design horizons must be agreed. (see p.66 in [1])

(4) The selection of water management options. A range of WMO can be simulated to test their impact on the water system. We propose testing a portfolio of options that come from individual plans but are likely to have impacts on the regional system. Decision-makers should agree on the type, size, and location of each option. Alternatively, once the preferred options for testing are selected, a many-objectivity optimisation can be used to suggest potential combinations of options' implementation (size and location) given defined optimisation objectives. An example of a many-objectivity optimisation of nature based solutions in Norfolk using WSIMOD can be found in [11].

Box 1 illustrates the Step 1 implementation phase in the OxCam pilot study.

Box 1. Implementation of RWP process Step 1 for OxCam pilot study

Step 1 selection of…	OxCam study example	Pages in [1]
…critical checkpoints and analysis boundary	27 water bodies were selected for modelling to capture the flow and water quality indicators at 3 CCs: the outlets of the Cam, Granta and Rhee catchments	206
…water planning indicators	12 water availability (surface and groundwater), flood behaviour and water quality indicators were selected and modelled at CCs	211-212[3]
…planning scenarios and assumptions	Options were tested under five population and two climate (RCP4.5 and 8.5) scenarios	212-213
… water management options	A portfolio of 10 green/grey WMOs was selected including: three water resources (supply reservoir, per capita reduction and groundwater licence reduction), four urban (attenuation tanks, WWTP, storm tanks and sewer capacity expansions) and three rural (runoff attenuation features, tree planting and regenerative farming)	213-216

Step 2. Creating evidence on multifunctional WMO performance

The criteria set in Step 1 can be used to inform development of an integrated model for WMIO design and evaluation. A range of models listed in [1] is currently used to assess options in detail in water management plans. However, integrated tools such as WSIMOD add value in three aspects:

[3] A comprehensive list of integrated solutions appraisal criteria can be found on p. 67 in [1].

(1) Integrated simulation of flow and water quality at a catchment scale enables us to compare WMO across a range of scenarios and indicators relevant for multiple plans and organisations.

(2) Urban-rural processes integration support spatial coordination of WMO implementation decisions; and

(3) Explicit representation of spatial planning scenarios, infrastructure operation and policy provide a way to explicitly link urban planning with water management.

A generic high level overview of the WSIMOD structure is shown on p. 208 in [1]. An open-source version of the WSIMOD software with automatic data pre-processing for the UK is expected to be available in early 2023.

Model simulations will produce three sets of results relevant to decision-making (three coloured bars in Figure 5). The first set (solid yellow bar in Figure 5) includes results from the baseline (historical) simulations, used to validate the model and provide assessment of the current state of the system. The second set (hashed yellow bar in Figure 5) evaluates future scenarios using simulations without WMO to determine the level of change that will be expected due to climate, population, and other pressures on the system. The final set of simulations (red bar in Figure 5) evaluates future scenarios with WMO. This information can be used to define targets for evaluating effectiveness of WMO, either by using the concept of water neutrality or regulatory/operational requirements. Targets are defined as desirable levels of water system performance measured by the water planning indicators; WMO effectiveness then measures how successful options are in achieving set targets. It should be noted that when water quality indicators that measure the level of nutrients in rivers are used, this concept can be directly applied to much discussed nutrient neutrality assessments for new developments[4].

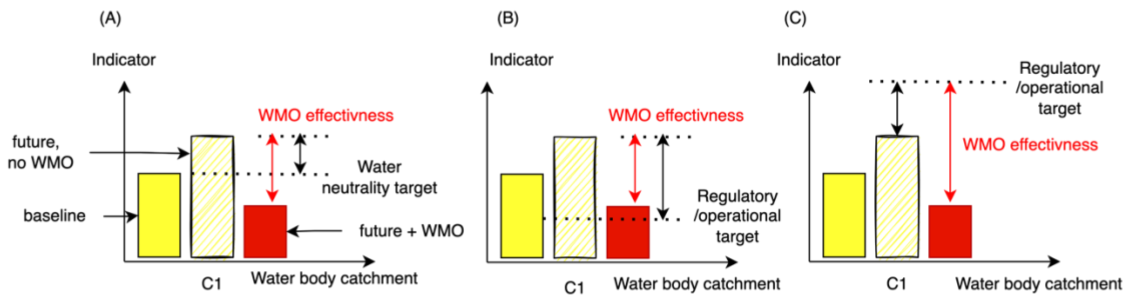

Figure 5. Illustration of three sets of results simulated using the integrated water system model. Different options for defining water planning targets and WMO effectiveness include water neutrality concept (A) and regulatory/operational targets (B and C).

The water neutrality concept implies that the future state of the environment, at a minimum, should not be worse than baseline conditions, which is achieved by introducing WMO that can offset the impact. Examples of this concept for assessment of water-neutral planning in London under housing development scenario can be found in [17]. Figure 5A shows an example for an indicator that must be minimised where hypothetical options overperform on the defined target (> 100% effectiveness), creating an environment-positive, regenerative solution. An alternative approach is to define the target based on regulation or operational requirements. If the target instead becomes improving conditions relative to the baseline, the WMO may prove insufficient, as shown in Figure 5B. In some water body catchments, assessment will show that

[4] https://tinyurl.com/yw9r5mex

regulatory/operational targets have not been exceeded (Figure 5C). This information defines systems with environmental conditions suitable for development, where implementation of WMO could enable expansion of the current plans, e.g., higher housing target. This information would need to go into a broader decision-making process and detailed modelling due to other potential impacts or improvements which have not been modelled yet (e.g., physical modifications). Finally, assessment of WMO effectiveness could be done by directly comparing future scenarios including the WMO with baseline assessment, as we have done in the OxCam work (see figure on p.217 in [1]). Although this approach shows whether we are improving or worsening the system compared to baseline status, its limitation is that it does not provide information on the required status. This could be important if, for example, we want to understand the implications of our decisions on river biota as discussed in [18].

It is important to mention that, depending on the number of criteria (locations, scenarios, indicators, and options) defined in Step 1, the amount of data produced can be significant, which requires further development as how to best present the information to decision-makers. In the OxCam work, we have used boxplots as a way to summarise the simulation results, and p.222-226 in [1] illustrate four WMO from water supply, quality and flooding portfolios that were analysed. The presentation of information could be further improved through data portals or online interactive platforms, such as WSIMOD Virtual Decision Room currently under development[5].

Step 3. Identifying opportunities for WMO portfolio implementation

Integrating different decision-makers around collaborative decisions on WMO requires improving communication and working on the connections between them through shared or at least mutually comprehensible language, metrics, and frameworks. Evidence produced during this step of the proposed systems approach could be used to initiating discussions about combining benefits and co-benefits in a Multi-Criteria Assessment (MCA) as proposed in [1] (see p.71). The underlying principle suggests that integrated planning should consider multifunctionality of WMO. So, for example, if an option that was designed as part of water resources planning has benefits for flood management and/or water quality as well, this information should be exchanged with organisations responsible for relevant plans. This may: (i) support discussions on joint funding of multifunctional WMO and/or (ii) change the design of some options in other plans as their function is partially achieved. The final production of a portfolio of options for implementation requires consultation. There may be a range of portfolios that get taken to consultation with different emphasis on environmental benefits, social value, cost, and other criteria. This may require some iterative work across the three steps set out here.

Results from our OxCam work show that wetlands, for example, provide a range of co-benefits including improvements in water quality but also contribute to improvement in drought and flood indicators (see p. 223 in [1]). We also note that the proposed RWP approach can reveal potential unintended consequences resulting from regional system interactions. For example, in OxCam a new reservoir will increase water use security under future climate change and population growth scenarios. However, this will be at the price of water quality deterioration caused by reservoir operations, particularly with respect to nitrate and phosphate concentrations in rivers (see p. 222 in [1]).

Finally, it should be reiterated that the described RWP process is not linear. A range of adjustments is expected to be made to criteria defined in Step 1 once the baseline and future scenario results are shared with the decision-makers. Initially, agreed indicators / targets may prove not to

[5] https://tinyurl.com/mrxf9bj6

be useful for Step 3 discussions, and modelling should provide the scope for exploring optimal sets of criteria. Finally, given significant uncertainty in future scenarios, the process of decision-making has to be enhanced by adaptive planning approaches such as Decision Making Under Deep Uncertainty [19].

Key recommendations

The proposed systems approach is based on the principle of integration and coordination, which needs to be addressed at multiple levels as shown in Figures 2 and 3. The proposed 3-step process provides a framework that can be used to support the transition towards a systems approach. We have identified the following key recommendations for achieving integration in RWP:

(1) **Create a framework for agreeing key aspects that will enable the communication and sharing of information between multiple decision-makers and water plans**. This information needs to include a selection of the water planning region and locations (critical checkpoints) that will be used for an assessment of the state of the system, definition of planning scenarios, indicators and assumptions that will be used to quantify the level of change and WMO(s) that will be tested for their effectiveness in offsetting any impact. Participatory approaches, such as PSM, can be used to support this process.

(2) **The use of integrated models to assess the state of the system and the effectiveness of the WMO(s)**. The integrated models should have the capability to simulate both water flow and water quality resulting from interactions between urban and rural systems, water infrastructure operation, environmental policies, and human behaviour. An integrated modelling framework will ensure that impacts from changes in the system can be propagated across the whole region, capturing upstream-downstream and cross-catchments interactions and interdependencies. Open-source WSIMOD software is a tool that could be used in this context.

(3) **The development of governance and funding models that will enable translation of the evidence that is generated into integration of selected WMO across multiple water plans**. Once the WMO have been through a process of a RWP assessment, the information on their co-benefits and trade-offs should be shared with all relevant decision-makers, and at a minimum those shown in Figure 1. This will enable a portfolio of options to be further co-designed using detailed simulation models while, at the same time, having in mind the multifunctionality of proposed interventions. Concurrently, the WMO co-benefits across water resources, water quality and flood management will create a starting point for discussing potential co-funding options, which is likely to increase in the uptake of interventions such as NBS. This could be done using tools such as MCA.

Future development and opportunities

This proposed systems approach to RWP is a first step in translating the CASYWat theoretical framework into a process for analysis of WMO through participatory processes and integrated modelling so that their co-benefits and trade-off can be assessed and included in multiple water plans. However, there is significant scope for further improvement. Operationalising the approach will require governance arrangements to be set-up that are fit for purpose. Operation within current planning frameworks will require collection of outputs from dedicated planning frameworks, then modelling and sending opportunities for integration back out to those frameworks in a timely manner. One possible option for this process is shown on p. 116 in [1]. Integrated modelling using WSIMOD can also be further improved by more detailed groundwater representation. While the model is particularly strong in combining water supply and water quality analysis, it only has a higher level, indicative output on flooding, which would require integration with geospatial modelling to get the same understanding of WMO impact. There is also an important research agenda to validate the results of green infrastructure and Nature Based Solutions implementation at scale. The modelling framework would also benefit from integration with a regional water allocation model such as PYWR [20].

Conclusions

This Working Paper provides a unified, systems perspective on water planning and management, which creates a platform for operationalising decisions on multifunctional WMO. The benefit of participatory approaches lies in creating a shared understanding of the water planning region, while integrated modelling enables the evaluation of different intervention scenarios to see how they perform across multiple outcomes and scales. While the Paper has provided OxCam as an example for process implementation, there are many more applications that would benefit from this approach. For example, the proposed process could be used to tackle Combined Sewer Overflows (CSOs) from a systems perspective, the need for which was emphasised in a recent CIWEM report [21]. The approach is currently used to support development of the Greater London Authority's Subregional Integrated Water Management Strategy. Finally, the platform provides the basis to investigate wider system integration – with transport, agriculture, and amenity benefits of landscape interventions.

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