# Predicting stream macroinvertebrate assemblage composition as a function of land use, physiography and climate:

## *a guide for strategic planning for river and water management in the Melbourne Water management region.*

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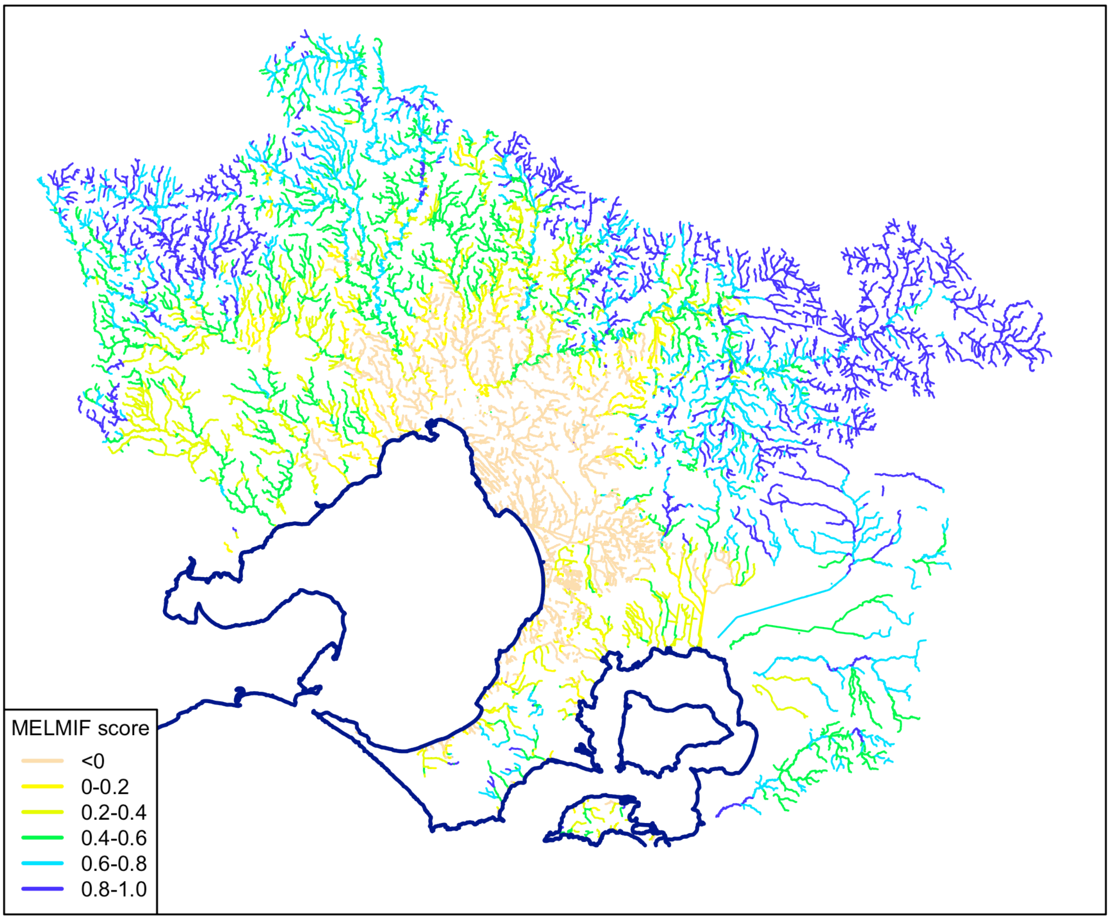


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**APPENDIX 1. AN ATLAS OF MACROINVERTEBRATE FAMILIES OF THE MELBOURNE REGION (393 pp.) is a separate volume.**

*The Cover image shows the predicted LUMaR scores for all reaches of the region under 2006 land cover and use. LUMaR is a new index of stream condition for the Melbourne region, derived in this report. See Chapter 6 for more information.*

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## Summary

The composition of macroinvertebrate assemblages is well established as a sensitive indicator of stream condition; because of their ubiquity, their diversity, their wide range of tolerances to natural and human-induced environmental variation, and their fundamental importance to the ecological functioning of stream ecosystems. The large, long-term record of macroinvertebrate collections from streams of the Melbourne region provides an invaluable resource with which to develop quantitative predictive models of stream condition to guide strategic planning for river and water management of the region.

In this study, we used the macroinvertebrate assemblage data of the Melbourne Water management region, collected from 1992 to 2009, to develop predictive models of stream ecological condition as a function of catchment land use, physiographic and climatic factors, and their interactions. We took care to collate and calculate predictor variables that not only indicate important environmental variables that are likely to differentially affect the occurrence of different macroinvertebrate species, but also indicate environmental changes that are made as a result of management activities. The resulting models provide direct predictions of the response of macroinvertebrate assemblages to management actions, and under potentially different future climatic conditions.

We ensured that land-use measures were spatially optimized to match the most plausible mechanistic pathways of influence. Urban impervious surfaces were weighted by distance to the nearest downslope stormwater drain, indicating the probability that each surface was connected to the stormwater drainage system. This measure of urban stormwater impacts (termed attenuated imperviousness, AI) was a substantially stronger predictor of macroinvertebrate assemblage response than total impervious coverage, which is more commonly used as a predictor of human impacts. Forest cover was weighted by both overland distance to the nearest stream, and in-stream distance to a site (and termed attenuated forest cover, AF): the influence of forest cover declined exponentially with distance from the site, so that forest cover 35 m up the bank from the stream was half as influential as forest cover on the bankside, and bankside vegetation 1 km upstream of a site was half as influential as bankside forest cover at the site. This preliminary analysis suggests that riparian corridors of 40-100 m width and 1-2 km upstream are required to protect stream ecosystems.

Boosted-regression-tree models, that allow for non-linear relationships and interactions between predictor variables predicted macroinvertebrate assemblage composition very well. A model for SIGNAL score (an index of macroinvertebrate sensitivity to disturbance) predicted observed SIGNAL scores in a set of independent test samples well (correlation coefficient $r$ = 0.85). The combined prediction of family richness (for 60 families with sufficient prevalence in the dataset to permit models of their distributions) was not as strong ($r$ = 0.81). However, the prediction of sensitive families (those that responded negatively to either AI or AF) was stronger ($r$ = 0.87). The predictive power of the combined models is thus strong.

We therefore used the predictions of assemblage composition in the absence of human impacts (by setting AI to zero and AF to 1) as the expected assemblage against which observed assemblages can be compared to assess degree of impairment. We derived a new index of stream condition, LUMaR, that combines the observed:expected ratio approach of bioassessment indices such as AUSRIVAS, with the weighting of taxa by their sensitivity to human impacts used in biotic indices such as SIGNAL. LUMaR is as strong a correlate with human impacts across the region as SIGNAL score (and both are much stronger than AUSRIVAS), but has the advantage of being more sensitive to low-to-moderate levels of impairment, and having an invariant value in the absence of human impacts across the region (unimpaired reaches in low-discharge, western streams have lower SIGNAL scores than unimpaired reaches of high-discharge, eastern streams, while unimpaired LUMaR scores = 1 in all reaches).

Riparian forest and urban stormwater impacts had similar degrees of influence on macroinvertebrate assemblage composition, but the influence of riparian forest on macroinvertebrate assemblages was strongest in streams with little urban stormwater impact.

Most invertebrate families show a decline in probability of occurrence at very low levels of AI and many are absent from streams with more than ~3% AI, suggesting that drainage of impervious surfaces is a stressor that is not peculiar to substantially urban areas.

Under current land-use and climatic conditions, local-scale management actions such as the construction of rock riffles, or revegetation of 20-to-40-m-wide riparian forests were predicted to have minor positive effects on macroinvertebrate assemblages in some rural streams: 3–6 additional sensitive families per sample were predicted, but little change in LUMaR score. The effects of such actions in streams of the metropolitan area or downstream of regional towns were predicted to be small or zero.

In contrast, widespread change of urban stormwater management practices aimed at mimicking pre-urban flow and water quality regimes are predicted to have a strong influence on macroinvertebrate diversity, with >5 additional sensitive families predicted in most streams currently affected by urban stormwater, and 11-15 families in some areas, such as streams draining the Dandenong Ranges.

Warmer and drier conditions are predicted to reduce the number of sensitive families per sample by >8 in many rural streams, particularly upland forested streams, or more if future climate is very dry. The planned urban expansion and infill of Melbourne is predicted to have a much stronger negative influence than climate change on streams draining the western, northern and south-eastern growth corridors, with >11 fewer sensitive families per sample, and reductions in LUMaR scores of 1–1.35, predicted if they are developed with current stormwater management practices.

Our models predict that the effects of moderate climate change could be averted, and the effects of more severe climate change mitigated, by revegetation of riparian forests. The negative effects of urban expansion could be averted, and those of existing urban land could be mitigated, by changing urban stormwater practices. The benefits of these changes could be strengthened by riparian afforestation in urban areas in which urban stormwater impacts have been effectively mitigated.

The development of our models has resulted in a new index of stream condition that allows better detection of low-moderate impairment and more consistent estimation of impairment across the region than the best existing macroinvertebrate index for the region. Our models also permit the direct prediction of gain or loss of sensitive invertebrate families as a result of environmental change or management actions, which provides a more intuitive measure of biotic change than the more commonly used index. However, our analyses of the limited species- and genus-level data for the region show that family-level models underestimate both the sensitivity of macroinvertebrate assemblages to landscape-scale human impacts, and the magnitude of the resulting loss of biodiversity. There is an order of magnitude more macroinvertebrate species in Melbourne’s streams than there are families.

### *A guide to this report*

This report is structured into seven chapters.

Following an introductory chapter, the biological and spatial data used in the study, and the steps we took to refine and collate them for use in statistical analyses are described in Chapter 2. An initial objective of this study was to identify differential impacts of different agricultural practices across the region. This initial analysis identified shortcomings in the classification of agricultural land-uses across the region, and the rarity and spatially clumped nature of many agricultural classes, limiting the potential for discrimination of effects among classes. We thus elected to first concentrate on a spatially explicit analysis of forest cover, as the converse of other land uses.

Two important data sets have been created as a result of this data collation: a) a corrected land-use map, with particular attention to tree cover has been produced as a result of this data collation; and b) this land-use layer was converted to a 10m-x-10-m-resolution raster layer that has permitted attribution of flow-distances to each grid-cell of each land use classification.

Chapter 3 aims to determine the optimal spatial weighting of forest cover, and the optimal temporal weighting of antecedent flow conditions, as predictors of macroinvertebrate assemblage composition. This allows a preliminary assessment of the optimal arrangement of forest cover, particularly with regard to riparian buffers, for the protection of stream ecosystems. SIGNAL score was used as the dependent variable in linear mixed effect models (which account for the potential dependence among multiple samples taken from groups of close neighbouring sites), and the plausibility of models with differently weighted measures of forest cover were assessed using the Akaike Information Criterion. This process was also used to test if AI was a more plausible predictor than total imperviousness across the Melbourne region. The models also included predictor variables indicating physiographic and climatic factors.

AI (impervious area weighted exponentially to the nearest downslope stormwater drain with a half-decay distance of 9.4 m) was a consistently better predictor of SIGNAL score than was total imperviousness. The most plausible weighting of forest cover was exponential weighting with a half-decay distance of 35 m overland and 1.0 km in-stream. The most plausible measure of antecedent flow was the last 48 months of discharge, linearly weighted so that the most recent month had a full weighting and months >48 months in the past had zero weighting.

Chapter 4 aims to develop a BRT model of SIGNAL score using the optimal variables determined in Chapter 3. The BRT model was constructed to permit the assessment of non-linear relationships and interactions among predictor variables. The two human land-use variables in the model were AI and attenuated forest cover (AF) (each using the optimal weighting function from Chapter 3). We also assessed the degree to which individual agricultural land-use classes explained residual variation unexplained by the BRT model.

The model predicted SIGNAL score very well ($r$ = 0.85 for an independent test dataset), with mean annual discharge, AI, AF, and antecedent flow being the most influential predictor variables. Other agricultural land-use classes did not explain residual variation in the model well.

In Chapter 5 we synthesise and summarise BRT models of occurrence for each of 60 families (described in detail in Appendix 1). We classified the families into 4 groups: 3 "sensitive" groups that were variably negatively associated by one or both of AI or AF, and a "weedy" group that were positively associated with AI and AF. We assessed if combining the predictions of the models for all families and for each class allows a good prediction of response of family richness and assemblage composition. The combined models predicted the richness of sensitive families more strongly ($r$ = 0.87) than SIGNAL was predicted.

In chapter 6, we use the limited species- and genus-level records in the macroinvertebrate data to assess the adequacy of family-level models for portraying assemblage response to human impacts and resulting biodiversity loss. While family-level models are effective at detecting ecological change to human impacts, family-level indices underestimate the sensitivity of most species, and the scale of biodiversity loss resulting from human impacts. We use the model predictions to derive a new index of stream condition, LUMaR, which provides improved detection of low-to-moderate levels of impairment and a more consistent estimation of impairment across the region than SIGNAL score.

Finally in Chapter 7, we use these models and LUMaR score to present predictions of macroinvertebrate assemblage response to a range of management actions, future land-use change and potential future climate change. We use maps of the region's streams to portray predicted losses or gains of sensitive families, and changes in LUMaR score resulting from three types of management action: in-channel riffle restoration, riparian afforestation (of three buffer widths), and removal of urban stormwater impacts through flow-regime management. We further explore the predicted interactions of these management actions with expansion and infill of urban land use in the region, and combinations of potentially drier and warmer future climates.

Urban expansion is the most severe threat to streams draining the western, northern and south-eastern growth boundaries, with substantial biodiversity loss predicted if current urban stormwater management practices are used in their development. Warmer and drier conditions are predicted to reduce biodiversity in rural streams, particularly upland streams. The effects of urban development could be averted and reversed by new approaches to stormwater management, and the effects of climate change mitigated through widespread riparian afforestation.

## Abbreviations

| | |
|---|---|
| AI: | Attenuated imperviousness |
| $AIC_c$: | Akaike Information Criterion adjusted for small sample size (Burnham & Anderson, 2002) |
| AF: | Attenuated forest cover |
| BRT: | Boosted regression trees |
| catign: | Percentage of catchment area underlain by igneous rock, derived from the BOM geofabric (Bureau of Meteorology, 2011) |
| CV: | Cross-validation |
| DEM: | Digital elevation model |
| meanQ: | mean annual discharge depth, derived from the BOM geofabric (Bureau of Meteorology, 2011) |
| LUMaR: | a new biotic index (Land Use Macroinvertebrate Response index) based on the presence of macroinvertebrate families in the Melbourne region, developed in this report |
| nriff: | number of riffle samples (a predictor variable in models using sample pairs) |
| nspring: | number of spring samples (a predictor variable in models using sample pairs) |
| SIGNAL: | a biotic index based on the presence of macroinvertebrate families (Chessman, 1995) |

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This document contains only the table of contents, summary, and references section of the full report. If you would like a copy of the full report and its appendix, please email Chris Walsh cwalsh@unimelb.edu.au.

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