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Multi-criteria decision analysis for the evaluation of water quality improvement and ecosystem service provision

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Abstract

Water and land management decisions require consideration of multiple factors. Multi-criteria decision analysis (MCDA) provides a structured, auditable and transparent tool that helps inform and add rigour to multi-option decisions. MCDA was used in a payment for ecosystem services (PES) project to evaluate options for delivering good ecological status in Tortworth Brook, Gloucestershire, UK. Following a process of stakeholder engagement , final options considered were: (1) doing nothing; (2) modifying existing sewage treatment works; (3) a single integrated constructed wetland (ICW) targeting multiple ecosystem service outcomes; and (4) catchment wide multiple ICWs. The analysis concluded that the 'do nothing' option and modifying the existing works are both likely to provide poor utility and value for money. Both ICW options offered the greatest utility in terms of optimising the benefits to all stakeholders.

Key words

MCDA, integrated constructed wetlands (ICWs), water quality, ecosystem services

Introduction

In 2000, the European Union (EU) adopted the Water Framework Directive (WFD) as a framework for water policy (EU 2000). The WFD set member states the target of achieving 'good ecological status' (for instance in terms of abundance of aquatic flora and fauna, the availability of nutrients, presence of chemical pollutants and morphological structures) for all water bodies by 2015. Whilst progress has been made, there is still a long way to go before quality of the waters within the EU achieve the desired status (EC 2015).Within lowland England, diffuse and point sources of pollution are implicated in compromising the ecological status of surface water bodies (Bowes *et al*. 2005; Neal *et al*. 2005). Of these, phosphorus from agriculture (Withers & Jarvis1998) and treated sewage effluent seriously threaten the achievement of good ecological status under the WFD (Jarvie *et al*. 2006).

Improving water quality using natural and constructed wetlands is well established (Vymazal 2011). The integrated constructed wetlands (ICW) concept builds on the traditional approach to constructed wetlands, but takes a more holistic view of the 'landscape fit' (across physical and social landscapes), embraces improved water quality requirements, explicitly delivers biodiversity enhancement and optimises several other ecosystem service outcomes (Scholz *et al*. 2007; Harrington & McInnes 2009). ICWs can, therefore, contribute to good ecological status whilst delivering wider societal benefits. However, barriers to ICW uptake have been encountered, and Everard *et al.* (2012) call for future research on mainstreaming ICW concepts. This slow uptake may stem from narrow disciplinary framing of legacy regulations (Everard & McInnes 2013) or a lack of vision by, and appropriate support tools for, planners and managers.

The concept of 'payments for ecosystem services' (PES) has emerged as a policy solution which works on the premise that individuals or communities are paid to undertake actions that improve ecosystem services (Jack *et al.* 2008). PES schemes usually involve payments to land managers in exchange for production of specified ecosystem services beyond those provided in the absence of payment (Smith *et al*. 2013). The multiple benefits provided by ICWs makes them attractive propositions within PES schemes; this has been examined in a feasibility study within Tortworth Brook catchment (Greaves *et al*. 2013).

Despite sound evidence that ICWs deliver water quality improvements and wider societal benefits (Doody *et* al. 2009; Harrington & McInnes, 2009), and that PES schemes can be effective measures for delivering win-win environmental solutions (Farley & Costanza 2010); barriers still exist to both the implementation of ICWs (Everard *et al*. 2012) and the development of often unavoidably complex PES schemes. Multi-criteria decision analysis (MCDA) offers an approach that can be used to develop sustainable outcomes, align potentially differing views of stakeholders and manage the complexity inherent in both PES schemes and water management decision-making. MCDA has been applied extensively to water management issues (Kiker *et al*. 2005; Mendoza & Martins 2006) where decision-making often involves considering multiple criteria, and conflicting objectives, some of which can be quantified, while others are difficult to measure or remain entirely subjective (Hajkowicz & Higgins 2008). For instance, in the complex field of flood management, MCDA and associated modelling have been effective tools for overcoming complexity and aiding prioritisation of outcomes (Chitsaz & Banihabib 2015) Since ICWs seek optimisation of ecosystem services, the MCDA approach provides an effective tool to help make structured, auditable, transparent and rigorous decisions that balance different types of knowledge (Dunning *et al*. 2000).

Through the use of a case study involving a water company and a landowner, this paper reports on how implementation of an MCDA approach can assist in addressing barriers to implementing sustainable solutions and aid in the development of novel water management options which deliver multiple benefits, to multiple stakeholders, in parallel with achieving good ecological status *sensu* WFD.

Study site and team

The Tortworth Brook catchment (part of the Little Avon catchment) covers approximately 17km^2 in Gloucestershire, UK (Fig. 1). Land-use is largely agriculture, small copses and village settlements. It has been classified as 'Poor' under the WFD due to elevated nutrient loadings, and particularly phosphorus (P) concentrations believed to arise from diffuse agricultural inputs and from point source emissions from sewage treatment works (STWs) (Environment Agency 2009), however due to data limitations the relative proportion of these vectors is unknown.

[Fig 1 Here]

Following best practice guidance (Smith *et al.* 2013), the primary stakeholders in the PES scheme were defined as Wessex Water (WW – the potential ecosystem services buyer, or the party that will pay for the environment to be managed in order to provide them with a specific service) and the Tortworth Estate (TE – the potential ecosystem services seller, or the party that will be paid to manage the environment to deliver the desired service). Both stakeholders were concerned about water quality in the Brook and were interested in developing a novel and sustainable approach to the improvement of environmental quality. MCDA was used by an independent team of experts with expertise in *inter alia* wetland design, nutrient dynamics, sustainability, environmental consenting, ecological assessment and MCDA (the TEAM – often referred to as the knowledge provider and/or intermediary) to help the primary stakeholders identify the best approach to improve the ecological status of the Brook. For the purposes of this case study the TEAM also played the role of the secondary stakeholders the guidance (Smith *et al.* 2013) requires to be included in the PES decision making process.

Methods

Defining the project steps

Many decision-making frameworks are applied within the UK water industry. These include *inter alia* traditional accounting with a focus on financial targets (Ogden & Anderson 1999), risk-based approaches which attempt to conceptualize options and outcomes in many different ways (Krieger 2013) and the application of environmental management systems which are commonly skewed by institutional pressures and the demands of economic performance (Schaefer 2007). MCDA is widely acknowledged to represent an appropriate approach for decision-making in the presence of potentially conflicting views or objectives and which can assist the decision-maker, in this instance a water company, to choose the best alternative from a range of options (Pietersen 2006). Using an MCDA approach contributed to and enabled a continuous evolution of options and ideas through an iterative process of consultation, feedback and evaluation by WW, TE and the TEAM. The MCDA approach followed a series of clear steps (using multi-attribute utility theory *sensu* Keeney & Raiffa 1993) (Fig.2). As the project progressed and all parties developed their understanding of the project potential, especially with regard to ICWs and the delivery of wider ecosystem services, this process facilitated WW and TE widening their aims and objectives.

[Fig.2 Here]

Primary and secondary aims

Two workshops were conducted with key representatives from WW (environmental management, sustainability and permitting personnel), TE (estate management and board members) and the TEAM. The workshops were chaired by a representative from the TEAM. The objectives of the first workshop were as follows:

- Introduce the PES process.
- Provide background information on ICWs.
- Initiate discussions around project options.
- Explore principles of engagement between the buyer and seller.
- Explore the buyer and seller's perception of risk.
- Clarify land ownership and property rights.
- Understand the drivers for change (including financial, legal and reputational).
- Understand potential costs and benefits for the buyer and seller.

The second workshop re-invited the same attendees to explore the initial aims as presented by WW and TE in the first workshop and examine in more depth the range of additional benefits that an ICW could deliver. The specific aims of the second workshop were:

- Establish more detailed project aims for WW and TE.
- Present the MCDA methodology.
- Discuss possible ICW options.
- Present and discuss a range of potential ICW locations.

One-to-one interviews were held with representatives of WW and TE, including site walkovers with both parties, to further investigate some of the elements discussed in the workshops. In addition, the TEAM held informal discussions with Environment Agency and the local planning authority to understand better consenting and planning issues.

The primary aims of WW and TE were considered essential outcomes, whilst secondary aims were considered desirable outcomes (Table 1). The TEAM also considered planning and regulatory constraints, and wider objectives including additional stakeholder benefits, long-term ecosystem services and overall sustainability. As such, the TEAM used their broader knowledge of policy and regulation to act as a surrogate for the interests of the wider environment and secondary stakeholders as well as performing the roles of intermediaries and knowledge providers as defined by Smith *et al*. (2013).

[Table 1 Here]

Option development

Desk and site investigations were undertaken by the TEAM to assess better how the desired primary and secondary objectives could be delivered. The TEAM developed several options for WW and TE which addressed standard water industry practices for phosphorus treatment through to implementing multiple constructed wetlands to deal with catchment-wide water quality issues. From one-to-one and group discussions, project aims were refined to address the aims of WW and TE and the structural requirements of the MCDA.

The four options considered were:

- Do nothing: continue current operations and future maintenance at the STWs.
- Modify existing STW: Use existing traditional electro-mechanical or chemical dosing phosphorus reduction technologies to modify the STW.
- Restricted ICW: Creation of a single ICW to reduce phosphorus loadings in the STW effluent.
- Catchment-wide ICWs: Create ICWs across the Tortworth Brook catchment to treat farmyard run-off, septic tank drainage, STWs outfalls and diffuse pollution.

Evaluation criteria development

Developing evaluation criteria required a wide cognizance of PES scheme objectives. Therefore, in addition to the primary and secondary aims of the buyer (WW) and seller (TE), secondary stakeholder benefits, long-term ecosystem services sustainability, project costs and regulatory and planning implications were also assessed (Table 2). In accordance with best practice (Smith *et* al. 2013), the TEAM used their expertise to provide knowledge, act as intermediaries and to emulate broader stakeholder perspectives throughout the process.

[Table 2 Here]

Top-level evaluation criteria were developed for the MCDA model (Table 3) using the considerations shown in Table 2. Using an iterative consultation process between WW, TE and the TEAM, initial weightings were assigned to each top-level criterion; the lower level considerations were simply divided into equal weightings (Fig. 3). The weightings reflect the importance of an evaluation criterion to making the decision.

To assess how well each option met the project aims (identified by the MCDA criteria), a qualitative scoring system was developed, which, with nine levels, was considered sufficient to differentiate across different qualitative assessments. This was used to score all criteria except project costs:

- Very Good (VG)
- Very Good/Good (VG/G)
- Good (G)
- Good/Acceptable (G/A)
- Acceptable (A)
- Acceptable/Poor (A/P)
- Poor (P)
- Poor/Very Poor (P/VP)
- Very Poor (VP)

Descriptors to guide the scoring were provided (Table 4) and although intermediate scores could be used, such as VG/G*,* no descriptors were provided. All three parties (WW, TE and the TEAM) beyond the core project team to overcome individual bias or single viewpoints. The qualitative scores were transferred directly into the computer program Logical Decisions® for Windows, and converted into numerical scores, based on a linear scale ranging from zero points (VP) to 100 points (VG).

An internal consultation process was used by both WW and TE to independently generate consensus scores for the following questions representing the primary and secondary aims of each stakeholder (40% weighting within the MCDA):

- How well does an option meet the project aim?
- How well does the option meet wider business objectives?

Following best practice as knowledge providers, the individual TEAM members independently scored the other MCDA criteria, then, through a process of discussion and comparison, jointly agreed the final scores used in the MCDA. The TEAM generated quantitative estimates for the most likely cost. Three values for estimated costs were derived from recent experiences with similar schemes in the UK and Ireland (for instance, Doody *et al.* 2009): the 5th percentile, the mode and the 95th percentile. These three values were included in the MCDA model as resampled estimates (Monte Carlo) using a triangular distribution with 10,000 iterations (Vose 2008). The uncertainty associated with costs is illustrated in the model graphics as error bars on the utility bars.

[Fig. 3 Here]

Results

Options assessment using evaluation criterion raw scores

The scores the evaluation criteria provided by TE, WW, and the TEAM are summarised in Tables 5 and 6. Overall, the ‘do nothing’ option was considered a poor solution by all parties. For both TE and WW the ICW options were clearly considered better than modifying the STW, with the catchment-wide ICW option expected to deliver the greatest benefits. However, the restricted ICW option was considered good for delivering a range of ecosystem services. Modifying the STW using traditional phosphorus removal technologies carried the greatest construction and operational costs (but the lowest regulatory risk), and the costs for catchment-wide ICWs were greater than the restricted ICW option.

The ‘do nothing’ option was considered ‘very good’ for planning consent, environmental impact assessment requirements, and permissions and licences because of no significant change in the status quo. However, the ‘do nothing’ option was poor at meeting future permissions and licences due to the current water quality issues. The restricted ICW option was considered good for meeting future licensing/permitting requirements. The technical effectiveness for meeting the primary and secondary project aims is clearly greatest for the catchment-wide ICW option, but is still good for the restricted ICW option.

[Table 5 Here]

[Table 6 Here]

Options assessment using MCDA

The MCDA shows clear divisions in utility between the options being considered (Fig.4). The restricted ICW and catchment-wide ICW options have high utility values (0.776 and 0.749, respectively) compared to low utility values from modifying the existing STW or doing nothing (0.472 and 0.225 respectively). However, the error bars for both the restricted ICW and catchment-wide ICW options (that represent uncertainty over project costs) show considerable overlap in utility, and, there is no clear ‘best’ ICW option.

[Fig. 4 Here]

The individual bands on the bars in Fig.4 show how much each evaluation criterion contributed to the utility value for each option. For example, both ICW options show similar utility for WW and TE. However, the catchment-wide ICW option offers better utility value for stakeholders, ecosystem services and technical effectiveness. The restricted ICW option is better for costs and regulatory risks.

A sensitivity analysis allows the effect that varying costs will have on the choice of best option to be assessed (Fig.5). The initial weight given to cost was 15%. Decreasing this weighting by 5% favoured a catchment-wide ICW option over the restricted ICW option. Increasing the cost weighting has no effect on the best option until 80% of the decision is based on costs: at this point the 'do nothing' option becomes the favoured option. Therefore, weighting the importance of costs between 10% and 80%, does not strongly influence the preference of an ICW option, and is therefore not cost sensitive, but choosing between the restricted ICW and catchment-wide ICW option is cost sensitive.

[Fig. 5 Here]

Although the catchment-wide ICW has the highest costs, it should also provide the greatest value for money (compared to the restricted ICW option) through its greater utility for technical effectiveness, ecosystem services and stakeholder benefits (Fig.6). The next best option in terms of value for money would be the restricted ICW option. The 'do nothing' option offers the poorest value for money.

[Fig. 6 Here]

Further sensitivity analyses demonstrates the preferred option would switch from the restricted ICW to the catchment-wide ICW option if the weightings given to the technical effectiveness and stakeholder benefits were increased from 5% to 10%; stakeholder benefits (excluding WW and TE) were increased from 10% to approximately 18%; or, ecosystem benefits was increased by 5%. When only the ecosystem benefits are considered important the catchment-wide ICWs clearly provides the greatest utility (Fig.7).

[Fig.7 Here]

Discussion

Developing and implementing sustainable water management options can be complex (Pahl-Wostl 2007), and implementing systemic solutions for multi-benefit water and environmental management is challenging (Everard & McInnes 2013). The application of MCDA objectively calculates a single utility value from multiple options, reconciles the views of different stakeholders and helps identify how different assessment criteria influence the final decision (Hajkowicz & Higgins 2008). Other structured approaches exist (Gregory *et al*. 2012), but MCDA is a well-established method that enables the requirements of the ecosystem and its sustainability to be represented, through expert input, which can include the interests of wider stakeholders. This approach is fully compatible with the development of PES schemes which should aim to ensure that the value of nature is fully reflected in decision-making (Smith *et al.* 2013). Additionally, the need for specific information within the MCDA forces a deeper level of thinking about the process than demanded by less structured approaches. The approach also forces all parties to evaluate in detail, exactly what it is they want to achieve, both as a direct consequence of the tradable services and, in the context of this case study, more widely within the Torthworth Brook catchment

The options considered were identified through an iterative, participatory and consensual approach involving both primary (WW and TE) and surrogate secondary stakeholders (the TEAM). The structured MCDA approach facilitated the identification of assessment criteria and their relative weightings to be conducted in a structured, open and transparent manner which promotes consensus in the final outcomes. Other studies which have applied an MCDA approach to water management issues have highlighted the need for further sensitivity analysis (Pietersen 2007; Bouchard et al. 2010). Whilst the approach adopted in this study presented consolidated views for WW and TE which encouraged an understanding of stakeholders' aims and highlighted where interests are shared or diverge (crucial for a win-win solution), further sensitivity analysis could have been undertaken across a broader constituency both within WW and TE. Notwithstanding this, the representatives of both WW and TE were mandated to communicate a collective view of their organisations and therefore the selection and scoring of criteria are considered robust. At Tortworth Brook, the iterative development of the MCDA model allowed initial consideration of an 'end of pipe solution' for the STW to evolve into a wider ambition at a catchment-scale driven by the mutual objective of a good ecological outcome.

Of the options evaluated, the 'do nothing' and modifying the existing STW are both likely to provide poor utility and value for money. Both ICW options clearly confer the greatest utility with the catchment-wide ICW option likely to provide better value for money and greater ecosystem services utility than the restricted ICW option. This reflects evidence from Ireland where catchment-scale ICWs provide cumulative benefits

(Harrington & McInnes 2009). There was some evidence suggesting a restricted ICW could be a better option for WW. However the best ICW option for TE was less clear.

The MCDA process identified the existing regulatory and permitting framework as a potential barrier to implementation (Table 6). This reflected disconnects between regulatory and other bodies observed from ICWs in Ireland (Everard *et al*. 2012). Often, these disconnects appear to relate to traditional approaches of managing issues from narrow, discipline specific perspectives rather than a systemic view of land-water management (Everard & McInnes 2013). The MCDA approach can therefore highlight such disconnects and assist in targeting wider stakeholder negotiations and discussions.

Differentiating the restricted ICW and catchment-wide ICW options would need a more detailed model, as would deciding the best option for a specific stakeholder. However, as a precursor to establishing a potential PES scheme, the MCDA-based semi-quantitative approach adopted in the Tortworth Brook case study helped to define the most favourable balance across all the criteria considered to be important to the decision-makers, whilst also optimising the benefits that nature can provide. Whilst many steps remain to progress from the principles established through this work, including negotiating agreements and implementation on the ground, this approach demonstrates that a buyer and a seller of ecosystem services can be brought together through access to the appropriate intermediaries and knowledge providers adopting an MCDA approach to reach a potentially implementable and mutually beneficial solution.

Conclusions

(1) MCDA is a useful tool for developing transparent, iterative and participatory water management solutions within the context of a PES scheme. MCDA allows stakeholder views to be captured and integrated, and facilitates understanding of the key decision-making criteria.
(2) The MCDA approach enables the interests of the wider environment to be semi-independently represented, rather than just the environmental aspects important to the business outcomes of the buyer and seller.
(3) The MCDA process forces deep thinking about issues that could be avoided or missed in less structured approaches. Modification of the MCDA approach in the light of emergent knowledge and shifting priorities supports adaptive decision-making.

(4) For the Tortworth Brook catchment stakeholders, an ICW approach is clearly of greater utility than traditional electro-mechanical engineered approaches to treating wastewater.
(5) There is little difference in the utility between either a single ICW or catchment-scale application of ICWs.
(6) The greatest potential barrier to implementing an ICW within Tortworth Brook catchment is overcoming regulatory risks and satisfying permitting and licencing requirements.

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References

Bouchard, C., Abi-Zeid, I., Beauchamp, N., Lamontagne, L., Desrosiers, J., and Rodriguez, M. (2010). Multicriteria decision analysis for the selection of a small drinking water treatment system. *Journal of Water Supply: Research and Technology-Aqua*, **59**(4), 230-242.

Bowes, M., Hilton, J., Irons, G. and Hornby, D. (2005) The relative contribution of sewage and diffuse phosphorus sources in the River Avon catchment, southern England: implications for nutrient management. *Science of the Total Environment*, **344**(1), 67-81.

Chitsaz, N., and Banihabib, M. E. (2015). Comparison of different multi criteria decision-making models in prioritizing flood management alternatives. *Water Resources Management*, **29**(8), 2503-2525.

Doody, D., Harrington, R., Johnson, M., Hofman, O. and McEntee, D. (2009) Sewerage treatment in an integrated constructed wetland. *Municipal Engineer,* **162**, 199-205.

Dunning, D.J., Ross, Q.E. and Merkhofer, M.W. (2000) Multi-attribute utility analysis; best technology available; adverse environmental impact; Clean Water Act; Section 316(b). Environment Science and Policy, 3:7-14.

EC, European Commission. (2015) Communication from the Commission to the European Parliament and the Council COM2015/120 The Water Framework Directive and the Floods Directive: Actions towards the 'good status' of EU water and to reduce flood risks. *European Commission.*

Environment Agency (2009). Water for life and livelihoods: River Basin Management Plan Severn River District. Environment Agency: Bristol, UK. 66pp.

Everard, M., Harrington, R. and McInnes, R. J. (2012) Facilitating implementation of landscape-scale water management: The integrated constructed wetland concept. *Ecosystem Services*. **2**. 27-37.

EU, European Union. (2000) Directive of the European Parliament and of the Council 2000/60/EC establishing a framework for community action in the field of water policy *Official Journal* C513.

Everard, M. and McInnes, R.J. (2013) Systemic solutions for multi-benefit water and environmental management. *Science of the Total Environment*, **461**, 170-179.

Farley, J., and Costanza, R. (2010). Payments for ecosystem services: from local to global. *Ecological Economics*, **69**(11), 2060-2068.

Greaves, J., Wood, N., Smith, G., Watson, D. and McInnes, R.J. (2013) The Tortworth Brook Project. Pilot Payments for Ecosystem Services Research Project Final Report. NE0139. Defra, London, UK, 157pp. http://randd.defra.gov.uk/Document.aspx?Document=11899_NE0139_DefraPaymentsforEcosystemServices(PES)%E2%80%93PilotPESResearchProject_FinalReport.pdf accessed 2 July 2014.

Gregory, R., Failing. L., Harstone, M., Long, G., McDaniels, T. and Olson, D. (2012). *Structured Decision Making: A practical Guide to Environmental Management Choic*es. Wiley-Blackwell, London.

Hajkowicz, S. and Higgins, A. (2008). A comparison of multiple criteria analysis techniques for water resource management. *European journal of operational research*, **184**(1), 255-265.

Harrington, R. and McInnes, R. J. (2009) Integrated Constructed Wetlands (ICW) for livestock wastewater management. *Bioresource Technology,* **100**(22), 5498-5505.

Jack, B. K., Kousky, C. and Sims, K. R. (2008). Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences*, **105**(28), 9465-9470.

Jarvie, H., Neal, C. and Withers, P. J. (2006) Sewage-effluent phosphorus: a greater risk to river eutrophication than agricultural phosphorus? *Science of the Total Environment*, **360**(1), 246-253.

Kiker, G. A., Bridges, T. S., Varghese, A., Seager, T. P. and Linkov, I. (2005) Application of multicriteria decision analysis in environmental decision making. *Integrated environmental assessment and management*, **1**(2), 95-108.

Krieger, K. (2013). The limits and variety of risk-based governance: The case of flood management in Germany and England. *Regulation & Governance*, **7**(2), 236-257.

Mendoza, G. A. and Martins, H. (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *Forest Ecology and Management*, **230**(1), 1-22.

Neal, C., Jarvie, H. P., Neal, M., Love, A., Hill, L. and Wickham, H. (2005) Water quality of treated sewage effluent in a rural area of the upper Thames Basin, southern England, and the impacts of such effluents on riverine phosphorus concentrations. Journal of Hydrology, **304**(1), 103-117.

Ogden, S. G., and Anderson, F. (1999). The role of accounting in organisational change: promoting performance improvements in the privatised UK water industry. *Critical Perspectives on Accounting*, **10**(1), 91-124.

Pahl-Wostl, C. (2007) Transitions towards adaptive management of water facing climate and global change. *Water Resources Management*, **21**(1), 49-62.

Pietersen, K. (2006). Multiple criteria decision analysis (MCDA): A tool to support sustainable management of groundwater resources in South Africa. *Water SA*, **32**(2), 119-128.

Schaefer, A. (2007). Contrasting institutional and performance accounts of environmental management systems: three case studies in the UK water & sewerage industry. *Journal of Management Studies*, **44**(4), 506-535.

Scholz, M., Harrington, R., Carroll, P. and Mustafa, A. (2007) The Integrated Constructed Wetlands (ICW) concept. *Wetlands,* **27**(2), 337-354.

Smith, S., Rowcroft, P., Everard, M., Couldrick, L., Reed, M., Rogers, H., Quick, T., Eves, C. and White, C. (2013). *Payments for Ecosystem Services: A Best Practice Guide*. Defra, London. 85pp.

Vose, D. (2008) Risk Analysis: a quantitative guide. John Wiley & Sons: Chichester, UK. 735pp.

Vymazal, J. (2011) Constructed wetlands for wastewater treatment: five decades of experience. *Environmental Science and Technology*. **45**(1), 61-69.

Withers, P. J. and Jarvis, S. C. (1998) Mitigation options for diffuse phosphorus loss to water. *Soil Use and Management*, **14**(s4), 186-192.

Table 1 Primary and secondary aims of WW and TE.

Aims	WW	TE
Primary aims	Removal of phosphorus from sewage discharge	Accumulation of nutrients in wetland as a future fertiliser resource
	Removal of nitrogen from sewage discharge	Reduction of phosphorus across the catchment
	Provision of storm discharge treatment to reduce loadings during high flows	Reduction of phosphorus in Tortworth Brook
		Reduction of phosphorus in the lake
		Reduction of nitrogen across the catchment
		Reduction of nitrogen in Tortworth Brook
		Reduction of nitrogen in the lake
Secondary aims	Understand the role of ICW treatment options in a catchment context	Creation of a wetland corridor through the estate
	Reduce pressure to continued expansion of STW	Improved habitats throughout the estate
	Long-term plan for catchment approaches rather than hard engineering	
	20 year plan to implement integrated catchment management	

Table 2 Overview of evaluation criteria used in considering the best overall option.

	Criteria	Considerations
Best overall option	Best Buyer / Seller option	Buyer / Seller project aims
		Buyer / Seller wider business objectives
	Best stakeholder option	Environmental gains
		Socio-economic gains
	Best planning / regulatory option	Probability of getting planning consent
		Probability of needing an environmental impact assessment
		Probability of getting permissions and licences
		Probability of meeting permissions and licences
	Best cost option	Design and implementation costs
		Construction costs
		Operational costs
	Best technical option	Buyer / Seller primary technical objective
		Buyer / Seller secondary technical objective
	Best ecosystem service option	Optimising provisioning services
		Optimising regulating services
		Optimising cultural services
		Optimising supporting services

Table 3 MCDA model top-level criteria.

Criteria	Description	Weighting (%)
Buyer and Seller benefits	A major contributor, as their endorsement of any particular option is crucial. This category was sub-divided on how well an option meets buyer/seller primary aims of the project, and how well it fits in with wider business plans, aspirations and expectations.	40
Stakeholder benefits	The benefits delivered by the scheme to other stakeholders as represented by TEAM.	10
Regulatory risks	Risks requiring consideration as they influence decision-making and design and effectiveness.	10
Project costs	Estimates of the actual project costs.	15
Technical effectiveness	An assessment of how well each option meets the technical objectives in terms of the buyer and seller's requirements.	10
Ecosystem services benefits	The wider ecosystem services delivered by the option, beyond and above those which are a part of a formal PES agreement.	15

Table 4 Description of scoring categories. Qualitative descriptors used to guide the scoring of how well each scheme met the project aims as defined by the MCDA criteria.

Category	Very good (VG)	Good (G)	Acceptable (A)	Poor (P)	Very poor (VP)
Ecosystem benefits	High level of confidence in maintaining and enhancing current ecosystem benefits	High level of confidence in maintaining existing ecosystem benefits and high probability of enhancing them	High probability of maintaining existing ecosystem benefits and low probability of enhancing them	High probability of damaging existing ecosystem benefits (probably recoverable)	High probability of seriously damaging existing ecosystem benefits (unrecoverable)
Project costs	Relatively low costs with low levels of uncertainty	Relatively low costs with high levels of uncertainty	Relatively Moderate costs with low or moderate levels of uncertainty	Relatively Moderate costs with high levels of uncertainty	Highest costs with low levels of uncertainty
Regulatory risks	Very low risk of regulatory constraints affecting project timetable or budget. Regulatory constraints can be anticipated and planned for	Low risk of regulatory constraints affecting project timetable or budget, assuming anticipated constraints are built into budget and timetable	Regulatory constraints are likely to affect project timetable or budget, but the *majority* can be anticipated and planned for	Moderate risk of regulatory constraints seriously affecting timetable or/and budget. The majority of the constraints can be anticipated and planned for, but there are also known areas of high uncertainty	High risk of regulatory constraints seriously affecting timetable or/and budget. Consequences difficult/impossible to anticipate or plan for. Outcome unpredictable, or high risk of being unfavourable
Stakeholder benefits	High level of confidence in maintaining and enhancing current situation	High level of confidence in maintaining existing situation and high probability of enhancing them	High probability of maintaining existing situation and low probability of enhancing them	High probability of damaging existing situation (but, probably recoverable)	High probability of seriously damaging existing situation (unrecoverable)
Technical effectiveness	High level of confidence in meeting and exceeding buyer/seller expectations	High level of confidence in meeting buyer/seller expectations and high probability of	High probability of meeting buyer/seller expectations, low probability of exceeding them	High probability of damaging existing situation (but, probably recoverable)	High probability of seriously damaging existing situation (unrecoverable)

exceeding them

Table 5 Scores provided by TE and WW for how well each option met their project aims and business objectives criteria (for codes see text).

		Options			
	Criteria	Do nothing	Modify existing STW	Restricted ICW	Catchment wide ICW
TE	Meeting project aim	VP	A	G	G/VG
	Meeting business objectives	VP	A	G	G/VG
WW	Meeting project aim	VP	G	VG	A
	Meeting Business objectives	VP	A	VG	VG

Table 6 Scores provided by the TEAM (for codes see Table 3).

		Options			
Criteria		Do nothing	Modify existing STW	Restricted ICW	Catchment wide ICW
Ecosystem benefits	Cultural services	VP	A/G	G	VG
	Provisioning services	VP	A	G	VG
	Regulating services	VP	A	G	VG,
	Supporting services	VP	P/A	G	VG
Project costs (£)	Design and implementation costs	0	20% of Construction costs	200k, 300k, 750k	400k, 600k, 1.5m
	Construction costs	0	1.5m, 2m, 2.5m	0.4m, 0.5m, 0.8m	1m, 1.5m, 2m
	Operational costs (annual)	0	50k 60k 70k	7k, 10k, 13k	50k, 150k, 250k
Regulatory risks	Planning consent	VG	G	A	VP
	Environmental impact assessment	VG	VG	A/P	P
	Need for permissions and licences	VG	G	P	VP
	Meeting permissions and licences	VP	A	G	A
Technical effectiveness	Meeting primary project aim	VP	P	G	VG
	Meeting secondary project aims	VP	VP	G	VG

Fig. 1. The Tortworth Brook catchment (in grey). Key: ● STWs; ★ Septic tanks (provided by Tortworth Estate); dotted line Tortworth Brook catchment boundary; broken line Bristol Avon and North Somerset Streams River Basin District.

Fig. 2. Project steps. Linear processes: solid arrows. Feedback steps: dashed arrows. (WW=Wessex Water, TE= Tortworth Estates, TEAM = knowledge provider/intermediary)

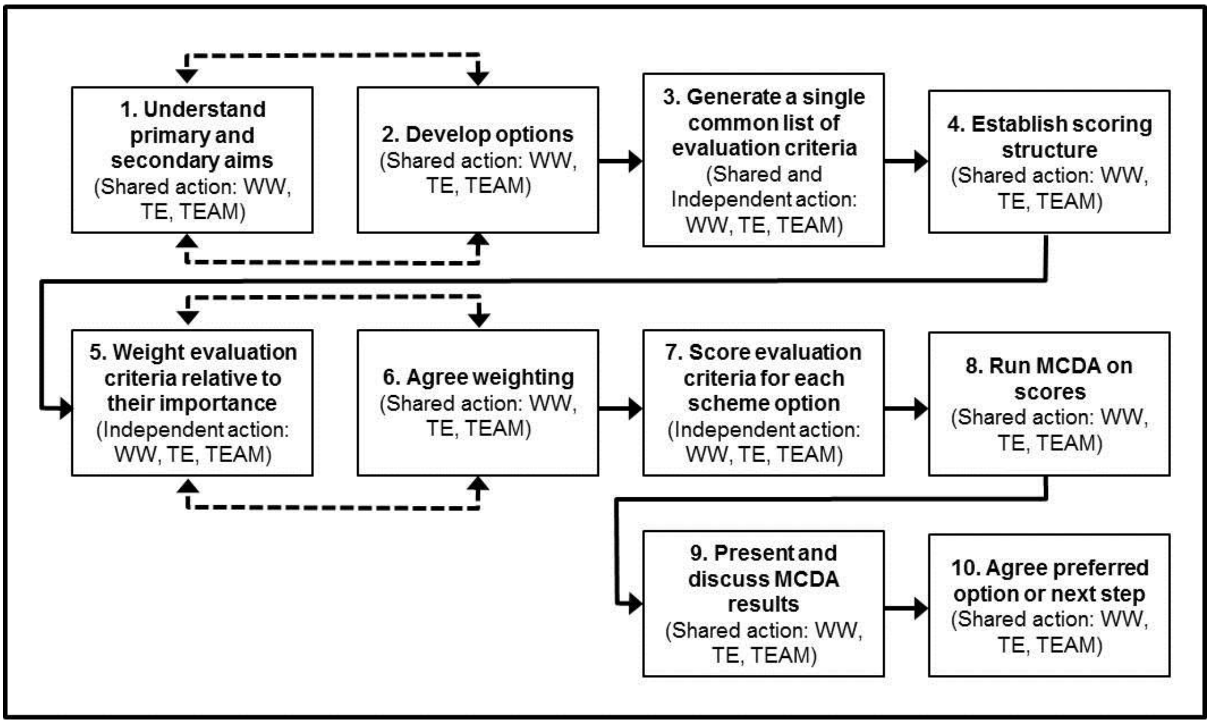

Fig. 3. Structure and weighting (percentages) used for the MCDA model showing weight placed on the criteria used to model the choice of best scheme option.

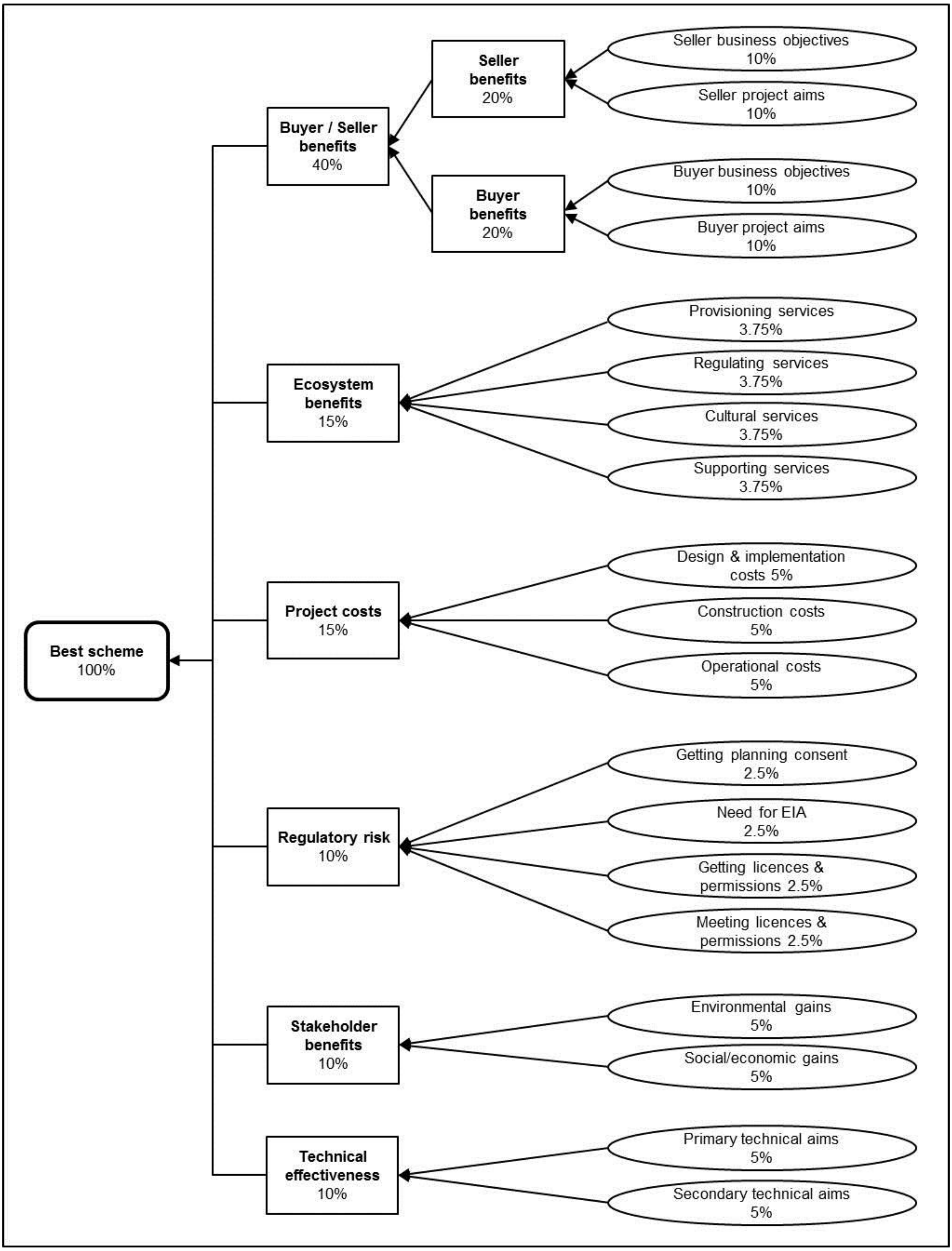

Fig. 4. MCDA utility chart. Error bars indicate the uncertainty over costs. The higher the utility score the better an option meets the project objectives

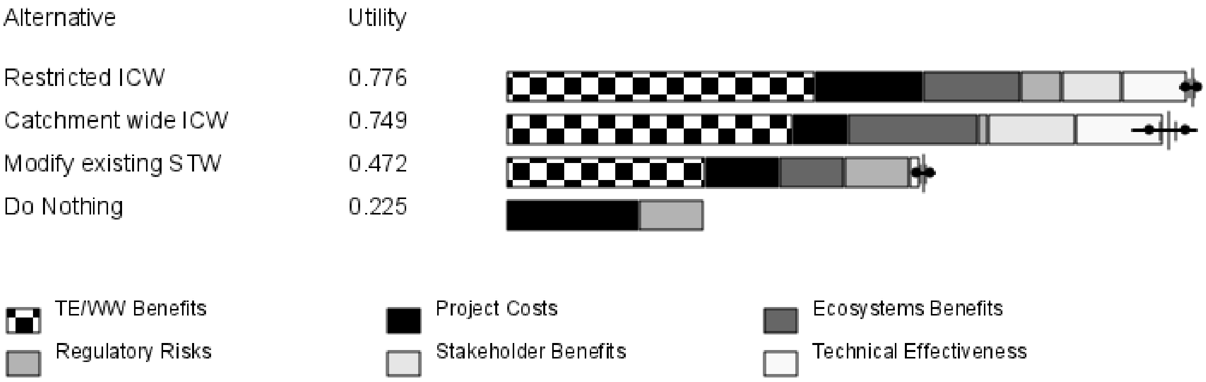

Fig. 5. Sensitivity analysis of project costs on the overall best option. The vertical line illustrates the initial 15% weighting.

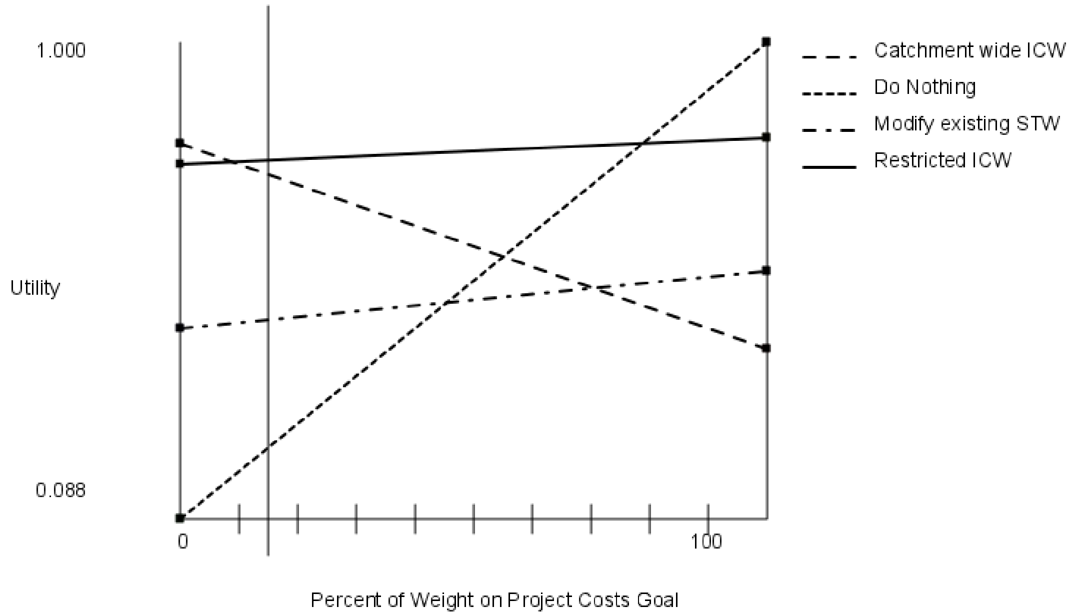

Fig. 6. Comparison of cumulative costs against cumulative utility.

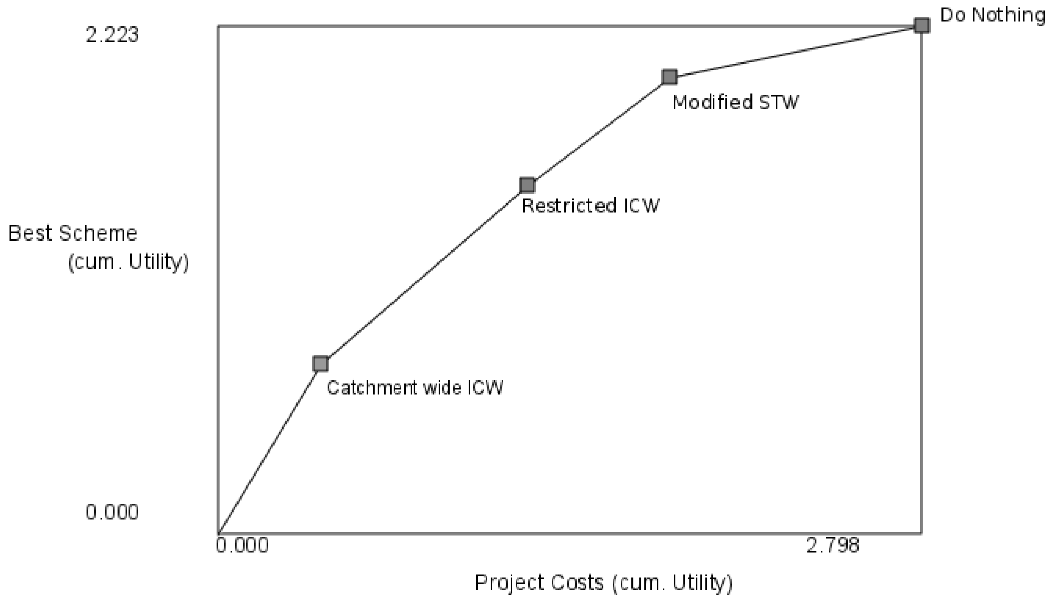

Fig. 7. MCDA utility chart for categories of ecosystem services.