Benefits and challenges of incorporating spatially-explicit quantitative modelling and action prioritisation in Melbourne Water's Healthy Waterways Strategy

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Key Points

- Spatially-explicit quantitative modelling of aquatic macroinvertebrates, fish and platypus enabled predictions of current and future habitat suitability across the entire network of streams within greater Melbourne, including the impacts of climate change and urban growth
- Habitat suitability models also enabled quantitative predictions of the benefits of key management actions (riparian vegetation, stormwater harvesting and treatment, removal of fish barriers) both in isolation and in combination
- The combined benefits of management actions for all modelled taxa, along with associated costs, enabled prioritization of actions using Zonation based on cost effectiveness
- Outputs from these models informed a collaborative process with stakeholders to ultimately identify priority actions and 50-year targets for Melbourne Water's Healthy Waterways Strategy

Abstract

This paper describes our experiences in applying spatially explicit, quantitative methods to Melbourne Water's Healthy Waterway Strategy for the greater Melbourne region, Victoria, Australia, and how they informed stakeholder deliberations on the identification of actions and targets for ecological values in the strategy's participatory framework. We developed habitat suitability models for 52 macroinvertebrate families, 13 native fish species, and platypus, and applied quantitative methods (Zonation) to prioritise cost-effective management actions throughout the >8,000km stream network to optimise the conservation and restoration of instream animal diversity. Using examples, we elaborate on the benefits of this approach (that were not possible with previous approaches to prioritizing investment) including:

- better use of available biological data, with discrete, point-location data used to generate spatially continuous estimates of instream biodiversity at unsurveyed sites
- improved granularity in mapping of biodiversity patterns, alerting stakeholders to values, constraints and opportunities they might have been unaware of
- ability to integrate and model strategic considerations such as different aspects of climate change impacts (warming, drying), land use change and their interactive effects
- ability to quantify the expected difference made by management actions, and to account for costs so that action planning can be based on cost-effectiveness
- ability to spatially prioritise management actions, and to interrogate and critically debate alternative actions at specific locations for planning and target-setting
- improved ability to map, summarise and communicate decision-relevant data to different audiences
- repeatable analyses that can be scrutinised, error-checked, critiqued and built upon

Finally, we discuss some of the nuances of communicating the workings of quantitative tools and their outputs for use in participatory settings, such as collaborative workshops for developing the strategy.

Keywords

Habitat suitability modelling, Zonation, macroinvertebrates, fish, platypus

Introduction

Melbourne Water is responsible for looking after the city of Melbourne's water supply catchments, treatment and supply of drinking water, removing and treating most of Melbourne's sewage, providing recycled water for non-drinking purposes. In doing so, Melbourne Water manages more than 8,400 km of rivers, creeks and major drainage systems (catchment areas of 60+ ha) throughout the Port Phillip and Westernport region, Victoria, Australia. While many of these rivers and creeks are affected by catchment urbanization, most flow through forested or rural areas and support diverse aquatic ecosystems (MW 2013a). Melbourne Water's vision is 'Enhancing Life and Liveability' by working collaboratively with other organisations and the community to provide safe, secure and reliable water services, desirable urban spaces and healthy waterways and bays. This vision is to be achieved in a context of rapid population growth, climate change, and community expectations for affordable services.

Melbourne Water invests heavily in waterway management, protection and restoration. Given the increasing pressures on aquatic ecosystems throughout the region and already substantial investment, it is essential that waterway management decision-making is underpinned by best available science. This includes knowledge of the current ecological health of rivers and creeks, key threats to those systems, likely future condition, and an understanding of the types of management activities most likely to protect or improve aquatic ecosystems in the future. In managing waterways, Melbourne Water seeks to align activities with eight key principles outlined in the Victorian Waterway Management Strategy (VWMS, DEPI 2013). Included among these principles is the need for an integrated catchment management approach, investment in activities that provide the most efficient and effective long-term improvements in waterway condition, evidence based decision making, and adoption of an adaptive management approach.

Here we describe a new approach to guide waterway management that is being developed to inform Melbourne Water's new Healthy Waterways Strategy (HWS) 2018-2028 that we believe closely aligns with the above principles. Central to this approach is the development and application of spatially-explicit quantitative ecological modelling of instream values (currently aquatic macroinvertebrates, fish and platypus). These models capture both the current status of environmental values from the reach to catchment-scale, but also provide predictions of how those values may change under projected future scenarios of urban growth and climate change, and identification of reaches where certain actions to protect and improve waterway health will be most cost-effective.

Melbourne Water's New Healthy Waterways Strategy

The new HWS intends to provide a single planning document for all waterway stakeholders and the community to work in partnership to maintain or improve the environmental, social, cultural and economic condition of rivers, estuaries and wetlands in the Port Phillip and Westernport region. The HWS is founded on a program logic that links high-level visions and goals for each of the major catchments within the region (Werribee, Maribyrnong, Yarra, Dandenong, Westernport) to economic, cultural, environmental and social values of the waterways. This logic extends to the environmental condition of the waterways (e.g. stream flows, water quality, physical form) that are managed to support key values and ultimately achieve the goals and vision in the long-term. This is reflected in the setting of 50-year targets for waterway values and condition, and 'Performance Objectives' that guide action over the first 10 years. Collectively, stakeholders developed vision and goals for each major catchment, identified key waterway health issues and management opportunities, and tested proposed priority actions against the investment program logic.

While principles for identifying priority areas and actions were clearly defined in the previous HWS, the process of identifying them was qualitative and reliant on expert opinion, and conceptual rather than derived using quantitative models. As such, some aspects of decision making in the previous HWS were not transparent or easily repeatable. Long-term targets, in particular, were indicative and largely served as a communication tool. As a consequence, there was little quantification of the relationship between management actions and associated outcomes for conditions or values to develop strategy targets. Also, with a separate stormwater strategy, the link between focus areas in the Stormwater Strategy (MW 2013b) and priority areas for key environmental values in the previous HWS (MW 2013a) was not clear.

A significant advance since the development of the last HWS (this is now the 3rd) has been the development of quantitative ecological models for instream environmental values (platypus, macroinvertebrates and native fish; e.g. see Walsh and Webb, 2016). The use of quantitative ecological models for instream environmental values in the new HWS has involved researchers more directly (particularly through the Melbourne Waterways Research-Practice Partnership (Coleman et al. 2016)), with the instigation of a Science Panel to guide scientific input into the strategy. The development and application of these models are part of identifying priority actions and setting quantitative targets for the HWS 2018-2028 is described below.

Quantitative predictions of stream biodiversity response to the landscape, climate, and human interventions

The ~8,400 kms of streams throughout the region are represented by ~8,200 hydrologically-delineated subcatchments. We used habitat suitability models (HSMs) to describe habitat suitability for 52 macroinvertebrate families, 13 native fish species, and platypus, so that we could visualise and quantify instream biodiversity value at the subcatchment scale (median reach length ~0.5 km), which provides information at a resolution that is directly useful for management. HSMs analyse relationships between the environmental characteristics at sites where a species is detected (and at sites where a species is *not* detected) to develop a quantitative model that predicts the likelihood of occurrence (technically detection) at a site as a function of habitat characteristics. The essential components and stages in the modeling process are shown in Figure 1. Biological presence-absence survey data were collated from multiple sources (primarily unpublished data collected by Melbourne Water, but also by Victorian EPA and the Department of Land, Water, Environment and Planning) for the period from 1990 to 2009 (inclusive) across all taxa. Sampling occurred extensively throughout the region, with no obvious bias in sampling coverage (though small and/or intermittent streams are, as to be expected, not as well-sampled as larger, perennial systems).

For each taxon of interest (i.e. macroinvertebrate families, fish species and platypus), we used a carefully selected candidate set of 10-12 environmental characteristics ('environmental predictors' in Fig. 1) to describe instream habitat suitability. Specifically, the chosen predictors were a balance of three considerations: i) theoretically-informed ecological relevance (*sensu* Austin 2002); ii) availability of spatial data across the region (because ultimately, we required predictions across the region); and the amenability of a predictor to management intervention (so that HSMs reflect biological responses to different environmental and/or management scenarios). Examples of predictors that are expected to be broadly influential in shaping the habitat suitability of instream taxa (see Figure 1) include mean annual air temperature, mean annual runoff depth (an indicator of stream perenniality and variability), attenuated imperviousness (a measure of the amount of impervious cover that is directly connected to a stream reach, and reflects stormwater impact; Walsh and Kunapo, 2009) and attenuated forest cover (a measure of the amount of riparian forest cover; Walsh and Webb, 2014).

We chose Boosted Regression Trees as our modelling technique because it: a) performs well in direct comparison with other modelling techniques (Elith *et al*. 2006); b) can fit non-linear relationships, and naturally model interactions (De'ath 2007; Elith *et al*. 2008; Chee & Elith 2012); and c) it can accommodate outliers and missing data (Breiman *et al*. 1984; Hastie *et al*. 2009). We evaluated models both quantitatively (using metrics such as area under the receiver operating characteristics curve, AUC, and percentage deviance explained calculated from 'held-out' data in the cross-validation process) and qualitatively, by assessing the fitted environmental response curves against ecological expectations ('understand' in Fig. 1), and by comparing mapped HSM predictions against observed data (not used in model-fitting) and expert knowledge of a species' distribution in the region.

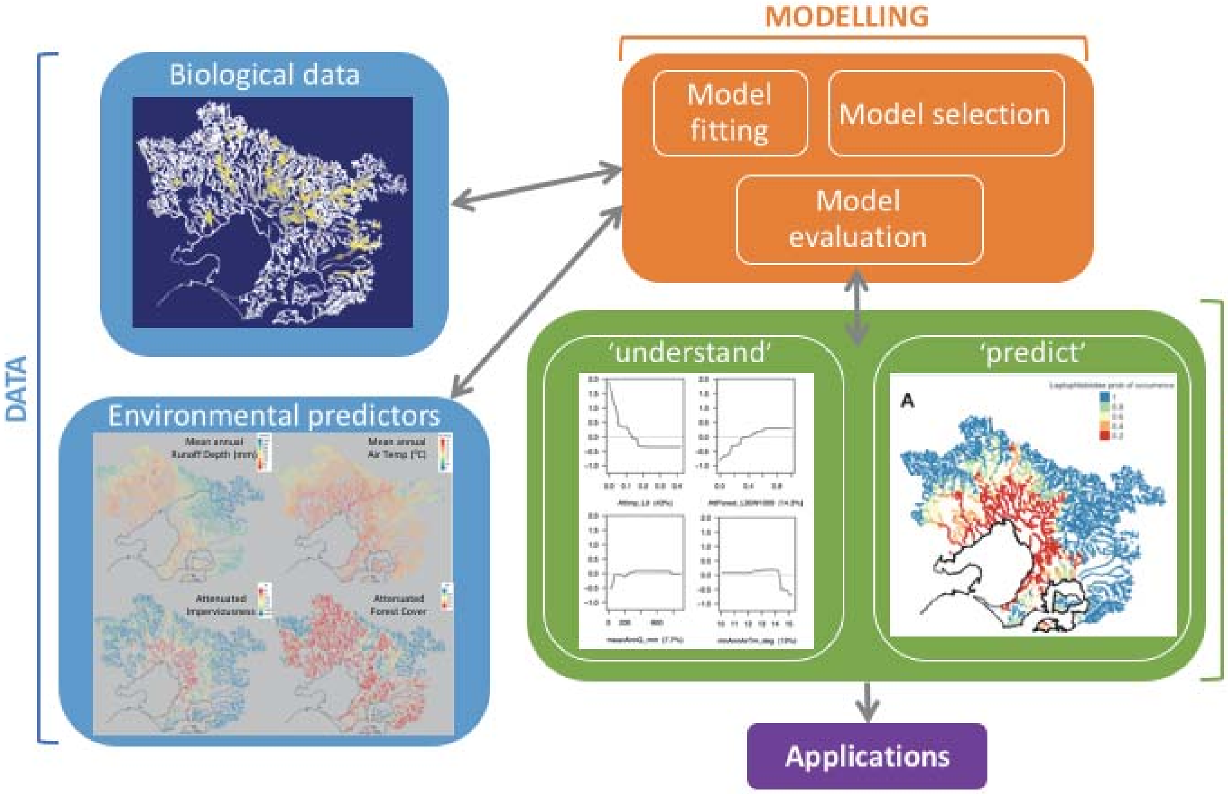

Figure 1. Key components and stages in the habitat suitability modelling process (after Lahoz-Monfort, Guillera-Arroita & Elith, personal communication)

In the HWS development process, we used our HSMs to generate predictions (and maps) of biodiversity response (i.e. for the 66 taxa listed previously) to show stakeholders the: a) spatial distribution of instream biodiversity under current conditions; b) expected changes in instream biodiversity under a business-as-usual future (BAUF; i.e. warmer, drier and stormwater from new urban developments is untreated); and c) expected benefit to instream biodiversity from applying different management actions. Finally, we used the HSMs to construct inputs for Zonation (Moilanen *et al*. 2008, 2011), a quantitative software tool used to prioritise cost-effective management actions across the entire stream network. We illustrate these applications below.

Example of the Process

For the purposes of long-term strategic planning, we used a 50-year horizon and focused on important widespread threats in the form of warming, drying and increased impervious cover (due to urbanisation) for our BAUF scenario. Broadly consistent with DELWP (2016) and within the experience of our models, warming was represented by a 1.5°C increase in mean annual temperature and drying was represented by a reduction in mean annual runoff depth (equivalent to a 25% reduction in outflow from the Yarra River mouth). The extent of future impervious land cover was estimated using planning zone data.

To engage stakeholders in understanding and visualising waterway values under current and BAUF, we predicted and mapped these scenarios for each of the five major catchments in the region (see examples in Fig. 2A and 2B respectively). In workshops, stakeholders deliberated over these predictions as they developed ideas for mitigating actions. In parallel, we undertook a quantitative spatial prioritization analysis of a suite of ‘candidate actions’ that reflect core waterway management activities. The aim was to identify *what* action to deploy *where* in order to optimise instream biodiversity benefit.

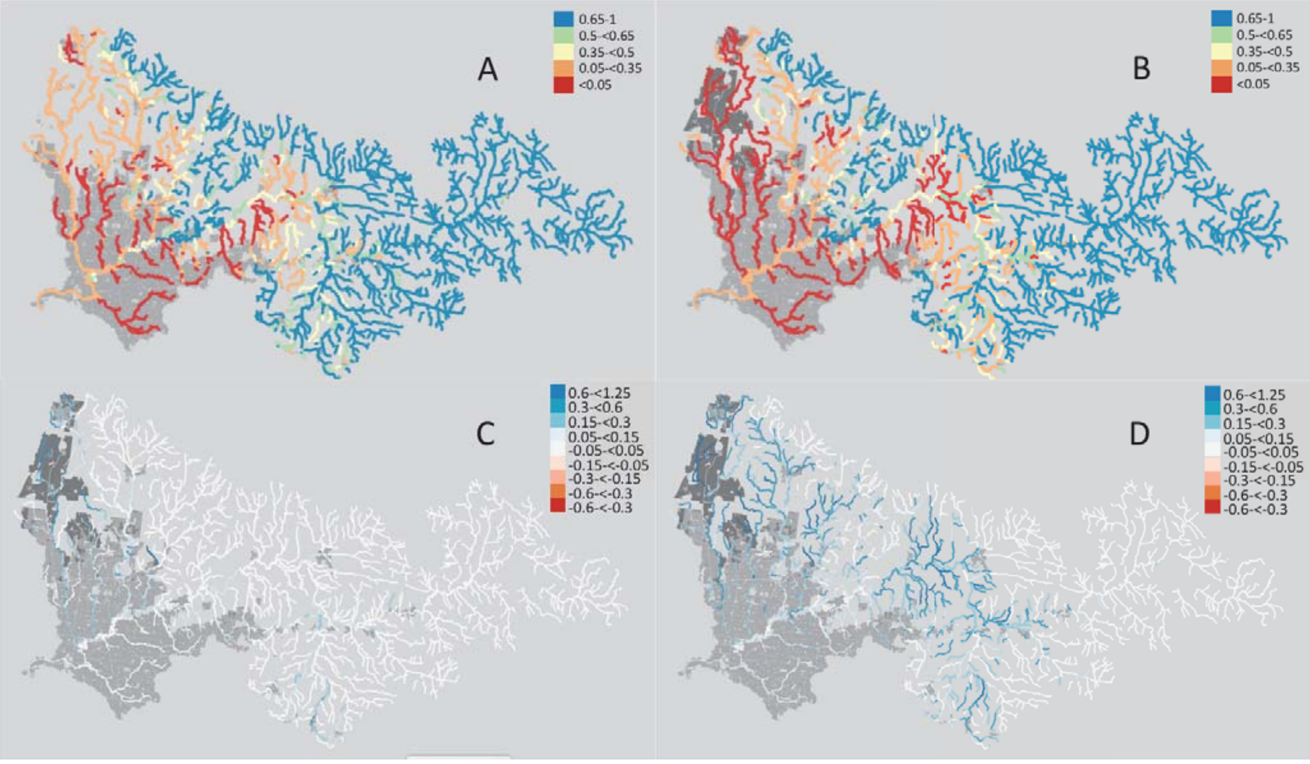

Figure 2. These maps use an integrated measure of macroinvertebrate assemblage composition (LUMaR: Walsh & Webb, 2013) to illustrate instream condition across the Yarra catchment in the region. Mid-grey shading = existing impervious cover and dark grey = future impervious cover. (A) and (B) show the distribution of LUMaR scores under current and business-as-usual future (BAUF) conditions, respectively. Values above 0.5 indicate good stream condition. (C) and (D) are 'difference maps' that summarise the difference made by actions relative to a BAUF, where whitish shades indicate little difference made by the action, and blue and red shades indicate positive and negative changes, respectively. (C) shows the difference made if stormwater runoff from future impervious cover (dark grey areas) was appropriately managed. (D) shows the difference made if the riparian zones of all streams were revegetated to a 20 m width either side as well as appropriate management of stormwater from future impervious cover.

Our five candidate actions were: riparian revegetation to 20 m width on each side (hereafter 'RV20'), manage all stormwater runoff from *future* development only (SW2), manage all stormwater runoff from *future* and *existing* development (SW1), and actions combining riparian revegetation and the two stormwater actions, yielding RV20_SW2 and RV20_SW1. The benefits to native fish of removing barriers along the mainstem of waterways (excluding major dams and weirs) was also modelled independently to select priority sites for fishway construction based on cumulative positive differences in habitat suitability (FW2).

To show stakeholders what our models predict under different management actions, a series of mapped predictions based on interventions such as managing stormwater runoff from future impervious areas (Fig. 2C), and combining stormwater management with revegetation of the riparian zone to a 20-m width (Fig 2D), were presented. Broadly speaking, drying and impervious expansion are predicted to have particularly strong detrimental impacts on instream biodiversity, and management actions implemented in combination are expected to generate greater benefits than any action used independently (Fig. 2D versus 2C). Reaches that were already fully vegetated and unaffected by impervious cover (now and into the future) were assigned a *status quo* (SQ) 'action'. The benefit of an action was estimated individually for each taxon as the change in habitat suitability relative to the BAUF scenario. An outline of the key steps of the Zonation prioritization analysis and 10- and 50-year target setting is as follows:

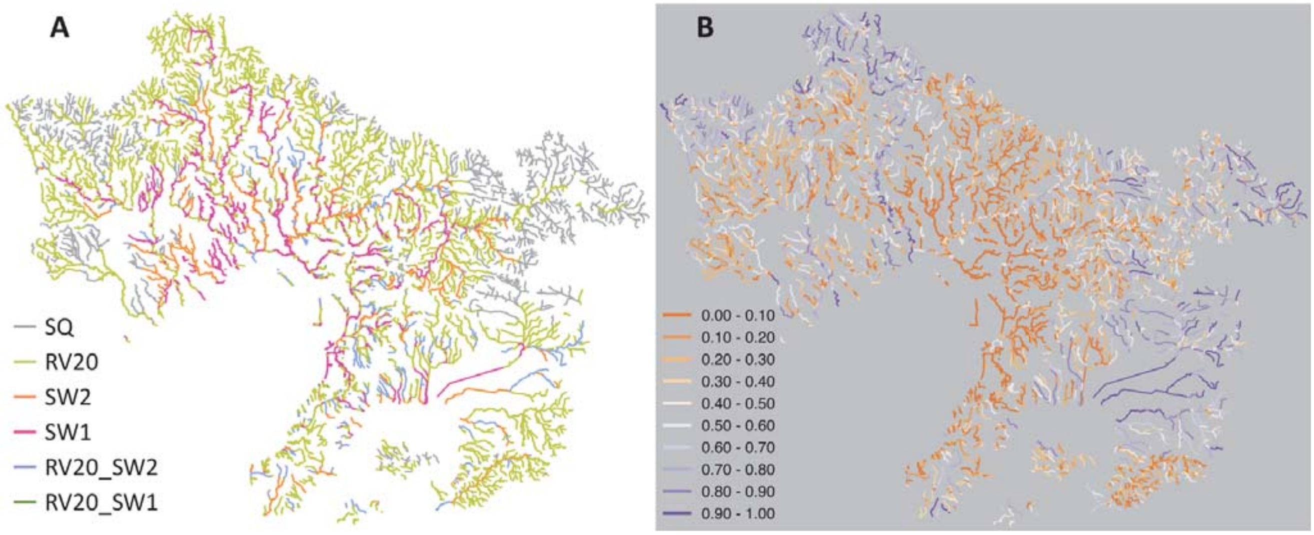

Figure 3. (A) the most cost-effective action identified for each of the 8,200+ subcatchments. (B) continuous ranking of spatial priorities (scaled from lowest rank 0 to highest rank 1) produced by the Zonation analysis in which the most cost-effective action was 'applied' in each subcatchment.

1. Develop unit-based costs for each of the candidate actions (i.e. RV20, SW2, SW1, RV20_SW2 and RV20_SW1), including spatial variation in the costs for each action (e.g. higher revegetation costs in areas with rocky and steep terrain, or where rabbit control and supplementary watering is needed)
2. For each of the 8,200+ subcatchments in the region, we computed the cost associated with each candidate action—this varies depending on individual subcatchment context such as amount of extant riparian vegetation, presence of woody weeds, and total amount of future impervious cover in the upstream contributing catchment. Using our HSMs, we estimated the biodiversity benefit associated with applying each action
3. Using the data from step 2, we identified the most cost-effective (benefit/cost) action at each subcatchment (Fig 3A)
4. Using our HSMs, we 'applied' the most cost-effective action at each subcatchment, generated habitat suitability predictions for all taxa and used these as inputs to Zonation. Other inputs to Zonation included species weightings (e.g. upweighting species that are threatened or in serious decline in the region, e.g. platypus), and species-specific connectivity requirements (e.g. migratory native fish)
5. The Zonation analysis produced a ranking of spatial priorities across the region (Fig 3B).
6. Together, steps 4 and 5 produced a suggested solution for *what* action (Fig. 3A) to deploy *where* (Fig 3B) in order to optimise instream biodiversity benefit
7. The predicted benefits of the selected suite of priority actions within the 10- and 50-year program were aggregated to 69 Management Units for presentation and reporting

We stress that this analysis did *not* dictate HWS actions and targets. Top ranking subcatchments were first reviewed and 'sense-checked', both within Melbourne Water and externally with stakeholders. The Zonation priorities were then compared against the actions proposed by stakeholders to determine the final suite of priority actions, i.e. several actions were either up-weighted or down-weighted in priority based on stakeholder expertise and local knowledge. The resultant collection of priority subcatchments and associated actions then formed the basis of preliminary 50-year strategy targets (Melbourne Water, 2018).

Benefits

The process provided a repeatable and transparent process for making predictions, and for prioritising actions at reaches that can be scrutinized, error-checked and built upon as more data are collected. The maps of predicted changes in habitat suitability under potential future scenarios and the maps of ranked priority actions in reaches across the region were powerful communication tools that were quickly embraced by stakeholders. The benefits of the maps included: spatially continuous estimates of in-stream biodiversity at unsurveyed sites; improved granularity of biodiversity mapping that identified constraints and opportunities that might have otherwise been missed; and engaging visual aids that can be interrogated to inform debate on alternative actions at specific locations for planning and target setting. The ability to quantitatively predict biodiversity changes under scenarios that combine potential climate change and alternative management actions, and to account for costs and cost-effectiveness, is incredibly powerful for designing presentations for different audiences, and for efficiently communicating complex information to support informed deliberations and decision-making.

Challenges

The complexity of the modelling can lead to perceptions of a 'black box'. Overcoming this required effort to build confidence and gain support among internal and external stakeholders, which was a significant challenge in the face of rigid timelines. Despite initial concerns, and some challenges in communicating the modelling approach to diverse audiences of stakeholders, the co-design workshops provided an opportunity to broadly explain the logic of the modelling process, which was well received by stakeholders.

Development of the habitat suitability models and Zonation analyses was a resource-intensive process. The models were developed over more than four years of research and development, and once the strategy development process began, there was a need for intensive collaboration between strategy staff and researchers. The strategy team ran at least three co-design workshops for each of five sub-regions, requiring a significant time commitment of not only strategy staff, but of the researchers who developed the models. For each workshop, sets of predictions needed to be explained and presented to permit their inclusion in deliberations. Finally, gaining reliable cost data was an unexpected challenge and reinforced the need for a more structured approach to the collection and management of information about the costs associated with future waterway improvement projects.

Conclusions

While a departure from past approaches to strategy development, we believe that this quantitative modelling approach has helped give effect to central principles in the VWMS that encourage partnerships and community involvement, evidence-based decision making, identification of integrated catchment management opportunities, and identification of cost effective management responses. Importantly, the approach is transparent and repeatable, and produces testable predictions of response that can be linked to the Monitoring, Evaluation, Reporting and Improvement (MERI) framework. This will help Melbourne Water track progress in strategy implementation and outcomes, demonstrate accountability and learn, therefore enabling adaptive management and continuous improvement.

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