Melbourne Water, Department of Environment and Primary Industries and the University of Melbourne

Improving Our Understanding of Water Sensitive Farm Design Pollution Treatment Systems

Final Position Framework – May 2013

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Executive Summary

Overview and purpose

A key aim of Melbourne Water (MW) is to improve the health of waterways, including reducing pollutant loads to waterways, where the main pollutants are nitrogen, phosphorus and sediments. Key sources of these pollutants are stormwater from urban development, through the connected drainage system, and runoff from rural land, through surface and subsurface flows and sediment transport.

Melbourne Water's Rural Land Program (RLP) is an extension and incentives program for Water Sensitive Farm Design (WSFD), providing information and financial assistance to landholders in target catchments to prevent the generation and transport of nutrients and sediments from farms to waterways. The program promotes practices such as managing stock and pastures to minimise surface run-off, and works to treat runoff or protect water sensitive areas, such as constructing sediment ponds or fencing and revegetating drainage lines and erosion gullies.

However, the application of treatments and practices associated with WSFD in a rural context is relatively new and requires a greater understanding. A partnership was established between MW, University of Melbourne (UoM) and Department of Environment and Primary Industries (DEPI) to explore these issues.

A key component was the development of a Position Framework to better understand on-farm pollution reduction systems and practices as a means of managing diffuse pollution on rural land, in order to reduce nutrient and sediment loads to waterways.

Limitations and assumptions

The Position Framework provides a compilation of findings related to the issues that are relevant to the RLP. The document does not attempt to consider these issues in relation to the broader activities of MW nor does it prioritise which activities are more important for the RLP. The document was developed collaboratively by the project partners and can be used as a resource by any of the organisations involved.

Whilst the document presents the views of the partners there has been minimal analysis as to the implications of these findings for MW. It is expected that MW will develop an implementation plan for RLP drawing on recommendations from the Position Framework in addition to other inputs.

Conclusions

Overview

The development of the Position Framework by the partners has identified that WSFD is an important approach for the implementation of the Rural Land Program. Of particular importance has been the need to more carefully consider what the RLP aims to protect and how activities can be prioritised to most effectively manage these assets and values.

The partnership approach has also identified the significant capability in Water Sensitive Urban Design (WSUD), catchment management and agricultural best management practices (BMPs) and the need to integrate this expertise and knowledge for RLP.

This Position Framework identified how this knowledge should be applied and where there is a need for additional knowledge to be generated. This section provides conclusions for each of the components of work and suggestions for activities that need to be undertaken by RLP. A path to implement sections of the Position Framework by all partners is provided.

Understanding the impact of land uses

Some agricultural land uses, such as intensive horticulture and dairying, are likely to be larger sources of nutrients and pollutants than others. However, research to date has found that the loss of natural vegetation near streams and small drainage lines is a stronger determinant of ecological impairment of streams than any one agricultural land use. Thus, in the absence of considering cost-effectiveness, management of land near rivers, streams and small drainage lines should be a priority, and the implementation of treatment systems should conserve and use the natural retention properties of agricultural landscapes.

An immediate need to meet this objective is to identify the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration.

Effective management of the region's small streams and drainage lines will require an understanding of hydrologic and water quality processes beyond annual loads of pollutants. Targeted research projects are required to assess, at smaller scales than existing studies, in-stream ecological response to different agricultural classes

Effectiveness of WSFD systems and practices

Rural activities, and hence runoff characteristics, are variable to the extent that optimum management strategies will always be site dependent. Specific strategies cannot be ranked in a way that will be generally applicable over the wide range of land uses in the area of interest.

Where land use and other local conditions are known, a short list of likely best performing management practices can be established, but the resulting improvement cannot be predicted accurately due to a lack of monitored data.

Models developed in the urban area for structural treatment measures are likely to be suitable in structure for application in the rural area, but their fit to rural conditions needs to be recalibrated.

An effective and efficient management program is likely to comprise several components of different forms. There is a need to validate models describing effectiveness of treatment systems in the rural area.

Spatial characterisation

MW has access to a substantial range of spatial data that can contribute to the aims of the RLP. Consolidation of these data should be a priority, as well as the development of improved integration of existing digital elevation and hydrologic models with land use data to permit objective delineation of the drainage network.

Development of consistent soils and land use layers is critical for a range of uses for MW, including modelling of rural land use impacts. A consistent soil layer to 1:100,000 should be considered as a minimum soils data set and finer scale (1:50,000) information would be worth considering to assist with prediction of likely riparian responses.

An improved and adaptive spatial land use layer is also essential; without this the changes between rural and urban loads over time will not be able to be predicted. The Victorian Land Use Information System (VLUIS 2010) provides a contemporary basis for updateable land use changes and can include all specified requirements required by MW including changes in urban, rural, treed, water and infrastructure classes as well as any rural land use.

Landscape modelling

MW currently has limited basis to assess the impacts of rural land uses and management practices. Further investment in landscape modelling, including the capacity to link contributions from urban and rural sources, will provide a stronger basis for assessing the contribution of rural and urban management options. This enhanced understanding is critical, given the pressures for urban growth and rural intensification and the need to quantify rural land use/management sediment and nutrient loads.

Several landscape modelling options are available which can build on MW's success in developing and using the MUSIC model. The choice of landscape modelling investment should be made considering the fineness of resolution required and whether incorporation of groundwater impacts is important, as this could be crucial to assess nitrogen impacts and to inform in-stream ecological responses. Additional considerations are whether MW wishes to retain some in-house capacity for using and/or developing models.

Given the importance of water quality issues facing Port Philip and Westernport Bays, it is recommended that MW maintain the capacity to run models and preferably to also develop them. Strengthening partnerships with research agencies (Department of Environment and Primary Industries, University of Melbourne) in model development would be desirable. As a minimum, translation of MW's existing E2 information into the internationally recognised, GIS-based and freely available SWAT model is recommended. Incorporation of the SedNet algorithms within SWAT would enable comparison of nutrient and sediment impacts from land management, waterways and gully erosion. Integration of the CAT model within Source Catchments provides an alternative option. Both the SWAT and CAT options provide the ability to link with groundwater models if required now or in the future.

Economic optimisation

The basis for investment decisions within RLP currently utilises minimal quantitative information for how to most cost-effectively address water quality issues. Assessment of the unit costs of reducing nutrient loads from major sources (rural and urban) linked to the outputs from the landscape modelling through a developed and tested economic optimisation framework is proposed as a minimum basis to assess the cost-effectiveness of management actions. Incorporation of economic optimisation information within an internationally recognised environmental investment framework (such as INFFER, based on benefit:cost analysis) would be relatively simple. Use of INFFER would also enable simple incorporation of broader ecological benefits and costs based on current knowledge of cause and effect relationships. Together these tools would provide a more robust and defensible basis for MW to justify investment decisions in either or both of rural and urban management options.

Guidelines for design and adoption

The review of the design and adoption of treatment systems for the RLP highlighted a number of key priorities for focus in the implementation of the next phase. This should build on the existing knowledge and partnerships established in the current RLP.

Of particular importance is the recognition of the diversity of landholders in the region and the potential for voluntary adoption to be an effective means of facilitating change for each of these groups. There will be a need to understand the motivations and circumstances of the targeted groups and be pragmatic about the likely use of WSFD treatment systems and modified management practices.

It was also acknowledged that others are involved in the establishment of sustainable management approaches and these partnerships need to be fostered. Once it is known what outcomes are to be achieved and who is the targeted group there are a number of fundamental principles to establishing an effective extension program. These principles were developed based on analysis of successful extension programs and include an understanding of the complex decision making process for landholders and the need to constantly adapt activities based on assessment of success.

Guidelines for policy and regulation

Current legislation and regulations do not provide a strong basis for addressing diffuse source pollution from rural land. In the immediate term there may be few drivers for exploring regulatory reform, but it is in MW's interests to explore options for increasing the effectiveness of a range of approaches to improving waterway health, and to be ready to act as appropriate.

In the short term there are several practical things MW can do or consider. The first is to work collaboratively with the Victorian government to encourage reform and incorporate aims for reducing diffuse pollution into relevant legislation and policy when possible. Second, declaration of priority catchments under *Catchment and Land Protection Act 1994* to enable Special Area Plans to be developed could be considered for the catchment draining to Sugarloaf reservoir. Development of 'Best Practice' Environmental Management Guidelines could be considered for agricultural land with reference to the SEPP (Waters of Victoria); these could be included in local planning schemes of relevant councils. Another activity could be to develop a template for promoting water sensitive farm design within irrigation and drainage management plans linked to diversion licenses. Preparatory work in development of landscape modelling and economic optimisation approaches is important to underpin future policy and regulatory approaches which may occur, as public concerns about water quality grow.

Recommendations

The following table provides a summary of the key areas for improvement and the associated recommendations. These recommendations have not been prioritised.

Table ES-1: Summary of recommendations provided for sub-project areas

Area	Recommendation summary
Understanding the impacts of rural land uses	▪ Conduct targeted research projects to assess, at smaller scales than existing studies, in-stream ecological response to different agricultural land uses ▪ Identify through consolidation and analysis of existing GIS data, the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration ▪ Ensure that the parts of the landscape that provide the greatest potential for natural retention and transformation of contaminants (small drainage lines) be protected, and used as natural treatment systems as a first priority. Management of the region's small streams and drainage lines will require an understanding of hydrologic and water quality processes beyond annual loads of pollutants.
Effectiveness of WSFD systems and practices	For on-farm management practices: ▪ Use the guidelines in the summary of effectiveness of on-farm practices (section 4.2.6) and local expert opinion if available to choose management practices that will be effective for the given problem at the given site ▪ Monitor a representative sample of treated sites to improve knowledge of treatment effectiveness under local conditions. For structural treatment measures: ▪ Use existing urban models (i.e. MUSIC) to obtain indicative results and relative performance of structural treatment measures appropriate to the site, and select measures accordingly. Modify model parameters to account for any known differences in water quality descriptors ▪ Monitor a representative sample of structural treatment measures to allow improved recalibration of urban models for local rural conditions.
Spatial characterisation	**Review of current spatial data:** improve the current spatial data including land use, digital elevation models (DEM), hydrological data and water quality site layers.
	Develop an improved and adaptive spatial land use data: use the VLUIS 2010 data as the base, and include most current impervious/pervious data layer, most current treed extent, hydrological data and dams and water bodies.
	Develop a consistent spatial soils data layer: 1:100,000 scale should be the minimum resolution, and finer scale 1:50,000 could be considered.
Landscape modelling	Define a preferred position for catchment modelling to predict the impact of runoff from rural land. Consider the following catchment modelling options for further development: ▪ Adopt the internationally recognised SWAT catchment modelling framework. This option is likely to be best value if funding is limited and there is also limited in-house catchment modelling capability ▪ Include SedNet within the SWAT framework, which will be important if gully and streambanks are to be considered as well as paddock management options. This requires additional funding compared with the SWAT only option ▪ Integrate DEPI's CAT model within SourceCatchments, This option considers the surface modelling approach fully coupled with the groundwater model. A degree of commitment to develop and maintain in-house catchment modelling capability is required for this option.

Area	Recommendation summary
Economic optimisation	Test an approach utilising the biophysical modelling (CAT/SourceCatchments or SWAT as outlined above) and an optimisation method, which is appropriate for this complex problem whilst being straightforward to implement for modellers. Bioeconomic modelling can be used as an input to an environmental benefit:cost analysis (e.g. INFFER) and would also be useful.
Guidelines for design and adoption	Identify geographical areas that are required to achieve RLP objectives and target specific landholder groups. Operating within this context it is essential to then: ▪ Obtain a deeper understanding of landholders and their circumstances and needs ▪ Explore the characteristics of the treatment systems and management practices ▪ Analyse relevant partners and their alignment with RLP objectives ▪ Analyse major issues for the design and implementation of extension programs.
Guidelines for policy and regulation	▪ Declare priority catchments under *Catchment and Land Protection Act 1994* to enable Special Area Plans to be developed. ▪ Develop Best Practice Environmental Management Guidelines for agricultural land for referencing in the SEPP (Waters of Victoria), and ultimately in local planning schemes of relevant councils with predominantly rural land. ▪ Develop a template for promoting water sensitive farm design within irrigation and drainage management plans linked to diversion licenses.
Guidelines for monitoring	Consider the following steps in designing, implementing, operating and reporting a monitoring program to assess WSFD treatment systems and practices: ▪ Defining objectives ▪ Selecting which variables to be monitored ▪ Taking into account spatial and temporal considerations ▪ Assessing and managing uncertainty ▪ Selecting appropriate monitoring equipment ▪ Data validation and quality control ▪ Data handling and storage ▪ Use of data to provide information and knowledge. It is recommended that MW take a disciplined approach to each monitoring activity undertaken under the RLP, stepping through each of these components. Particular emphasis is recommended to the careful definition (and agreement among all stakeholders) of objectives of each monitoring programme.

Next steps

The development of this Position Framework required the establishment and effective working relationship of the project partners. A final workshop was undertaken to review the work undertaken and the conclusions drawn for each of the components. This stage of the process highlighted the next steps required for each of the partners to improve our knowledge associated with Water Sensitive Farm Design and implement improved management of the assets through the RLP.

The next steps for the different project partners focuses specifically on:

- Development of an implementation plan for the RLP by MW, and
- Broader partnership approach with consideration of joint funding opportunities.

These are discussed further in section 12.3.

1 The Rural Land Program and Water Sensitive Farm Design

Authors: Silvana Predebon (MW), Anne-Maree Boland (RMCG) and Carl Larsen (RMCG)

1.1 Research Context

1.1.1 Melbourne Water

A key aim of Melbourne Water (MW) is to improve the health of waterways, including reducing pollutant loads to waterways, where the main pollutants are nitrogen, phosphorus and sediments. Key sources of these pollutants are stormwater from urban development, through the connected drainage system, and runoff from rural land, through surface and subsurface flows and sediment transport.

1.1.2 Water sensitive urban design (WSUD)

The urban stormwater program is well established in MW, and includes several capacity building and incentive programs for Water Sensitive Urban Design (WSUD). There is a substantial amount of research and documentation regarding the application of different water sensitive design treatments, and programs across the urban development industry to support the installation of design treatments.

MW and the University of Melbourne have an established working relationship in regards to researching the effectiveness of different WSUD treatments, developing and applying decision support tools to guide investment, and proving information and incentives for stormwater managers to adopt best management practices.

1.1.3 Water sensitive farm design (WSFD)

The goal of the Rural Land Program pilot is to reduce diffuse source TN, TP, TSS loads to Port Phillip Bay and Westernport Bay, by minimising the generation and export of these pollutants from agricultural land in priority catchments.

The term ‘water sensitive farm design’ (WSFD) is used to refer to a range of practices and interception schemes primarily employed on high rainfall or irrigated agricultural land to prevent the flow of nutrients, sediments and other pollutants of agricultural origin being exported to waterways (directly or indirectly). The interception schemes include in-field treatments like grass swales, cover crops, and shelter belts, and edge-of-field treatments like sediment traps, wetlands, and riparian buffers. A model, the water quality ‘metric’, estimates the reduction in nutrient loads from installation of any one of the treatments when applied to any one farming situation.

1.2 Rural Land Program

1.2.1 History

MW’s Rural Land Program (RLP) is an extension and incentives program for WSFD, providing information and financial assistance to landholders in target catchments to prevent the generation and transport of nutrients and sediments from farms to waterways. The program promotes practices such as managing stock and pastures to minimise surface runoff, and works to treat runoff or protect water sensitive areas, such as constructing sediment ponds or fencing and revegetating drainage lines and erosion gullies.

The program is based on voluntary participation of landholders. Landholder participants in target catchments are usually recruited through the traditional method of one-to-one contact, then step through a process involving farm assessments through to (in most cases) funding agreements for works.

Focussing on working in the catchment for river health outcomes is an emerging priority for MW which complements their work on the bed and banks. While MW has a history and is recognised as a leader in urban stormwater management, the management of runoff in a rural context is a new area of work for the organisation. The main approach to managing runoff in the pilot RLP has been the promotion of water sensitive farm design principles and treatments.

1.2.2 Objectives

The goal of the RLP pilot is to reduce diffuse source TN, TP, TSS loads to Port Phillip Bay and Westernport Bay, by minimising the generation and export of these pollutants from targeted, privately managed rural agricultural land in priority catchments.

The objective of the RLP pilot was to demonstrate that strategic extension services and targeted financial assistance will promote sustained implementation of a suite of selected Agricultural BMPs, by a sufficient proportion of a targeted audience, to achieve a cost-effective treatment option for diffuse-source TN, TP and TSS from dryland grazing and intensive horticultural properties.

The *Stormwater Strategy* (Appendix 2) and the *Healthy Waterways Strategy* (Appendix 3) now drive the activities of the RLP.

The long-term vision of the *Stormwater Strategy* (Melbourne Water, 2012) is that sustainable stormwater management supports prosperous communities, thriving landscapes and healthy waterways and bays. It delivers on multiple community outcomes including healthy waterways and bays, alternative water supplies, wellbeing and amenity, and public safety.

The following implementation targets relate directly to the RLP:

- **Implementation target (IT) 5:** At least one alternative engagement model trialled to improve our understanding of the effectiveness of rural land management delivery methods
- **IT15:** 250 rural landholders will be engaged to increase action for reducing diffuse pollution from agricultural land
- **IT16:** Rural runoff management practices are refined and evaluation techniques are developed to assess performance in reducing pollutant loads discharged to waterways and bays, at both the farm-scale and catchment-scale.

The *Stormwater Strategy* also lists many commitments, mostly related to MW working with a wide range of stakeholders and partners, including rural landholders, to sustainably manage stormwater for multiple outcomes.

The long-term aim of the *Health Waterways Strategy* (Melbourne Water, 2012) is that healthy and valued waterways are integrated with the broader landscape and enhance life and liveability. They:

- Connect diverse and thriving communities of native plants and animals
- Provide amenity to urban and rural areas and engage communities with their environment
- Are managed sustainably to balance environmental, economic and social values.

The strategy focuses on the key environmental conditions of waterways (habitat, water quality, flows, connectivity, physical form) to support key values such as macroinvertebrates, fish, platypus, frogs, vegetation, birds and amenity.

1.2.3 WSFD technologies and practices

Managing stormwater from agricultural and rural properties is an important part of protecting waterways and bays in the Port Phillip and Westernport region (Melbourne Water, 2012). Nutrient, sediment and agricultural chemicals are the focus of stormwater management on farms. WSFD aims to address diffuse pollution from agricultural land, specifically by preventing runoff of nutrients and sediments to water sensitive areas. Although the terminology may be relatively new, the concept of improving nutrient and water management on farms to avoid off-site effects has been promoted for a few decades, often under a banner of sustainable farming.

Stormwater can be managed on agricultural properties through improved farm management practices such as (Melbourne Water, 2012):

- Better on-farm nutrient management
- Re-aligning tracks and fences
- Revegetating gullies.

Runoff can be treated effectively through works such as:

- Sediment traps
- Wetlands and filter beds
- Swales and drains to reduce volume and velocity
- Vegetation buffers along waterways.

The recently produced water sensitive farm design guide provides principles for the activities that landholders should be undertaking to reduce the impact of runoff to waterways (Melbourne Water, 2012). These include:

- Plan to protect the water sensitive areas on your property
- Exclude water sensitive areas from production
- Vegetate your water sensitive areas
- Manage your property to optimise soil health
- Understand, monitor and plan your property’s nutrient inputs and outputs
- Design and manage drainage systems to reduce erosion and prevent runoff lowing directly into water sensitive areas

- Design and manage tracks, roads and crossings to reduce erosion and runoff
- Design, construct and manage treatment systems to intercept and treat sediment and nutrient loads.

1.3 Problem definition

The MW RLP is focused on the effectiveness of treatments and their impact in managing pollutant transport and loads from land to waterways. Research partners (MW, DEPI and UoM) identified a need to quantify the impact of treatments to:

- Assist in guiding investment (where to invest spatially – prioritisation of areas and in what activities to invest)
- Promote benefits and provide evidence for investment
- Assist landholders in making decisions on land management practices and pollution treatment systems
- Develop effective design guidelines for WSFD techniques (analogous to the MW Engineering Procedures Manual: Urban Stormwater).

The aims of a future research project were to address existing knowledge gaps in nutrient and sediment management on agricultural land, through:

- Quantifying the relative benefits and performance of WSFD treatments for reducing pollutant transport from agricultural land to waterways
- Developing WSFD to maximise performance
- Validating and improving modelling tools or the current 'metric' and
- Assisting in prioritising local and catchment scale WSFD works.

More detailed objectives and key questions to be answered were discussed at the workshop with participants highlighting the shared objectives of:

1. Health of waterways including ecological and public health aspects
2. Health of bays focusing on water quality particularly long-term loads (Westernport Bay – sediments and nitrogen and Port Phillip Bay – nitrogen)
3. Health of streams focusing on water quality (base flow concentrations and loads), hydrology and morphology
4. Understanding the impact of practices and farming systems and benefits of treatments and practices
5. Need to consider the whole range of factors that will impact on the achievement of healthy waterways including – Biophysical, Policy, Social and Economic

The critical pollutants were identified as:

- Nitrogen (N), phosphorus (P) and sediments
- Pesticides/herbicides
- Unidentified pollutants – 'novel nasties' (toxicants).

The key issues of concern in waterways were considered to be water quality, hydrological and geomorphic. Importantly, it was agreed that an integrated approach is needed rather than just focussing on one of these three threat mechanisms.

2 Position Framework

Authors: Silvana Predebon (MW), Anne-Maree Boland (RMCG) and Carl Larsen (RMCG)

2.1 Overview

2.1.1 Genesis of the framework

WSFD is an area of interest for the RLP with the potential to draw on expertise and knowledge from partners involved in rural land management and WSUD.

The concept for developing a Position Framework arose from a facilitated workshop held with project partners on 1st May 2012. The project partners included MW, Department of Environment and Primary Industries (DEPI) and the University of Melbourne (UoM).

The original aim of the workshop was to develop a high-level project plan for conducting field trials to test the effectiveness of pollution treatment systems in reducing nutrient and sediment loads to waterways. The discussions exploring this aim led to the recognition that current knowledge needed to be identified before a field trial could be designed. Rather than undertake a traditional literature review to inform potential field trials, a Position Framework was suggested, which could integrate the interests of the project partners in water sensitive design treatment systems, and address agreed objectives. The meeting notes were circulated, and partners generally agreed on a Program Logic for developing the position framework. The intent of the Position Framework is to identify the work needed to address gaps in knowledge in the implementation of WSFD.

In order to initiate the development of the Position Framework a process was designed involving a number of key workshops with project partners and a clear focus on activities for the next 12 months.

The Position Framework aims to improve understanding of WSFD and will inform implementation planning for the RLP in Water Plan 3.

2.1.2 Purpose of the framework

The overall objective of the Position Framework is to better understand on-farm pollution reduction systems and practices as a means of managing diffuse pollution on rural land, in order to reduce nutrient and sediment loads to waterways.

The primary and secondary objectives and associated key questions are described in further detail in Table 2-1.

Table 2-1: Objectives and supporting questions

Objectives for MW RLP	Key Questions
Primary objectives	
I. Determine the effectiveness of pollution reduction systems and practices, in order to validate co-investment in treatments and provide assurance in promoting treatments to landholders	a. How effective are pollution reduction systems and practices in improving ecosystem health (catchment scale) through reducing the transport of nutrients and sediments to waterways and bays, both in the short-term and long-term?
II. Obtain field data for comparison to modelled data (particularly in regards to the decision-support tool developed for the RLP, the "metric")	b. What existing models and validation information (field data collection) would be appropriate in assessing the effectiveness of pollution reduction systems and practices on rural land?
Secondary objectives	
III. Define key drivers and motivators for landholders to construct and maintain pollution reduction systems and practices	c. What benefits do pollution reduction systems and practices provide to landholders at the farm scale and what are the associated costs, both initial and maintenance?
IV. Translate application of treatments at a farm scale to the catchment scale	d. Where in a catchment should pollution reduction systems be located and practices undertaken to achieve the greatest benefits relative to cost (environmental and socio- economic)?
V. Identify the effectiveness of key regulating standards in Victoria for facilitating uptake of pollution reduction systems and practices	e. What existing policy and regulating standards in Victoria relate to WSFD principles, construction of pollution reduction systems and associated management practices? f. How can policy and regulation and its implementation be improved to facilitate uptake of pollution reduction systems and practices?

The pollutants to be included in the study are nitrogen, phosphorus, and sediments although the approach should be one that can be replicated for toxicants/chemicals. The pollution treatment systems to be included are bioretention systems, sediment traps, filter beds, grass swales, and wetlands.

2.1.3 Structure

The Position Framework is structured as follows:

- **Section 1** outlines background and objectives of the Rural Land Program (RLP) and Water Sensitive Farm Design (WSFD)
- **Section 2** provides an overview of the Position Framework including purpose, program logic and research framework
- **Section 3** presents the key findings and recommendations of the understanding the impacts of land use (project area 2 in the program logic)
- **Section 4** presents the key findings and recommendations of the effectiveness of WSFD systems and practices at farm scale (project area 3 in the program logic)
- **Section 5** presents the key findings and recommendations of the spatial characterisation (project area 1 in the program logic)
- **Section 6** presents the key findings and recommendations of the landscape modelling characterisation (project area 1 in the program logic)

- **Section 7** presents the key findings and recommendations of the economic optimisation framework (project area 4 in the program logic)
- **Section 8** presents the key findings and recommendations of the guidelines for design and adoption (project area 5 in the program logic)
- **Section 9** presents the key findings and recommendations of the guidelines for policy and regulation (project area 6 in the program logic)
- **Section 10** outlines the recommended approach to monitoring the effectiveness of on-farm practices and structural treatment measures to achieve water quality outcomes
- **Section 11** provides a summary of the key findings and recommendations, an analysis of the gaps in knowledge and opportunities for further research
- **Section 12** provides the conclusions and next steps.

2.1.4 Limitations and assumptions

The Position Framework provides a compilation of findings related to the issues that are relevant to the RLP. The document does not attempt to consider these issues in relation to the broader activities of MW nor does it prioritise which activities are more important for the RLP. The document was developed collaboratively by the project partners and can be used as a resource by any of the organisations involved.

Whilst the document presents the views of the partners there has been minimal analysis as to the implications of these findings for MW. It is expected that MW will develop an implementation plan for RLP drawing on recommendations from the Position Framework in addition to other inputs.

2.2 Program logic

The program logic for the Position Framework is shown in Figure 2-1 below. This provides the thinking that was current at the commencement of the project and links the project areas and outputs of the RLP to the long-term outcomes and aspiration goal of MW.

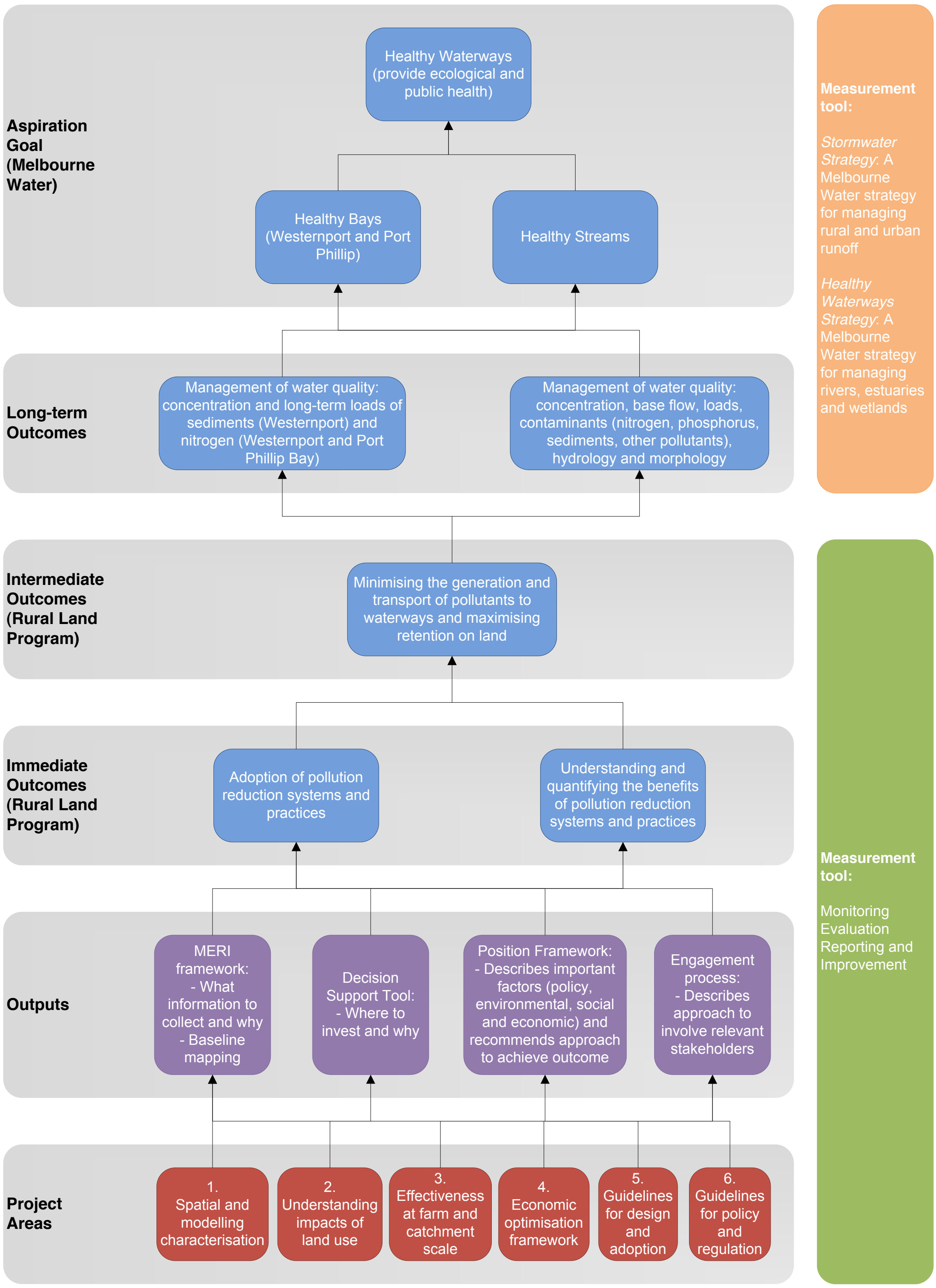

Figure 2-1: Program logic

2.3 Research framework

The research framework outlining the project areas, key components and relevant questions to be addressed is outlined in Table 2-2 below.

Table 2-2: Research framework

Project area	Key components	Relevant questions
1. Spatial and modelling characterisation	▪ Available data and gaps in land use data – soil information for hydrological modelling ▪ Preferred indicators – ecological and other ▪ Existing models that could be applied to a rural diffuse pollution context and that are compatible with MUSIC ▪ Data requirements for models ▪ Establish criteria to help MW decide upon a sound modelling approach ▪ Analysis of feasible catchment modelling approaches based on criteria and considering the resolution of potentially available input data (e.g. soils, land use) ▪ Propose recommended catchment modelling approach or options including consideration of degree of resolution required between soil characterisation and land use ▪ Demonstrate how diffuse and urban sources will be linked through modelling	b. What existing models and validation information (field data collection) would be appropriate in assessing the effectiveness of pollution reduction systems and practices on rural land? d. Where in a catchment should pollution reduction systems be located and practices undertaken to achieve the greatest benefits relative to cost (environmental and socio-economic)?
2. Understanding impacts of land uses	▪ Land use and land use change in regions (key industries); alternative land uses ▪ Review of previous analysis for RLP ▪ Division by agricultural use using VLUIS/ABS (e.g. classed as intense, non-intense, irrigated, dryland, native vegetation) ▪ Guided by MW's approach and analysis (i.e. pollutant load hotspots to the bays, metric compatibility) ▪ Farming systems and farm scale modelling	b. What existing models and validation information (field data collection) would be appropriate in assessing the effectiveness of pollution reduction systems and practices on rural land? d. Where in a catchment should pollution reduction systems be located and practices undertaken to achieve the greatest benefits relative to cost (environmental and socio-economic)?

Project area	Key components	Relevant questions
3. Effectiveness at farm and catchment scale	▪ On-farm reduction systems and edge of field practices per rural land use which are believed to have an impact on sediment, P and/or N reduction ▪ Provide estimates of effectiveness of management practices if available (eg high, medium, low or %) and cite evidence to justify ▪ Outline how farm management practices will be linked to catchment modelling approach in section 1 ▪ What are the limitations and minimum requirements?	a. How effective are pollution reduction systems and practices in improving ecosystem health (catchment scale) through reducing the transport of nutrients and sediments to waterways and bays, both in the short-term and long-term? b. What existing models and validation information (field data collection) would be appropriate in assessing the effectiveness of pollution reduction systems and practices on rural land? d. Where in a catchment should pollution reduction systems be located and practices undertaken to achieve the greatest benefits relative to cost (environmental and socio-economic)?
4. Economic optimisation framework	▪ Cost-effectiveness of management interventions and spatial prioritisation ▪ Factors to consider when undertaking economic analysis at a catchment scale – including broader ecological costs and benefits ▪ Conceptual framework outlining the link between catchment modelling and economic optimisation	c. What benefits do pollution reduction systems and practices provide to landholders at the farm scale and what are the associated costs, both initial and maintenance? d. Where in a catchment should pollution reduction systems be located and practices undertaken to achieve the greatest benefits relative to cost (environmental and socio-economic)?
5. Guidelines for design and adoption	▪ Physical, social and economic aspects and instruments for landholder adoption ▪ Understanding key drivers and motivators of landholders	c. What benefits do pollution reduction systems and practices provide to landholders at the farm scale and what are the associated costs, both initial and maintenance?
6. Guidelines for policy and regulation	▪ Review of existing diffuse-source regulations and their effectiveness of implementation ▪ Need for linkage between diffuse and point sources in the regulatory and modelling approaches ▪ Brief scan of overseas experience and assessment of what MW can learn from these experiences	e. What existing policy and regulating standards in Victoria relate to WSFD principles, construction of pollution reduction systems and associated management practices? f. How can policy and regulation and its implementation be improved to facilitate uptake of pollution reduction systems and practices?

2.4 Summary of objectives, questions and research framework

A summary of the objectives, questions and research framework is provided in Table 2-3.

Table 2-3: Summary of objectives, questions and research framework

Objectives for MW Rural Land Program	Key Questions for Development of Position Framework	Project area
Primary objectives		
I. Determine the effectiveness of pollution reduction systems and practices, in order to validate co-investment in treatments and provide assurance in promoting treatments to landholders	a. How effective are pollution reduction systems and practices in improving ecosystem health (catchment scale) through reducing the transport of nutrients and sediments to waterways and bays, both in the short-term and long-term?	3. Effectiveness at farm and catchment scale
II. Obtain field data for comparison to modelled data (particularly in regards to the decision-support tool developed for the RLP, the "metric")	b. What existing models and validation information (field data collection) would be appropriate in assessing the effectiveness of pollution reduction systems and practices on rural land?	1. Spatial and modelling characterisation 2. Understanding impacts of land uses 3. Effectiveness at farm and catchment scale
Secondary objectives		
III. Define key drivers and motivators for landholders to construct and maintain pollution reduction systems and practices	c. What benefits do pollution reduction systems and practices provide to landholders at the farm scale and what are the associated costs, both initial and maintenance?	4. Economic optimisation framework 5. Guidelines for design and adoption
IV. Translate application of treatments at a farm scale to the catchment scale	d. Where in a catchment should pollution reduction systems be located and practices undertaken to achieve the greatest benefits relative to cost (environmental and socio- economic)?	1. Spatial and modelling characterisation 2. Understanding impacts of land uses 3. Effectiveness at farm and catchment scale 4. Economic optimisation framework
V. Identify the effectiveness of key regulating standards in Victoria for facilitating uptake of pollution reduction systems and practices	e. What existing policy and regulating standards in Victoria relate to WSFD principles, construction of pollution reduction systems and associated management practices? f. How can policy and regulation and its implementation be improved to facilitate uptake of pollution reduction systems and practices?	6. Guidelines for policy and regulation

3 Understanding the Impacts of Land Uses

Authors: Chris Walsh (UoM) and Silvana Predebon (MW)

3.1 Land use in the Port Phillip and Westernport catchments

There are a diversity of landholder types and industries in the Port Phillip and Westernport (PPW) catchments including commercial farms and lifestyle properties. The main industries represented in the catchment are:

- Flowers
- Fruit and berry fruit
- Dairy
- Broad acre grazing (beef and sheep meat)
- Cropping
- Poultry
- Horse breeding
- Vegetables
- Wine
- Forestry
- Lifestyle landholders.

The important land uses from an economic production perspective in each of the sub catchments is provided in Table 3-1 below.

Table 3-1: Land use in the Port Phillip and Westernport catchment

Rural catchment area	Economic production
North East (Yarra river basin)	▪ Mixed horticulture ▪ Equine ▪ Lifestyle ▪ Beef
South East (Dandenong and Westernport river basins)	▪ Grazing (beef) ▪ Dairy
West (Maribyrnong and Werribee river basins)	▪ Grazing (beef and sheep) ▪ Broadacre cropping ▪ Equine

Rural land accounts for approximately 85% of the PPW region and comprises many land uses, including forests, plantations, rural settlements, roads, quarries, mines and agricultural enterprises. Agricultural land occupies about 54% of the total area (Figure 3-1). Agricultural production systems vary from extensive paddock or field-based systems through to intensive production processes, such as feedlots and industrial facilities, short cycle intensive cropping and greenhouses (Melbourne Water/EPA, 2009). Across the region, rural water quality typically declines in association with land use change, from good to very good in forested headwaters to moderate to poor in agricultural districts, and poor or very poor in urban areas (Melbourne Water, 2007).

Modelling indicates that urban land uses and urban and rural roads are major contributors of diffuse loads, however, agricultural contributions are significant in PPW catchments that have larger areas of agricultural land (Melbourne Water, 2009). Agriculture dominates diffuse loads in rural catchments such as the Lang Lang and Bass.

The agricultural land use groupings ('functional units') used by PortsE2 catchment modelling (Melbourne Water, 2009) can be considered as two major groups:

- **Pasture/Non-irrigated cropping:** is widespread across the PPW region (Figure 3-1) and is dominated by dryland broad acre grazing, including commercial beef, sheep and dairy production, niche industries, hobby farms and recreational horses. As it occupies the largest proportion (50%) of agricultural land in the PPW region, Pasture/Non-irrigated cropping contributes the largest proportion of modelled total diffuse loads.
- **Intensive Horticulture** (Annual and Perennial horticulture and Irrigated pasture and cropping): occurs more discretely within the PPW region, occupying about 4% of the total land area. It occurs around several production centers including the Bacchus Marsh and Werribee Irrigation Districts, the Koo Wee Rup drainage district and the Woori Yallock catchment. Horticulture has the potential to contribute a disproportionately high relative total nutrient load contribution per unit of land compare with pasture/non-irrigated cropping.

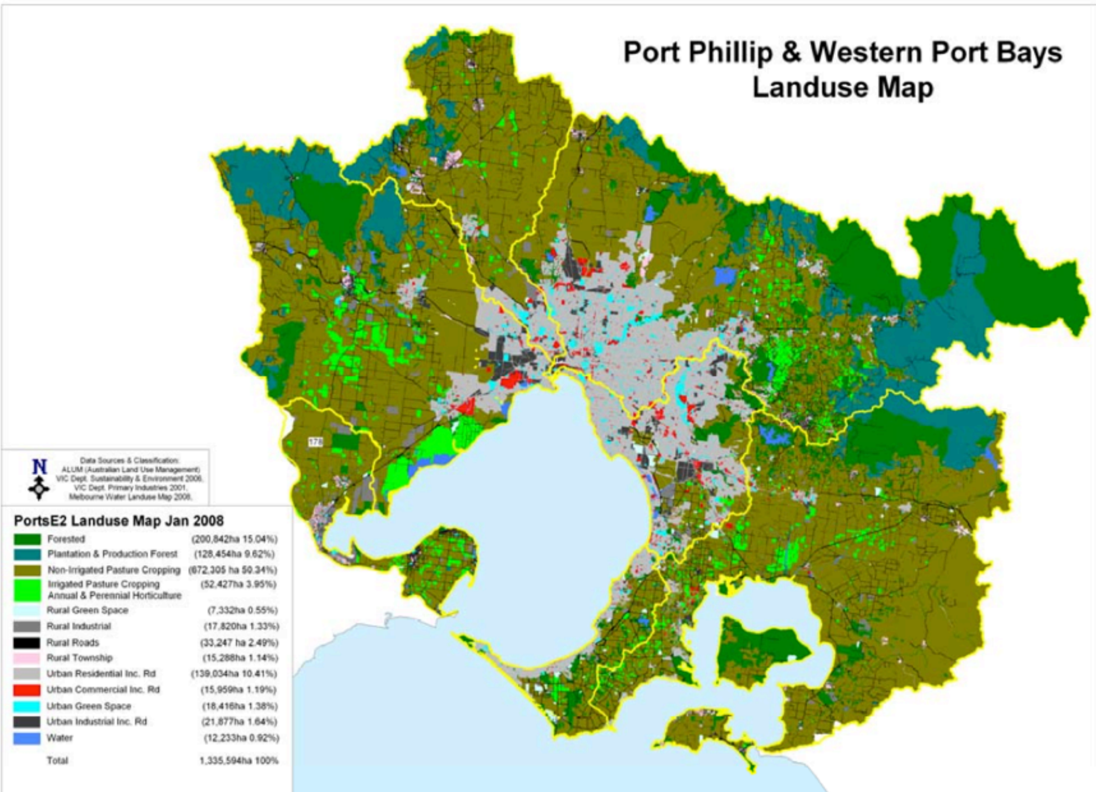

Figure 3-1: Land use in the Port Phillip and Westernport catchment

3.2 Land use implications

Intensive agriculture (horticulture and dairying) is likely to be a more important source of nutrients and other pollutants than other less intensive grazing systems, and this is reflected in the models underlying PortsE2 framework. However, as discussed in the following sections, there is little evidence to date that different agricultural land use classes result in different degrees of ecological impairment in stream ecosystems. Independent of the nature of land use (whether it be agricultural or urban), the spatial proximity and drainage connection of cleared land to waterways are more important determinants of waterway impairment than any one use of that cleared land (e.g. Walsh and Kunapo 2009).

The lack of evidence of differential ecosystem impacts resulting from different agricultural uses is not proof that all agricultural systems have equivalent impact. A possible reason for this lack of evidence is that studies of stream ecosystem response to catchment land-use are conducted across wide regions (e.g. Walsh and Webb 2013), while in a region such as Melbourne, different farming practices tend to be clumped together in small geographic areas. As a result only a small number of streams might be influenced by any one agricultural practice, resulting in weak effects in broad-scale studies. Targeted research projects assessing stream response to different agricultural classes is needed to resolve this question.

In the following sections and in the next chapter, changes to a range of farming practices are considered that could help to reduce the generation and transport of pollutants to receiving streams. Nevertheless, the importance of the location of any agricultural land use and its drainage connection to receiving waters are primary determinants of the potential impacts to streams. The importance of location and drainage connection also point to the prime importance of maximising the efficiency of treatment technologies by, as much as possible, conserving and using the natural retention properties of the landscape in treatment design.

3.3 Aquatic ecosystems and the focus of RLP

MW seeks to protect a wide range of aquatic ecosystem types that are interdependent, and that differ in the primary external drivers of their ecological function (Figure 3-2).

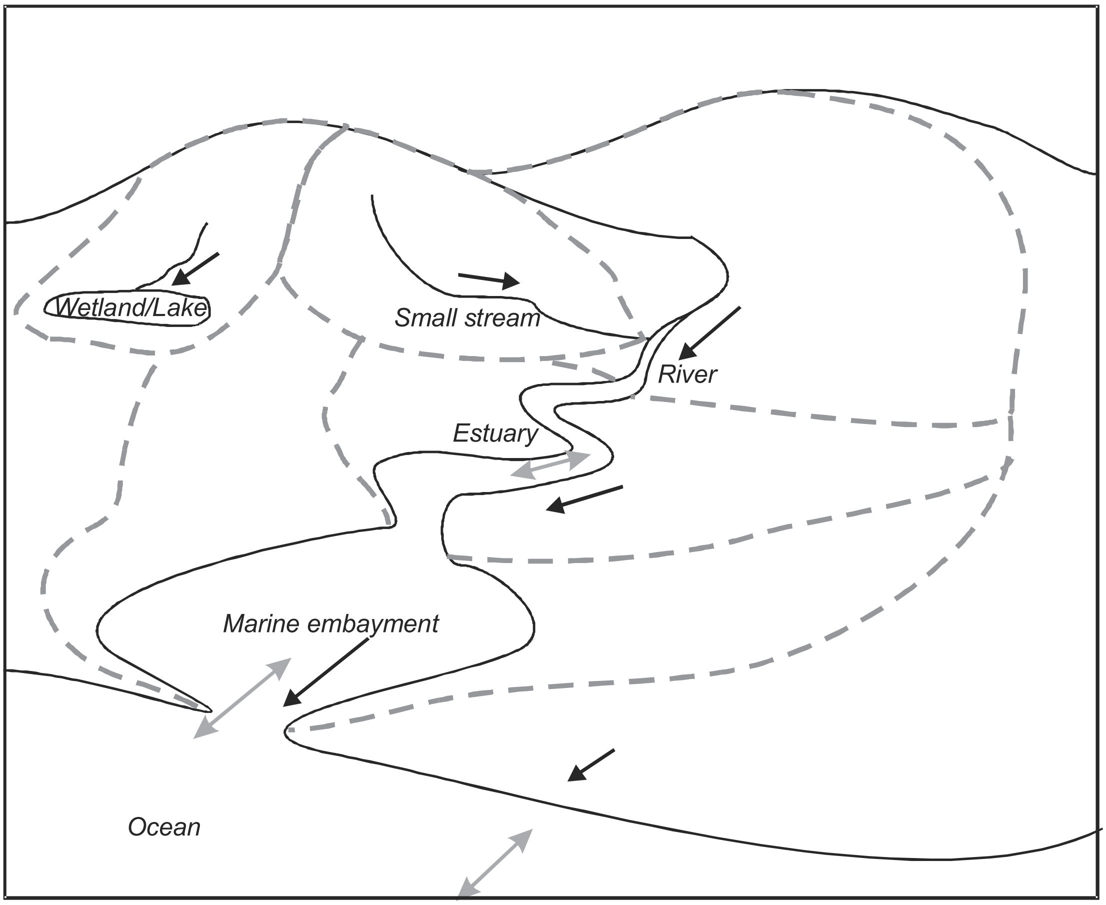

Figure 3-2: Types of receiving waters and their catchments (grey dashed boundaries). For each receiving water type, the direction of freshwater flow is indicated (black arrow), and for receiving waters with marine influence, the bi-directional nature of tidal flushing is portrayed (grey arrows)

The ecological structure and function of two large coastal embayments, Port Phillip and Westernport, are driven to a large extent by imports of riverine water and its associated contaminants. The systems are of a large enough volume, with sufficient tidal mixing of marine water, to be well buffered against temporal variation in the delivery of riverine water. Such buffering is evident by the small degree of variation in salinity in the embayments.

As a result, annual loads of contaminants delivered to the bays serve as useful predictors of the ecological status of the bays. Harris *et al*. (1996) identified increased nitrogen loads from catchment activities as a serious threat to Port Phillip Bay. They identified discharges of the Yarra River (together with Melbourne's stormwater drains) and of the western treatment plant to be nitrogen sources of comparable magnitude. Since then the discharge of N from the western treatment plant has been reduced to about one-third of levels typical of the early 1990s, shifting focus onto riverine and urban stormwater discharges. The delivery of N and other contaminants from these sources is variable within and between years, being dependent on rainfall patterns.

The health of Westernport Bay, with its more extensive, shallow seagrass meadows is likely more affected by the combined effects of sediment and nutrient loads, delivered to the bay by the catchment's rivers.

The health of both Melbourne's large coastal embayments is therefore dependent on the health of the region's rivers and streams.

Existing objectives for stream management in the Melbourne region have been strongly influenced by the CSIRO study of Port Phillip Bay (Harris *et al.* 1996). Catchment management reporting has focused on reporting on pollutant loads, but the connection between load reduction and protection of Melbourne's rivers and streams is not always clear. In the urban context the pursuit of reduced catchment loads through construction of urban stormwater treatment wetlands has shown no improvement in the ecological condition of streams (Walsh 2004), in many cases on-line constructed wetlands have replaced stream ecosystems potentially causing barriers to migration along streams.

The focus on the need to reduce loads to large, downstream water bodies has, at least in the urban context, failed to address the environmental needs and required management actions to protect the river network that delivers the loads to the bays. This failure to protect stream ecosystems not only fails to protect their inherent values (such as the biodiversity they support), but also fails to maximize the important function of healthy streams (and small streams in particular) as hotspots for contaminant retention and transformation (McClain *et al.* 2003).

While coastal embayments are strongly influenced by riverine imports of contaminant loads, influences on stream and riverine ecosystems are more varied.

Riverine environments are defined by their flow regime. Thus variability in stream flow is important at both intra-annual and inter-annual time scales (Poff *et al.* 1997; Poff *et al.* 2010). The flow-through of water in riverine systems means that the concentrations of contaminants experienced by riverine biota are not as buffered as they are in coastal embayments. Therefore, important temporal variation in concentrations may not be captured by summary statistics such as annual loads.

The influence of the riparian environment on streams is much greater than that of coastal embayments (and other less linear water bodies). The ratio of the length of interface with the terrestrial environment to the total volume of a riverine system is much larger than that of a coastal embayment, and the ratio increases for smaller streams. The importance of riparian land to in-stream ecological structure and function is well established, with riparian cover being a strong determinant of the amount of solar energy reaching the stream, and the degree of exchange of organic and inorganic materials between the surrounding terrestrial ecosystem and the stream (e.g. Pusey & Arthington 2003). Riparian forests are of direct importance to this exchange of materials through the provision of wood and leaves to the stream that provide habitat and a primary source of carbon for stream food webs, as well as input of terrestrial insects into the stream food-web. Riparian vegetation also serves to stabilize banks, thus moderating the supply of sediment to streams.

Riparian vegetation is also important in intercepting nutrients and other terrestrial contaminants. In larger streams and rivers, the effect of riparian interception of contaminants will be smaller compared to inflow of contaminants from upstream waters. The relative importance of riparian interception of contaminants is greater for smaller streams for two reasons: a) smaller streams receive less flow from upstream waters and b) the size of the interface between water and sediments relative to the volume of in-stream water increases for smaller streams. This second reason explains the increasing importance of small streams as sites of contaminant retention and transformation (REF).

The dominance of small streams across the landscape of the MW region (Figure 3-3), their importance as hotspots for the retention and transformation of contaminants (McClain *et al.* 2003), and the dependence of the health of downstream rivers, estuaries and coastal embayments on them (Freeman, Pringle & Jackson 2007) makes small streams an obvious focus for management aiming to protect the full suite of aquatic ecosystems across the region. However, such a focus raises the question of how small a stream or drainage line should be considered a stream ecosystem.

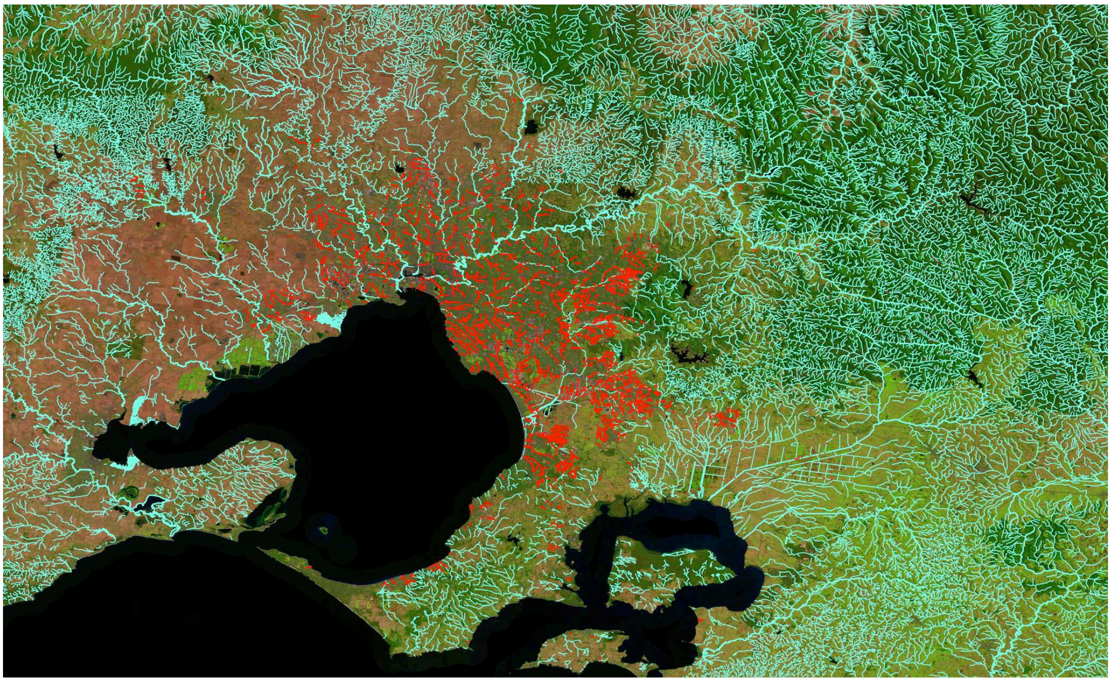

Figure 3-3: The stream network of the Melbourne region. Red lines indicate man made drains, most of which are underground pipes or sealed drains that have replaced small streams.

This question has recently been the subject of legal debate in the US, with the focus of the question being on which waters fall under the protection of the Clean Water Act (Doyle & Bernhardt 2011). A similar question is of relevance to MW to delineate streams that are classed as MW's assets from upland drainage lines that are either the responsibility of local government authorities or of private landholders: the delineation at least in urban areas is a catchment area of 60 ha. Drainage lines with larger catchments are generally considered to be MW assets.

As well as being physically unrealistic across such a large region with wide ranges of topography and climatic conditions, such a delineation is unlikely to be useful for management decision making, especially considering that drainage lines with <60 ha provide ecological values and services that determine the ecological structure and function of larger streams.

Doyle and Bernhardt (2011) defined a range of physical, chemical and biological criteria that distinguish hillslopes from streams, including the presence of flowing water (rare on hillslopes, frequent in streams), morphology (hillslopes are unchanneled), rate of chemical conveyance downstream (low on hillslopes, moderate in streams), potential for chemical transformation (high on hillslopes, moderate in streams), and the presence of specifically aquatic biological processes and biota.

The potential for chemical transformation is perhaps of most importance in defining the uppermost extent of management focus, as processes such as denitrification are likely to be maximal along drainage lines that frequently allow storage and slow conveyance of water through sediments. Many such drainage lines in the Melbourne region (particularly in the wetter eastern part) are likely to have catchment areas <60 ha. When such drainage lines are intact, with adequate buffering of vegetation, they are likely to provide multiple ecosystem services including the retention of floodwaters, retention and transformation of nutrients and other contaminants, and protection of downstream waters.

Unfortunately, as in the urban environment, adequate protection of such drainage lines often competes with human use of the adjacent rural land. They are often transformed into drains that permit the greater use of the land through which they flow. Such drains are often portrayed as serving the purpose of flood protection (Laurance 2007), but they usually exacerbate floods further downstream, and certainly diminish the in-catchment retention of nutrients and contaminants, along with loss of biodiversity, both in the drainage line itself and in downstream waters.

As in the urban environment, a tension exists for management to maintain such drains as drainage assets alone or to increase their retention capacity for the protection of downstream waters. The latter course of action is likely to have a cost to the landholder if it requires the annexing of otherwise productive land. Nevertheless, such a possibility should not distract from the potential importance of such drainage lines as systems of inherent biodiversity value and providers of ecosystem services to downstream waters.

Thus, the RLP, in seeking to protect the streams, rivers, estuaries and bays of the Melbourne region, should aim to target the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration. This classification will not be achievable across the region using a single catchment size criterion, and will require a combination of spatial analyses and ground truthing. In reality, the RLP works on a voluntary basis, and while the first base is the minor drainage lines, they are not targeted according to listed criteria or in catchment context.

3.4 The effects of rural land use practices on aquatic ecosystems: a review

3.4.1 The nature of agricultural impacts on stream ecosystems

Agricultural land use has been repeatedly shown to degrade the ecological structure and function of stream ecosystems (e.g. Hall *et al.* 1999; Saalfeld *et al.* 2012). It has been implicated in shifts in composition of algal, invertebrate and fish assemblages and changes in stream function. Reported effects include the loss of larger, longer-lived stream invertebrates (Larsen & Ormerod 2010), increased heterotrophic metabolism, presumably through the increased provision of organic carbon (Iwata *et al.* 2007), and enrichment of waters with N and P (Carpenter *et al.* 1998).

The problem of agricultural degradation of streams and rivers has commonly been characterized primarily as one of degradation of water quality. Novotny (1999) identified four aspects of agricultural land use that affect water quality: a) degradation resulting from conversion of native lands to agriculture; b) increased erosion and soil loss; c) chemical pollution by fertilizers and pesticides; and d) pollution from animal operations.

However, the first two of the factors listed by Novotny (1999) lead to hydrologic and morphologic changes to channels that are likely to act in concert with water quality changes.

Deforestation increases sediment yields greatly, and subsequent soil loss from cleared fields is at least an order of magnitude higher than from forest. Erosion and sedimentation from agriculture causes substantial morphologic and water quality changes in streams (Wood & Armitage 1997), including smothering of instream habitat, transport and storage of nutrients and other pollutants and increased turbidity with concomitant in-stream effects.

Loss of topsoil is, of course also a major threat to the future productivity of agricultural landscapes (Lal 1998). Legacy organochlorine pesticides are likely to be stored in agricultural soils, strengthening the need to minimize soil erosion to prevent transfer to downstream aquatic ecosystems (Munn & Gruber 1997)

Catchment deforestation also alters the hydrologic balance, increasing total volume of runoff, always resulting in increased high flows. If agricultural practices permit the retention of soil storage capacity, then increases in baseflows are also possible, but if clearance and grazing reduce catchment storage baseflows are likely to be reduced (Bond, Lake & Arthington 2008). Such hydrologic effects are exacerbated if agricultural land practices rely on water extraction from streams and rivers. Such extraction contributes to effects of drought (both large-scale irrigation and numerous local and small-scale extractions to meet stock and domestic demand (coined “death by a thousand sucks” by Bond, Lake & Arthington 2008)).

Deforestation also has a direct influence on stream ecosystem structure and function when riparian forest is removed. The central importance of riparian zones to the functioning of stream ecosystems, including its role in determining the primary sources of carbon to the stream food web (Pusey & Arthington 2003) was discussed in paragraph 10 of section 3.3.

Increased use of fertilizers and pesticides over the last 50 years have contributed to severe pollution of surface and groundwater in many parts of Europe, North America (Lovell & Sullivan 2006), and Australia (Lester & Boulton 2008).

Eutrophic conditions associated with urban and agricultural land use promote invasive species (Quinn, Schooler & van Klinken 2011) and nutrient enrichment associated with agriculture accelerates breakdown of organic matter in streams, indicating a shift in ecological function (Paul, Meyer & Couch 2006), although the positive effects of nutrient enrichment on OM breakdown can be countered by the negative effects of sedimentation (Niyogi, Simon & Townsend 2003).

The effects of agricultural land use on stream ecosystems are therefore complex, with multiple interacting effects on basal food resources, water quality, hydrology and channel morphology. It is thus important to incorporate in-stream ecological indicators when assessing agricultural impacts on streams.

3.4.2 Location, location, location: the importance of spatial arrangement

Many large-scale studies of the impacts of land use on biota only consider broad definitions of land use such as “agriculture” (e.g. Hall *et al.* 1999; Saalfeld *et al.* 2012). In most such studies, agricultural land use (or forest cover) was measured as a proportion of catchment (e.g. Roth, Allan & Erickson 1996; Bond, Thomson & Reich 2012). King *et al*. (2005) and subsequent papers (Van Sickle & Johnson 2008; Peterson *et al.* 2011) have demonstrated that weighting of rural land use by its flow-path distance to- and along- streams, using decay functions with a mechanistic underpinning, increases the predictive power of models of stream condition compared to lumped catchment proportions of land use. This fact supports the desirability of moving to a finer scale modelling approach, which is discussed further in section 6.

Use of near-stream land, and land in drainage lines in which water accumulates (Peterson *et al.* 2011), is therefore likely to be an important driver of stream condition in landscapes in which water drains to streams through natural flow paths. In the Melbourne region, forest cover (and conversely agricultural landcover) within 40–100 m of a stream, and 1–3 km upstream predict macroinvertebrate assemblage composition in streams better than more distant land uses (Walsh & Webb 2013).

Agricultural lands close to streams are more likely to be sources of nutrients and other contaminants to streams than more distant land (Tufford, McKellar & Hussey 1998; Tran *et al.* 2010). For example, as much as half of the Lake Mendota (USA) catchment did not contribute significantly to N Loading (an important driver of the lake ecosystem): the greatest sources of N came from a heterogeneous riparian corridor of 0.1–1 km width depending on topography and rainfall (Soranno *et al.* 1996)

However, human alteration of drainage lines, such as the drainage of fields, can greatly increase the spatial extent of catchment land areas that have a strong influence on stream condition (Walsh & Webb 2013). For instance, tile drainage is likely to reduce the positive effects of riparian forests on in-stream denitrification rates (Arango & Tank 2008).

Nolan and Stoner (2000) found that poorly drained soils reduced the transfer of nitrate to groundwater, in part because slow movement combined with anoxic conditions promoted denitrification. This points to the importance of maximising the use of land that has the greatest potential for retention and transformation of contaminants: most often areas of water accumulation (i.e. drainage lines).

The degrading effects of increasing the hydraulic efficiency of drainage lines will be even greater if the drainage line being altered is a small stream. Small streams have substantial potential for N removal via denitrification (Mulholland *et al.* 2009), particularly when they are hydrologically connected with high-nitrate surface water (Roley, Tank & Williams 2012). Smaller streams are associated with greatest N removal (Alexander, Smith & Schwarz 2000), underlining the importance of maximizing the retention capacity of small streams.

Conversely, Alexander et al. (2000) note that the lesser N removal of larger streams points to the importance of reducing N imports directly to large rivers. Riparian forests also provide important benefits to large streams. For instance, reduced sedimentation and increased in-stream biodiversity can be afforded by regenerating riparian forest downstream of headwater agricultural land use (Thornton *et al.* 2000; Niyogi *et al.* 2007).

The importance of the functions of small streams and of forested land near streams in mitigating the impacts of agricultural land use has led to the use of vegetated 'buffer strips' as a common practice for stream protection.

Many studies that have shown the importance of riparian forests in retaining a range of contaminants from agricultural land use including both reactive and mobile forms of N (Lowrance *et al.* 1984; Peterjohn & Correll 1984; Osborne & Kovacic 1993). Lovell and Sullivan (2006) reviewed the benefits of forested buffers, pointing to their multiple environmental and economic benefits, including protection of river ecosystems through retention of contaminants and soil, and protection of terrestrial biodiversity in agricultural landscapes. Ecosystem services provided by vegetated buffers include controlling diffuse pollution transport, habitat improvement and ecological productivity, stream shading, hydrologic connectivity (with floodplains), carbon sequestration, biomass production, cultural services (Stutter, Chardon & Kronvang 2012).

Somewhat surprisingly, a study of potential agricultural 'best management practices' in the Melbourne region (Read Sturgess and Associates 2001), assessed the removal efficiency for N of vegetated buffer strips as zero, resulting in them being considered an ineffective means of reducing nitrogen loads in the region. This questionable assessment should be reviewed, together with related assessments of the potential for agricultural practices to reduce N loads to Port Phillip Bay (Rooney & Chesterfield 2000). The result also underscores the importance for having more work on estimating the effectiveness of best-management practices.

More research into the importance of spatial arrangement of land use on stream ecosystem structure and function is required. However, our knowledge to date points to the importance of using natural services provided by drainage lines and small streams in mitigating agricultural impacts.

3.4.3 Other aspects of rural impacts on stream ecosystems

1. Stocking rates and chemical application

Nutrient flows to aquatic ecosystems are related to stocking densities and excess chemical (including fertiliser) and manure production (Carpenter *et al.* 1998). One management intervention to counter such a problem is to moderate stocking rates and chemical application, recognising that nutrient flows are also related to bare and compacted surfaces, poor drainage design and other factors.

Treatment systems such as vegetated buffers can effectively retain pesticides and herbicides that adhere to soil particles (Lovell & Sullivan 2006), but some of the more mobile chemicals are difficult to retain through structural treatments and are more appropriately managed through regulation of their use.

The other primary source of nutrients is animal waste: the extent of which is a function of stocking rates, animal operations (collection of animals into small areas for activities such as milking), and proximity to the stream. Proximity to the stream raises an additional consideration that to some extent can be a concern independent of riparian forest cover: stock access.

2. Stock access

Stock access alters riparian forest community structure, including the spread of weeds and reduction in recruitment of native species (Lester & Boulton 2008). By these changes to the riparian community, by destabilizing banks and by direct addition of wastes to streams, stock access can alter the quantity and quality of organic material available in the stream, as well as contributing to nutrient and faecal contamination in streams. Stock access along small drainage lines can also increase the chance of faecal pollution (Tyrrel & Quinton 2003).

In agricultural NE USA streams with comparable concentrations of nitrate to streams of the Melbourne region, faecal sources were implicated as greater contributers to nitrate concentrations than industrial fertilizers (Mayer *et al.* 2002).

Stock access can occur under riparian forest canopies, so it is an unaccounted for effect in studies such as that of Walsh and Webb (2013). Across the Melbourne region, a lack of data limits our ability to determine the extent to which stock access degrades the region's streams.

3. Farm dams

There has been a large increase in the number of farm dams in many upland catchments of Australia over the last decade—37% increase in number and 48% volume in the Murray-Darling Basin (van Dijk *et al.* 2006). The volume of farm dams in the rural areas of the MW region is typically 5–10 ML/km^2 in the west and 10-30 ML/km^2 in the east (with a hotspot in the middle Yarra with more than 30 ML/km^2) (van Dijk *et al.* 2006, Fig 26). Cumulatively, farm dams have a potentially large impact on stream flows. In catchments with soil depth <2.5 m, the mean reduction in stream flow resulting from a 1 ML dam is >0.77 ML/y, and reductions are even higher in drier regions (Lowe, Nathan & Morden 2005). Using the undeveloped discharge of Olinda Creek at Mt Evelyn estimated by Burns *et al*. (2012) of 103 mm/y, a dam density of 10 ML/km^2 and 30 ML/km^2, would reduce streamflow by >7.4%, and >22.4% respectively, in an average year. Reductions in baseflow would certainly be substantially greater during droughts, when flow stress of streams will be greatest (Bond, Lake & Arthington 2008).

The impacts of farm dams that are on-line are compounded by their forming a barrier to migration along streams (McGuckin & Bennett 1999). Such impacts are greater when they are placed on larger streams, but the potential for them to act as barriers even on small first order streams remains an area of potential further research.

Substantial in-stream benefits are possible through different farm management practices, such as designing dams to allow dry-weather flows to pass, and maximising the capture of runoff from farm impervious surfaces into dams. Runoff from impervious surfaces in rural areas is potentially a large impact to rural streams that has previously been overlooked.

4. Road and other impervious runoff

While agricultural land use has been repeatedly shown to degrade the ecological structure and function of stream ecosystems (e.g. Hall *et al.* 1999; Saalfeld *et al.* 2012), the loss of biodiversity in streams of agricultural catchments remains less than that observed in the universally degraded streams that receive urban stormwater runoff in conventionally drained urban catchments (Moore & Palmer 2005; Walsh & Webb 2013).

The effects of drained runoff from impervious surfaces are severe and are apparent at extremely low levels of catchment cover (Walsh & Webb 2013). The potential for retention of impervious runoff for beneficial purposes is large (and usually simple) in rural areas. Consideration of rural management practices for the protection of streams should not neglect the importance of impervious drainage practices.

3.5 Recommendations to protect aquatic ecosystems from the impacts of rural land use

There is currently no strong evidence that one agricultural land use is more detrimental that another at a catchment scale. Targeted research projects are required to assess, at smaller scales than existing studies, in-stream ecological response to different agricultural land uses.

Given the diversity of aquatic ecosystems that MW seeks to protect, the interdependence of ecosystems requires careful consideration in developing a program for mitigating the impacts of rural land-use. In the urban context, a strong focus on contaminant load reduction to protect Port Phillip Bay has resulted in a focus on technologies for stormwater treatment, usually instead of using the natural retention processes of healthy rivers and streams. In the rural context, where stream values and ecological condition are usually better conserved than in the urban context, there is even a stronger argument for ensuring that the parts of the landscape that provide the greatest potential for natural retention and transformation of contaminants (small drainage lines) be protected, and used as natural treatment systems as a first priority. Management of the region's small streams and drainage lines will require an understanding of hydrologic and water quality processes beyond annual loads of pollutants.

The RLP, in seeking to protect the streams, rivers, estuaries and bays of the Melbourne region, should begin by identifying the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration. Such a classification of drainage lines and streams (as distinct from hillslopes) will not be achievable across the region using a single catchment-size criterion, and will require a combination of spatial analyses and ground truthing.

Collectively, a range of agricultural practices such as vegetative filter strips, barnyard improvements, sediment detention basins, livestock fencing, and no-till farming have been shown to result in some protection of ecological structure and function in streams (Gabel, Wehr & Truhn 2012). The relative effectiveness of different approaches on stream protection requires assessment.

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4 Effectiveness of Water Sensitive Farm Design Systems and Practices

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4.1 Overview

The effect of agricultural activity on runoff water quality has long been noted. While describing the sources of water for the city of Rome, Frontinus (97) stated: 'New Anio ... is taken from the river [not from a spring like the others], which with cultivated fields of fertile soil round about, and hence less stable banks, even without the adverse effects of rain flows muddy and turbulent'. More recently, and closer to home, studies have shown that agriculture greatly increases concentrations and loads of many contaminants in rural runoff compared with undisturbed vegetation. Variability is also substantially increased due to the wide range of activities that can occur in the rural landscape.

Bartley et al. (2012) noted the high variability of Australian rural water quality data both within and between sites and found median TSS concentrations during runoff events from agricultural land up to 100 times higher than the median from forest sites. The increase was only a little less for TN and TP. Drewry et al. (2006) reviewed nutrient generation from land use and export to waterways using both Australian and overseas data, and found elevated loads and concentrations from agricultural catchments compared with forested areas. On a whole catchment basis, McKergow et al. (2005) found that clearing of native vegetation and replacement with cropping and grazing systems in the catchment of the Great Barrier Reef increased nutrient exports to a level many times the natural rate. Kroon et al. (2012) found the same for both nutrients and suspended solids, and also noted substantial loads of pesticides which would not previously have been present. Smith et al. (2012) found that pesticides are widespread in runoff and can exceed guideline levels, and noted with concern the presence of complex pesticide mixtures.

Overseas experience has been broadly similar, allowing for some differences in agricultural practices (Omernik 1976; Beaulac & Reckhow 1982). A review by Young et al. (1996) compared loads from southeast, west, and northeast Australia with the North American data of Beaulac & Reckhow (1982). They concluded that North American export rates are often higher than Australian rates for comparable land use, but their summary tables could equally be used to emphasise the high variability of the observed data. With higher loads, elevated concentrations, and increased variability, there can be little doubt that agricultural runoff presents a problem that requires attention.

In urban areas reviews of water quality studies have rarely found large or significant differences in runoff quality between the zoning-based land uses typically used in urban areas – residential, industrial, and commercial – although there are significant differences between land uses based on actual surface type – roads, roofs, and open space (Athayde et al. 1983; Duncan 1999). The result is that concentration data needed for modelling urban areas can for the most part be drawn from a single statistical distribution. Based on the information available, it appears that this simplifying factor does not apply to agricultural runoff. The large variation in quality between different agricultural land uses requires more emphasis on case by case analysis, both for estimating default water quality, and for predicting the likely effect of changes in land use and on-farm practices.

4.1.1 Contaminants

The contaminants most frequently addressed in the agricultural sector are sediments, normally measured as total suspended solids (TSS), the nutrients total nitrogen (TN) and total phosphorus (TP), and a suite of pesticides appropriate to the farming activities under study.

Sediment export from agricultural land degrades the land it is sourced from, and can disrupt aquatic habitats and change flow conditions in streams. Turbidity associated with finer suspended material reduces light penetration through the water column. Sediments are also associated with a wide range of other contaminants, of which the most important for agriculture are phosphorus and some pesticides, so that effective sediment management will help to control these contaminants as well (Duncan 1999).

Nitrogen and phosphorus are both essential nutrients, and either may be the limiting nutrient at a site. Increase in availability of a limiting nutrient may cause eutrophication – excessive and unbalanced growth of plants and algae leading to oxygen depletion – in receiving waters. Total nitrogen and total phosphorus may both be analysed into a number of component species, depending on chemical availability, oxidation state, and solubility. The most important division in the present context is into dissolved and particulate forms. Phosphorus tends to adsorb to fine particles, so that a large fraction of total phosphorus behaves as if it were particulate (Duncan 1999). Most species of total nitrogen are dissolved, but a portion of organic nitrogen may be particulate in form (Taylor et al. 2005). Dissolved and particulate nutrients may require quite different management strategies, due to their different flow paths (Cogle et al. 2006) (Drewry et al. 2006).

Pesticides are a diverse group of contaminants which are widely distributed in agricultural catchments, and can be divided into insecticides, fungicides, and herbicides (Smith et al. 2012). They are by design toxic to their intended target, and can continue to have toxic effects after export to receiving waters. Their tendency to adsorb to particles covers a wide range, which affects the preferred management strategies (Oliver & Kookana 2006).

4.2 Effectiveness of on-farm practices

Good on-farm practices aim to reduce the adverse effects of excessive or contaminated runoff at or very close to the source. They are directed more at prevention than cure. On-farm practices to manage runoff and contaminant exports vary widely, in the farming activities and contaminants targeted, in the climate, geology, and land forms of sites of interest, and in the observed or estimated performance of a given management practice at a given site. Variability is without doubt the most uniformly reported characteristic of studies in the field (Department of Primary Industries Victoria 2007) (Hamlett & Epp 1994) (Monaghan et al. 2008) (Oliver & Kookana 2006) (Roberts 2011) (Simpson & Weammert 2009) (Zollweg & Makarewicz 2009). Furthermore, studies with comprehensive monitoring of effectiveness are relatively sparse, and occasionally a synthesis of local expert opinion has been used instead. As a first step in managing the observed variability, the following sections concentrate mainly on Australian studies.

4.2.1 Sediment

Sediment export is associated with erosion – from bare ground, from gullies, and from watercourses – and preferred sediment management strategies reflect this. Costin (1980) investigated runoff and erosion behaviour on pasture at Ginninderra, near Canberra, and found that surface runoff and soil loss were inversely related to cover (as pasture, detached litter, and sheep dung). Cover values less than about 70% were associated with some large increases in runoff and soil loss, as separate bare patches tended to join up and create continuous flow paths. Event soil loss was strongly related to event runoff. Chronic bare areas closely connected to streams can lead to high sediment yields despite the remainder of the catchment having good pasture cover (Carroll et al. 2012).

Cogle et al. (2006) concluded that management strategies targeting improved vegetation cover in grazing lands delivered the greatest reductions in sediment and particulate nutrient loads. Carroll et al. (2012) noted the effect of bare ground on sediment concentrations and yield, and found that widespread adoption of minimum and zero tillage in fallow and crop rotations are practices that will provide the greatest reduction of sediment in cane and cropping. Practices that retain high pasture cover and biomass have a large effect on reducing hillslope runoff and erosion on grazing land.

Roberts (2011), using possibly optimistic expert opinion in the absence of observed field data, found that the most effective actions for an upper La Trobe River dryland dairy farm were location of intensive animal areas away from waterways with management to minimise pugging and runoff, and fencing of gullies to exclude stock and encourage vegetation. Stott & Roberts (2012) concluded that improved management of permanent waterways and ephemeral streams – weed control, revegetation, no stock access – was likely to be most effective for a typical dairy farm in the Corner Inlet (South Gippsland) catchment. For a typical beef farm in the same area, fencing and revegetation of eroding gullies was ranked higher than waterway management, due mainly to differences in the baseline of currently acceptable practice. Measured concentrations and loads of TSS dropped by an order of magnitude after fencing and vegetation of a riparian strip near Albany, WA (McKergow et al. 2003), which was attributed to reduced bank erosion and increased channel stability rather than changes in surface sediment delivery.

4.2.2 Nutrients

Nutrient export is associated with the management of concentrated nutrient sources – fertilisers and manure. According to Ovens et al. (2008), the nutrient efficiency – the ratio of nutrients in products sent out to nutrients in inputs brought in – of over 400 farms in SW Western Australia is typically low (median 0.24 for N, 0.32 for P). Surplus nutrients can enter the environment immediately or accumulate on the land as a potential future risk. Particulate or adsorbed nutrients will behave similarly to sediments, and will respond to the same management activities. Dissolved nutrients will require different strategies, typically centred more on prevention than treatment.

Managing fertiliser inputs to just meet crop requirements, rather than applying excess and attempting to remove it later, is a common theme (Birch 1982; Cogle et al. 2006; Department of Primary Industries Victoria 2007; Carroll et al. 2012), particularly for dissolved nutrients. A second main theme is the prevention of stock access to waterways (Department of Primary Industries Victoria 2007; Stott & Roberts 2012). The mechanisms here are direct input of manure and urine to the watercourse while stock are present, and the association of phosphorus with sediment eroded by trampling. Other measures aimed at erosion reduction, such as fencing of gullies (Roberts 2011) and maintenance of vegetation cover (Cogle et al. 2006) will also help to limit particulate phosphorus export. Since both dissolved and particulate nutrients are carried by runoff, strategies that reduce farm runoff (e.g. ripping, efficient irrigation management) will also reduce nutrient export via surface runoff (Birch 1982; Department of Primary Industries Victoria 2007), although increased export of dissolved nutrients via groundwater may possibly occur (Frink 1991; Gassman et al. 2006).

Overall, the relative contributions of gully, streambank, waterway and land based sediment and nutrient pollution is highly context specific and includes soil type, climate and land practices, each of which need to be understood to make sound evidence-based decisions. The intensity of agricultural industries is critical – intensive industries (such as horticulture and dairying) can have very high nutrient surpluses and hence nutrient losses.

4.2.3 Pesticides

Pesticide export is associated with the import and handling of these products, since they are nearly always artificial products that do not occur naturally in the environment. Pesticide export is managed by minimising inputs, and by controlling the subsequent movement of the quantities that are used. Inputs may be reduced by optimising to achieve best control with minimum application rate (Carroll et al. 2012) and by selective application to only the areas required (Oliver & Kookana 2006; Carroll et al. 2012). Further movement can be reduced by appropriate choice of pesticide for rapid dissipation and selective action, and by strategies that minimise runoff and sediment movement (Carroll et al. 2012). Oliver & Kookana (2006) found that pesticide export from row crops in the Ord River Irrigation Area was significantly reduced by selectively spraying beds only rather than spraying the whole field. Incorporation of pesticides into the soil prior to furrow irrigation significantly reduced export of a strongly sorbed pesticide, but the load reduction was not significant for weakly sorbed pesticides. Popov et al. (2006) found that concentrations and loads of weakly sorbed pesticides were substantially reduced by flow over grassed filter strips.

A recent study sampled 24 sites in the Port Phillip and Westernport catchments (mostly in the Middle Yarra catchment), using a combination of water grab samples, sediment samples, and passive samplers (Rose et al. 2009; Schäfer et al. 2011), and identified a total of 61 pesticides at the monitored sites. The fungicide trifloxystrobin, the insecticide pirimicarb, and the herbicide simazine were found to be most toxic to the invertebrates *Daphnia magna* and *Selenastrum capricornutum* at the majority of sites (Schäfer et al. 2011). Simazine and the insecticides chlorpyrifos and DDT infrequently exceeded the ANZECC/ARMCANZ (2000) guideline values, but many more pesticides found are not listed in the Guidelines. DDT and dieldrin (organochlorine insecticides deregistered more than twenty years ago) were found regularly in sediment samples at some sites above Interim Sediment Quality Guideline Trigger Values (low) (Rose et al. 2009). Yet the most significant result of the study is surely the sheer number of pesticides identified in the catchment.

4.2.4 Implementation and adoption

Issues of implementation and adoption can be viewed in several ways. From a purely physical point of view, land closer to watercourses is likely to have more effect on runoff quality, so good management here is particularly important. Carroll et al. (2012) have noted the disproportionate effect of chronic bare areas close to streams. Basnyat et al. (1999) addressed distance and linkage to streams in detail, and found that water quality correlates most significantly with streambank land use, significantly with land use in a defined contributing area, but not significantly with whole catchment land use. The greater effect of land closer to watercourses is similar in principle to the drainage connection of Hatt et al. (2004) and others in urban and peri-urban areas, and is due to the closer physical connection of source to destination. The use of riparian buffer strips to manage stream condition (McKergow et al. 2003) (Abernethy & Rutherfurd 1999) also recognises the heightened significance of near-stream land use.

Vegetated buffer strips are sometimes included with on-farm management practices and at other times with structural treatment measures, depending partly on whether they occur by default or by retrofit. McKergow et al. (2003) reviewed the processes and practicalities of riparian buffers, and concluded that their action relates more to livestock exclusion and bank stability (land management) than treatment of overland flows (structural measures). They found a very large decrease in sediment concentrations and loads, but much more limited impact on nutrient export. Local design guidelines for riparian buffers are available (Abernethy & Rutherfurd 1999) (Melbourne Water 2012), and are also implicit in the definitions of Roberts (2011) and Stott & Roberts (2012). In the limiting case, small catchments with extensive riparian buffers merge into substantially undisturbed catchments with more natural water quality and ecology.

At a larger catchment scale, Cogle et al. (2006) observed that most sediment and nutrients came from areas of high rainfall and steep slopes relatively close to the measuring point. Material eroded from more distant areas had more opportunities for redeposition before leaving the catchment. Prairie & Kalff (1986) used a simple power function to model the reduction in total phosphorus export per unit area with increasing catchment size, which is a consequence of this effect. They also noted the related effect of slope – smaller catchments are typically steeper and hence more subject to erosion.

Current practice (prior to modification) is a significant factor for both research on effectiveness of management strategies and the implementation of recommended practices. Department of Primary Industries (2007) noted pragmatically that the greatest reductions in nutrient export were made by targeting landholders in areas where best practice implementation was limited. On the research side, Roberts (2011) and Stott & Roberts (2012) introduced a baseline of current acceptable practice from which to assess the effectiveness of proposed changes in management. Where this has not been done, uncertainty about baseline practice adds another source of variability to the observed results.

The effectiveness of a management strategy at a broader scale depends on its level of adoption by landholders, which in turn depends on both physical and behavioural factors. Physical factors include climate, soil types, topography and land use (Roberts et al. 2012). While discussing the Chesapeake Bay Project, Simpson & Weammert (2009) noted that performance data from highly managed research projects tends to over-estimate (possibly by a large margin) the effectiveness of management strategies in the real world of variable temporal scales, hydrologic flow regimes, soil conditions, climate, management intensity, vegetation, and BMP designs.

Cary & Roberts (2011) investigated behavioural issues and categorised possible management actions according to their public net benefits and private net benefits. They concluded that actions with public benefits are likely to be adopted if there are high enough private benefits, but are unlikely to be adopted without further incentives if there are negative private benefits. With the possible exception of fertiliser management (Stott & Roberts 2012) (Monaghan et al. 2008), nearly all management practices come at some cost to farmers. As a result, voluntary adoption at the scale typically required is unlikely to occur. Further incentives to adoption include nominal payments to landholders, full opportunity cost payments, and effective enforcement of existing effluent regulations (see also Roberts et al. 2012). For further discussion of adoption of conservation practices by rural landholders, see Pannell et al. (2006).

4.2.5 Performance

Many studies have assessed the relative performance of on-farm practices to manage runoff and contaminant exports, both by literature review and by monitoring or modelling at specific sites. Those with Australian content include Carroll et al. (2012), Cogle et al. (2006), Department of Primary Industries (2007), Oliver & Kookana (2006), Roberts (2011), Roberts et al. (2012), and Stott & Roberts (2012). Perhaps the most comprehensive literature review of Australian and overseas performance estimates is incorporated in the summary tables of Roberts (2011).

Results have been summarised as far as possible in Table 4-1, which provides a tabulation of the on-farm management practices that are typically found to be effective, and an approximate ranking of practices under a number of conditions. Where effectiveness is given in numeric form, it is important not to treat the numbers as exact and confirmed results. They are estimates of typical behaviour over a wide range of conditions. Some papers, recognising this, provide only qualitative comments or just list the best one or two options for their specified conditions. These comments are also included in Table 4-1.

The information available is sufficient to establish a short list of likely best performing management practices at a particular site. But given the variability noted above, and the relative lack of monitored data, it is not currently possible to estimate the resulting improvement with great accuracy. To improve this situation, a program to monitor and analyse a representative sample of treated site is recommended.

Many possible practices can potentially be used to mitigate a particular problem. Each single practice usually has a maximum effectiveness, due to the size of the problem the practice addresses or the area it can be applied to. Hence a comprehensive management program is likely to comprise several distinct practices. Since cheaper and more cost-effective practices are usually (and quite reasonably) implemented first, the result is a highly nonlinear relationship between total effectiveness and total cost (Roberts et al. 2012). Hence it can happen that producing a given change is achievable and cost-effective, while producing twice the change is either prohibitively expensive or physically unachievable. In such cases, modifying the desired change and freeing up funds for work elsewhere may need to be explored.

4.2.6 Summary

Combining the information in Table 4-1 and the commentary above, several persistent themes can be noted.

- Volume of runoff is always important, since most contaminants are carried by runoff. The higher the runoff volume the higher the contaminant load. Runoff can be reduced by maintaining high ground cover, and diverting concentrated flows away from drainage lines.
- Connection to watercourses is always important, since highly connected land areas have a larger and faster effect on the watercourse. Good management practice is most important on highly connected land. Connection can be lowered by diverting concentrated flows away from drainage lines, and by provision of buffer strips on perennial and ephemeral watercourses and wetlands.
- Where contaminants are imported in the course of farm operation (fertilisers, pesticides), good management of these materials is important. Usage should be as low as possible consistent with achieving the intended purpose, and managed to minimise runoff.
- Where concentrations of livestock occur, good management of effluent from these areas is important. Livestock concentrations should not be close to watercourses. On-farm effluent storage should be sufficient to avoid overflow or reuse during wet periods.
- Where erosion is known to occur, management to control the erosion is important. Hillslope erosion can be reduced by maintaining a high proportion of ground cover. Gully erosion can be reduced by fencing gullies to exclude stock and encourage revegetation. Streambank erosion can be reduced by provision of riparian buffer strips and prevention of stock access to streams. The relative contributions of gully, streambank and land based erosion are highly context specific and modelling would improve confidence about the most cost-effective investments.
- Targeting good management practices that are currently done poorly is likely to be effective, since there is more scope for improvement.
- Good management practices that are adopted widely by landholders are likely to be effective, due to large areas involved.
- Management practices are likely to be adopted voluntarily if there are sufficiently high private benefits, but voluntary adoption alone is unlikely to be sufficient. Adoption can be improved by incentive payments, and by regulation coupled with effective enforcement.
- The information available is sufficient to establish a short list of likely best performing management practices at a given site, but not enough to predict the resulting improvement accurately. To improve this situation, a program to monitor and analyse a representative sample of treated sites is recommended.

Table 4-1: On-farm management practices

On-farm management practice	Land use	Location	Reference	TSS		TP		TN		Pesticides	
				Effectiveness	Rank	Effectiveness	Rank	Effectiveness	Rank	Effectiveness	Rank
Widespread adoption of zero and minimum tillage in fallow and crop rotation	Cane and cropping	Lit Review	Carroll et al (2012)	best	1						
Retain high pasture cover and biomass	Grazing	Lit Review	Carroll et al (2012)	large	1						
Stabilise streams and mitigate channel erosion	Grazing	Lit Review	Carroll et al (2012)	significant	2						
Match fertiliser application closely to crop requirements	Cane	Lit Review	Carroll et al (2012)			reduces losses	1	reduces losses	1		
Reduce pesticide inputs & select to reduce risk of movement (rapid dissipation, selective action)	Cane	Lit Review	Carroll et al (2012)							minimised	1
Retain surface cover and reduce runoff and sediment movement	Cane	Lit Review	Carroll et al (2012)							further minimised	2
Improved vegetation cover	Grazing	GBR catchments	Cogle et al (2006)	greatest reduction	1	greatest reduction	1				
Best management practice (fertiliser application and tillage methods)	Intensive agriculture	GBR catchments	Cogle et al (2006)					greatest reduction	1		
Nutrient retention (sufficient on-farm storage, drains fenced and well grassed)	Dairy	Port Phillip & Westernport	DPI (2007)				1		1		
No stock access to watercourses	Dairy	Port Phillip & Westernport	DPI (2007)				2				
Fertiliser application rate	Dairy	Port Phillip & Westernport	DPI (2007)				3				
Track design and management (not close to watercourses and runoff diverted away)	Dairy	Port Phillip & Westernport	DPI (2007)						2		
Effluent management (well managed, no effluent exported)	Dairy	Port Phillip & Westernport	DPI (2007)						3		
Nutrient retention (sufficient on-farm storage, drains fenced and well grassed)	Beef	Port Phillip & Westernport	DPI (2007)				1				
No stock access to watercourses	Beef	Port Phillip & Westernport	DPI (2007)				2				
Fertiliser application rate	Beef	Port Phillip & Westernport	DPI (2007)				3				

On-farm management practice	Land use	Location	Reference	TSS		TP		TN		Pesticides	
				Effectiveness	Rank	Effectiveness	Rank	Effectiveness	Rank	Effectiveness	Rank
Spray pesticide onto beds only	Furrow irrigated raised beds	Ord River Irrigation Area	Oliver & Kookana (2006)							significantly lower exports	1
Incorporate pesticide into soil before irrigation	Furrow irrigated raised beds	Ord River Irrigation Area	Oliver & Kookana (2006)							sometimes significant	2
Gully erosion management (fence to exclude stock and encourage vegetation)	Dryland dairy	Upper Latrobe R Catchment	Roberts (2011)	50%	1	25%	1				
Effluent management on hard surfaces (effluent storage for later application)	Dryland dairy	Upper Latrobe R Catchment	Roberts (2011)			10%	2	10%	1		
Intensive animal areas located away from waterways and sensitive areas	Dryland dairy	Upper Latrobe R Catchment	Roberts (2011)	50%	1	10%	2	10%	1		
Protection of natural wetlands (fenced to exclude stock, manage nutrient inflows)	Dryland dairy	Upper Latrobe R Catchment	Roberts (2011)					10%	1		
Wetlands and permanent waterways fenced to exclude stock and encourage vegetation	Typical dairy	Corner Inlet Catchment	Stott & Roberts (2012)	40%	1	20%	1	15%	1		
Ephemeral waterways fenced to exclude stock and encourage vegetation	Typical dairy	Corner Inlet Catchment	Stott & Roberts (2012)	25%	2	13%	2	10%	2		
All gullies fenced to exclude stock and encourage vegetation	Typical dairy	Corner Inlet Catchment	Stott & Roberts (2012)	20%	3						
Stock excluded from wet areas (alternatives provided), runoff minimised	Typical dairy	Corner Inlet Catchment	Stott & Roberts (2012)			10%	3	10%	2		
Effluent management (pond storage for all wet season runoff for later reuse)	Typical dairy	Corner Inlet Catchment	Stott & Roberts (2012)			10%	3	10%	2		
Actively eroding gullies fenced to exclude stock and encourage vegetation	Typical beef	Corner Inlet Catchment	Stott & Roberts (2012)	50%	1						
Permanent waterways fenced to exclude stock and encourage vegetation	Typical beef	Corner Inlet Catchment	Stott & Roberts (2012)	40%	2	20%	1	15%	1		
Landslips fenced and stabilised with vegetation	Typical beef	Corner Inlet Catchment	Stott & Roberts (2012)	35%	3						
Actively manage bare areas and reestablish pasture cover	Typical beef	Corner Inlet Catchment	Stott & Roberts (2012)			20%	1				
Ephemeral waterways fenced to exclude stock and encourage vegetation	Typical beef	Corner Inlet Catchment	Stott & Roberts (2012)			13%	2	10%	2		
Maintain ground cover in constructed drainage lines, stock access minimised when wet	Typical beef	Corner Inlet Catchment	Stott & Roberts (2012)			13%	2	10%	2		

4.3 Effectiveness of structural treatment measures

Structural treatment measures aim to reduce the adverse effects of excessive or contaminated runoff by physical treatment of a condition that has already occurred. They need not be located right at the source of the problem, which can be an advantage from a practical perspective. Treatment typically involves some form of storage, or filtration, or both. Storage can reduce peak flows that increase erosion, and allows time for some settling of particles and chemical reaction or biological uptake of dissolved species. Filtration can remove large material by physical obstruction, and finer and dissolved material by interaction with the filter media itself and with biofilms that tend to become established on the media.

Structural treatment measures that may find application in the rural area include ponds, wetlands, vegetated swales, vegetated biofilters or 'raingardens', and unvegetated media filters. Vegetated buffer strips are sometimes counted as structural treatment measures, but have been included here with on-farm management practices.

A number of papers have reported the performance of rural treatment measures, including Raisin & Mitchell (1995), Emmett et al. (1994), and Jing et al. (2002). Healy et al. (2007) have tabulated results from several further studies. Passeport et al. (2013) presented a detailed and practical review of structural treatment measures for total nitrogen reduction, some of which are suitable for agricultural areas, and provided a simple decision support table and an extensive reference list.

However, these structured systems lend themselves to more process oriented analysis, and they have been extensively analysed in the urban context. Water quality in storage-based systems has been modelled using the first order exponential decay principles of Kadlec (1995) and Kadlec & Knight (1996), further developed by Somes et al. (1998), Persson et al. (1999), (Wong et al. 2006) and others. Filter behaviour has been explored by analysis of published data (Wong et al. 2005, Appendix D), by means of extensive laboratory-scale studies (Zinger et al. 2007) (Lintern et al. 2011), and by monitoring of full-scale systems (Hatt et al. 2008). These and similar studies together form the basis of the MUSIC and Urban Developer models developed by the Catchment Hydrology and eWater CRCs.

Modelling the processes in a treatment facility means that individual sites can be compared according to their dimensions and attributes, rather than assuming a standard effectiveness for a given treatment type. If the contaminants in rural runoff are similar in all key respects to those in urban runoff, the urban models could be used unmodified in the rural area. If the rural and urban contaminants do differ in key respects (such as particle size distribution of sediments, or dissolved fraction of nutrients), but still approximately follow a first order exponential decay process, the urban models could still be used after recalibration. If the differences in behaviour of rural and urban contaminants are greater than this, further research and development of modelling processes will be necessary.

4.3.1 Treatment by storage

Prior to the modelling work noted above, Duncan (1998) assessed the performance of storage-based treatment systems (ponds, wetlands, and swales) described in the literature using qualitative indices to rank design features and data quality and relevance. That data set has now been reanalysed to separate highly urbanised sites from partially urbanised and rural sites. The results are shown in Figure 4-1 and Figure 4-2 below. Each graph plots performance against annual hydraulic loading, with highly urbanised sites (hollow markers) distinguished from less urbanised and rural sites (solid markers). Performance is expressed as output as a percentage of input, so that 1% represents almost complete removal (high performance) and 100% indicates no change (zero performance). Annual hydraulic loading is the mean annual flow divided by the surface area of the storage, and is used as a measure of storage size with respect to inflow. Figure 4-1 shows only the better quality data – flow weighted event monitoring of multiple events. Figure 4-2 shows all relevant data, including routine sampling and small sample sizes.

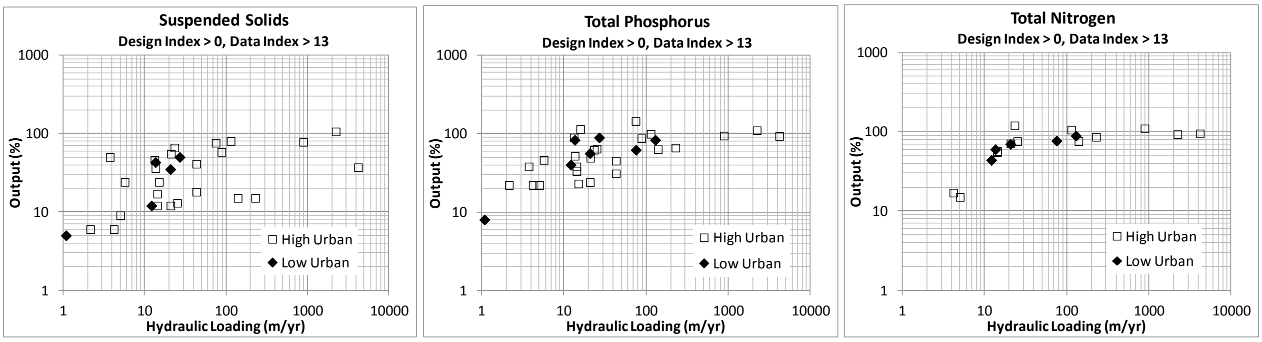

Figure 4-1: Output (%) versus hydraulic loading for good quality data

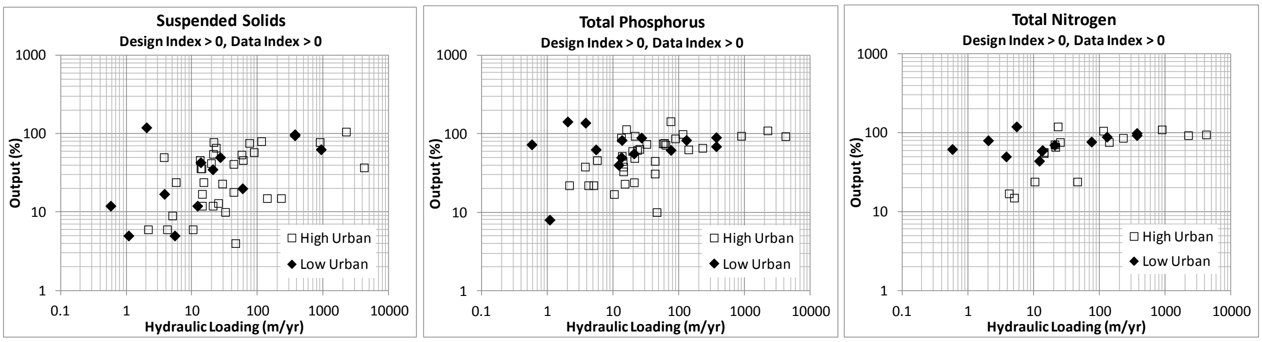

Figure 4-2: Output (%) versus hydraulic loading for all relevant data

Based on the better quality data in Figure 1, the less urban sites fall comfortably within the envelope defined by the high urban sites, and there is no suggestion of any consistent difference between the two groups. Using the larger set of all data in Figure 4-2, the two groups again match well for suspended solids, allowing for the larger scatter, which is to be expected. But the agreement is less satisfactory for the nutrients phosphorus and nitrogen. There is a tendency for performance to be poorer in the low urban group at low hydraulic loadings. This could be due simply to the greater scatter introduced by the less satisfactory data sets, but it could also represent a real difference in behaviour between the two groups. A consistent difference in nutrient speciation between the two groups (for example) could present a signal of just this form.

Water quality modelling based on exponential decay has proved to be satisfactory in the urban area. Given the similarity in range and form of the data in Figure 4-1 and Figure 4-2, and given that the mechanisms of contaminant removal are likely to be the same regardless of the inflow source, it is safe to assume that exponential decay modelling can also be used satisfactorily in rural applications. But given the possible differences in nutrient removal effectiveness in Figure 4-2, it is not safe to assume that the same calibrated model parameters will apply in both cases. Hence a program to recalibrate the models by means of monitoring and possibly more detailed literature review is recommended.

4.3.2 Treatment by filtration

Monitoring of biofilter and sand filter performance in treating specifically rural runoff appears to be particularly sparse. Healy et al. (2004) described the treatment of synthetic dairy waste, and Healy et al. (2007) provided an extended discussion and proposed further research. Ergas et al. (2010) achieved satisfactory removal performance by dosing an unvegetated multilayered filter with stored dairy farm runoff. Further studies of performance are available for the treatment of domestic wastewater, and particularly for urban stormwater runoff. But since the rate and effectiveness of treatment are likely to depend on the speciation of contaminants in the inflow, these studies cannot be used directly to assess rural performance. As for the storage based treatment options, the filter based treatment options need to build on the processes and models already developed in the urban area. And again, a program to confirm or recalibrate the models by means of monitoring and/or more detailed literature review is recommended.

4.3.3 Summary

The following conclusions can be drawn regarding structural treatment measures in the agricultural area.

- Studies of the performance of structural measures treating specifically rural runoff are not common in the literature.
- More extensive monitoring and modelling of structural treatment measures has been carried out in the urban area.
- Since the underlying treatment processes of the structural measures are the same regardless of the runoff source, model structure can be carried over from urban to agricultural applications.
- Since the rate and extent of treatment depends on the detailed speciation of the inflow contaminants, model parameters cannot necessarily be carried over from urban to rural applications. A program to recalibrate urban models to the rural environment is therefore recommended.

4.4 Conclusions

Farming activities are characterised by variability. The variability of farming operations carries through to output flows and contaminant exports, to the ecological outcomes in receiving waters, and to the effect of a given management practice or structural treatment measure. As a result, there is no single order of preference for mitigation measures, and any such ordering for general use would inevitably result in misdirection.

There is, however, some scope for conditional assessment of options, depending on the current type of land use, the current extent of best management practices, the likely level of landholder interest and support, and the agreed nature of the problems to be addressed. These conditional options are noted qualitatively in section 4.2 for the on-farm practices, and may be explored by modelling for the more structural off-site treatment measures.

The information about on-farm practices is sufficient to establish a short list of likely best performing management practices at a given site, but not enough to predict the resulting improvement accurately. To improve this situation, a program to monitor and analyse a representative sample of treated sites is recommended.

Models developed in the urban area for structural treatment measures are likely to be suitable in structure for application in the rural area. It cannot be assumed that urban model parameters will be appropriate for rural use. A program to recalibrate urban models to the rural environment is therefore recommended.

Management options take a variety of forms. They may be on-farm or off-site, mainly physical in operation or mainly behavioural, and may be specific to a particular land use or terrain type. Since any single treatment option is likely to be limited in its scope for improvement, an effective and efficient program is likely to comprise several components of different forms.

4.5 Recommended on-farm pollution reduction systems and practices

Rural activities, and hence runoff characteristics, are variable to the extent that optimum treatment strategies will always be site dependent. It is not possible to rank specific options in a way that will be generally applicable over the area of interest. However, it is possible to outline a strategy that will yield useful results immediately, with improved results and an expanding knowledge base into the future.

For on-farm management practices:

- Use the guidelines of section 4.2.6 and local expert opinion if available to choose management practices that will be effective for the given problem at the given site
- Monitor a representative sample of treated sites to improve knowledge of treatment effectiveness under local conditions.

For structural treatment measures:

- Use existing urban models to obtain indicative results and relative performance of structural treatment measures appropriate to the site, and select measures accordingly. Modify model parameters to account for any known differences in water quality descriptors (particle size distribution, dissolved versus particulate ratio, etc.)
- Monitor a representative sample of structural treatment measures to allow improved recalibration of urban models for local rural conditions.

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5 Spatial Characterisation

5.1 Review of current spatial data

Authors: Chris Walsh (UoM) and Joshphar Kunapo (UoM)

5.1.1 Overview

An inventory of spatial data was undertaken to compile a record of available spatial data for the MW region. There was particular emphasis on data requirements to populate Source Catchments and models to assess impacts of rural land management for each of Port Phillip and Westernport Bays. The inventory included the following spatial data layers:

- Landuse data
- Digital Elevation Models
- Hydrologic data
- Water Quality
- Ecological data.

The inventory consisted of an assessment of spatial and temporal coverage, resolution, data quality and level of integration among datasets. Our secondary objective was to identify gaps in data that could be filled, quality improvements that could be made, degree of integration required, and classes of land use that are likely to be useful for stream assessment (and potential cost of each improvements). The detailed inventory is provided below.

5.1.2 Landuse Data

There exist 8 current map layers with respect to landuse / land cover information for MW region as follows:

i. Detailed_LandUse_BBWW_DSS

ii. Impervious layer 2006

iii. MWlu_final

iv. Landuse layer developed by GraceGIS for 20 year vision template

v. Landuse (developed by MW for New bays catchment model) – 2012

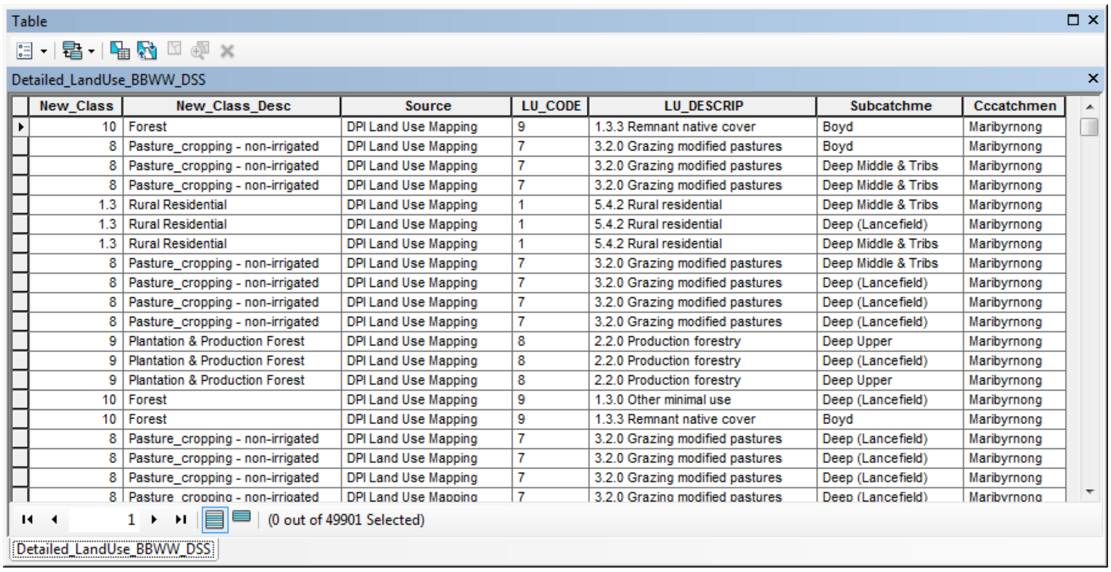
vi. Updated VLUIS layer from DEPI

vii. Farm Dams data

viii. Wetlands and water bodies by GraceGIS

Layer Name: Detailed_LandUse_BBWW_DSS

Description: Detailed landuse data provided by supplied by MW. As shown in Figure 5-1 below this data layer has 134 different landuse classes (Field Name: LU_DESCRIP) which are further grouped into 18 different categories (Field Name: New_Class_Desc).



Table

Detailed_LandUse_BBWW_DSS

New_Class	New_Class_Desc	Source	LU_CODE	LU_DESCRIP	Subcatchme	Cccatchmen
10	Forest	DPI Land Use Mapping	9	1.3.3 Remnant native cover	Boyd	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Boyd	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep Middle & Tribs	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep Middle & Tribs	Maribyrnong
1.3	Rural Residential	DPI Land Use Mapping	1	5.4.2 Rural residential	Deep Middle & Tribs	Maribyrnong
1.3	Rural Residential	DPI Land Use Mapping	1	5.4.2 Rural residential	Deep (Lancefield)	Maribyrnong
1.3	Rural Residential	DPI Land Use Mapping	1	5.4.2 Rural residential	Deep Middle & Tribs	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep Middle & Tribs	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong
9	Plantation & Production Forest	DPI Land Use Mapping	8	2.2.0 Production forestry	Deep Upper	Maribyrnong
9	Plantation & Production Forest	DPI Land Use Mapping	8	2.2.0 Production forestry	Deep (Lancefield)	Maribyrnong
9	Plantation & Production Forest	DPI Land Use Mapping	8	2.2.0 Production forestry	Deep Upper	Maribyrnong
10	Forest	DPI Land Use Mapping	9	1.3.0 Other minimal use	Deep (Lancefield)	Maribyrnong
10	Forest	DPI Land Use Mapping	9	1.3.3 Remnant native cover	Boyd	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong
8	Pasture_cropping - non-irrigated	DPI Land Use Mapping	7	3.2.0 Grazing modified pastures	Deep (Lancefield)	Maribyrnong

1 (0 out of 49901 Selected)

Detailed_LandUse_BBWW_DSS

Figure 5-1: Snapshot of attributes of Detailed_LandUse_BBWW_DSS layer

This data had been compiled from two original sources. The Victorian DEPI land-use map for the state of Victoria (2000-2001) was used for much of the region (green in Figure 5-2), with ground truthing corrections added subsequently by MW.

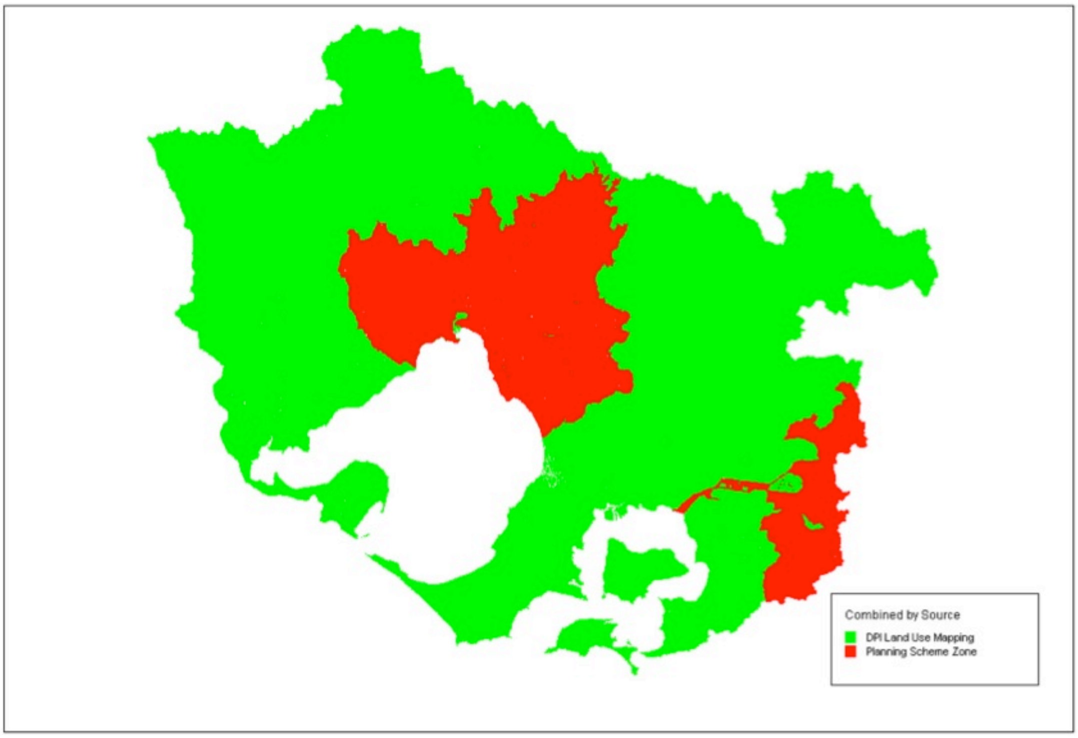


Figure 5-2: Map of areas covered by each data source

These data distinguished many different land use practices and were generally of a good quality. MW judged these data to be 84% accurate. A large area around the Melbourne metropolitan area and a smaller area in the upper Lang Lang and Bass catchments (red in Figure 5-2) were classified according to the Victorian Department of Sustainability and Environment (DSE) planning scheme zones 2006. Discrimination of land use practices in these areas was poorer.

Layer Name: Impervious layer 2006

Description: Grace Detailed-GIS Services (GraceGIS) developed this product as part of effective impervious modelling for MW. 35cm 4-band infra-red (IR) aerial photography of 2006 was used to extract imperviousness via automated methods for feature extraction. This is a fast look product and not an ortho rectified product. Road imperviousness which was hindered due to tree canopy presence on the aerial photos was added using road buffers method to compensate the loss of road imperviousness in the product.

One of the issues with the input 2006 photography is that the IR band was not corrected radiometrically to be seamless across the region. The cut of value between vegetation and non-vegetation varied drastically from area to area in this product. This has caused the automated output with varying degree of accuracy. This product resulted very good where there is little interaction of bare soils and dry areas with imperviousness. It is also found to be very good within urban areas. However, in some areas (mainly in rural), bare soils and very dry grass (non-green) areas resulted as impervious surfaces. However, considering the budget limitation for manual QA and fixing, the product was fit-for-the-purpose at that time.

Options for improvement: Now MW is equipped with a 2009 product of this IR ortho-corrected photography. It has 15cm product for most of the urban areas and 35cm product for rural fringe. The existing imperviousness model can be updated using this product to bring the product to better accuracy and currency.

Layer Name: MWlu_final

Description: Walsh, Webb and Danger (2013) made a number of changes to the Detailed_LandUse_BBWW_DSS (first layer) layer to develop this layer. The impervious data, developed by GraceGIS (second layer), was used in addition to better characterize urban areas. These impervious maps did not cover the rural Bunyip, Yallock, Lang Lang or Bass catchments. The only substantial impervious coverage draining to streams of interest in this region is in the town of Drouin and the major roads. Percentage impervious cover was estimated for each landuse polygon with >1% impervious coverage, and added as a field to the landuse data layer. As Drouin is >1km from a perennial stream, it was assumed that impervious surfaces were not connected to streams.

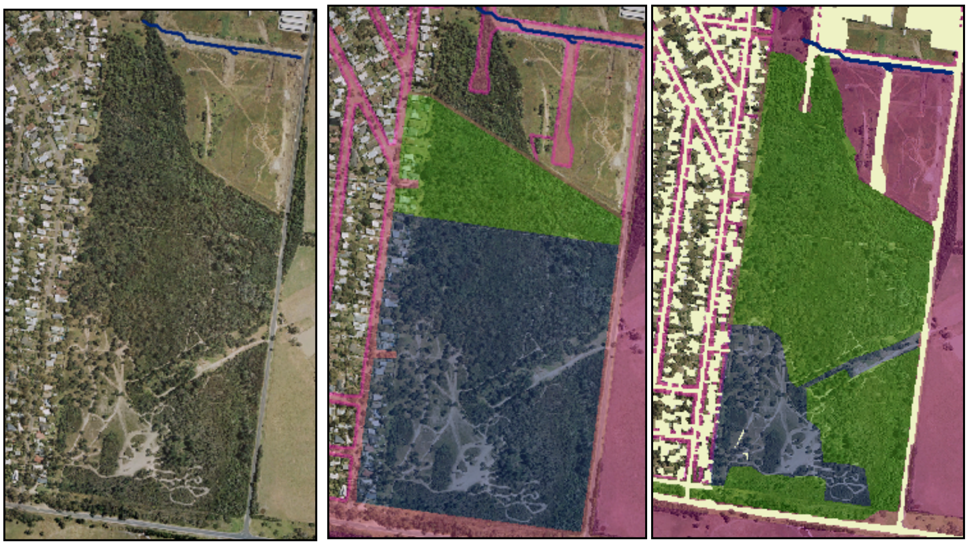
The 134 landuses recorded in the given MW landuse layer (Detailed_LandUse_BBWW_DSS) is far too many potential predictor variables for a statistical model, and classes were lumped into conceptually defensible groups (Table 5-1), while keeping the original 134 classes. The new classes were determined through consultation with MW staff, particularly with regard to the appropriate partitioning of agricultural practices. Several nominated categories were absent or almost completely absent from the study region (e.g. high-impact, non-irrigated perennial horticulture, and irrigated forest), and were therefore not considered further in analyses.

Following lumping, the data were ground-truthed using high-resolution satellite imagery (2004), resulting in manual reassignment for polygons incorrectly classified, and the splitting of large polygons that encapsulated multiple landuses. Across the entire study area, discrimination of Detailed_LandUse_BBWW_DSS between forest and cleared land was poor at small scales, particularly among areas classed as urban parks, rural residential, road reserves, and along stream frontages. As a result, the entire dataset was checked at small scales, using 2006 aerial imagery, and incorrectly classified areas of forest or tree cover were split and re-classified, and non-forested areas incorrectly classed as forest were similarly split and re-classified (Figure 5-3). While this process was conducted over the entire study area, particular care was taken to correctly classify forests along stream lines. During the process of forest redelineation and reclassification, any other misclassifications that could be confidently identified from aerial imagery were also corrected.

The CLASS_DESRIP 'Water' included some large water bodies, but not others (for instance the Maroondah and Upper Yarra reservoirs were not classed as water), and in most cases, large areas of surrounding land were classed as water. It also included aqueduct lines, and the wetted area (and beyond) of some, but not all, large waterways. Chris Walsh team reclassified waterways, aqueducts and land surrounding lakes and reservoirs to their dominant land cover, and restricted "Water" to areas of standing water. Large waterbodies were captured with high accuracy, but most small farm dams have not been captured.

Table 5-1: Landuse classes derived from the original 134 classes supplied by MW. L and H refer to low- and high-impact, respectively, as determined by MW staff. Lu_legend and code (field names in final analyses) refer to the final combination of landuse classes. For built urban land, impervious surface coverage was subtracted from the total area and the remaining area was classified as "pasture, grassland" or "Forest, tree cover"

Description	lu_legend	code
Urban areas with pervious areas dominated by turf/grass	Pasture, grassland	P
Urban areas with pervious areas dominated by forest	Forest, tree cover	F
Non-urban areas that are entirely turf/grass	Pasture, grassland	P
Non-urban areas that are entirely forest	Forest, tree cover	F
quarries and mines	Quarries, mines	Q
STPs	Wastewater treatment	STP
Tips	Landfill	LF
Forest - non-irrigated	Forest, tree cover	F
Pasture - non-irrigated	Pasture, grassland	P
Annual Horticulture/cropping - non-irrigated (classed as L by MW)	Ann horticulture (NI, LI)	AHNL
Annual Horticulture/cropping - non-irrigated (classed as H by MW)	Ann horticulture (NI, HI)	AHNH
Perennial Horticulture/cropping - non-irrigated (classed as L by MW)	Perr horticulture (NI, LI)	PHNL
Perennial Horticulture/cropping - irrigated (classed as L by MW)	Perr horticuture (I, LI)	PHIL
Perennial Horticulture/cropping - irrigated (classed as H by MW)	Perr horticulture (I, HI)	PHIH
Other intensive agriculture (animal, greenhouse, aquaculture)	Other agriculture (HI)	OIH
Water	Water	W
Roads lined by forest	Forest, tree cover	F
Roads lined by pasture	Pasture, grassland	P



a) b) c)

Figure 5-3: From left to right: a) Portion of 2006 aerial imagery (Dromana) used to check supplied land-use classification; b) Supplied land-use classification laid over the aerial imagery: unshaded = urban, light-pink = urban road, light-pink = pasture, green = forest, dark-grey = wastewater treatment; c) corrected land-use classification laid over the aerial imagery. All areas with obvious forest cover were reclassified as forest. Pervious urban areas and roads were classed as predominantly forest or grass (= pasture), and impervious areas from MW's impervious polygon data (cream) were subtracted from these urban areas to calculate pasture and forest cover in the urban areas

Layer Name: Landuse layer developed by GraceGIS for 20 year vision template

Description: This Landuse layer has been assembled from various sources and it has 5 classes as follows:

- Urban Existing
- Urban Future
- Forest
- Rural, and
- Water
    - Firstly, Detailed_LandUse_BBWW_DSS (also referred as PortsE2 layer) has been re-coded into 4 classes namely, forest, rural, urban and water. Note this work has no inputs from the layer MWlu_final.
    - Class R from DSCM_Scheme layer was extracted and merged with the urban class to form the class "urban existing". This urban existing class has been updated using aerial photos in some obvious parts.
    - Secondly, G and S classes from DSCM_Scheme layer were extracted and merged with Urban Growth Boundary layer (2005), to form "urban future" class. Some of these areas were manually updated based on MW inputs.
    - Thirdly, using recoded layer of Detailed_LandUse_BBWW_DSS forest layer has been extracted. To this forest 2008 layer was added to develop "forest" class.

- Fourthly, using recoded layer of Detailed_LandUse_BBWW_DSS "rural" layer has been extracted.
- Fifthly, using recoded layer of Detailed_LandUse_BBWW_DSS "water" layer has been extracted.

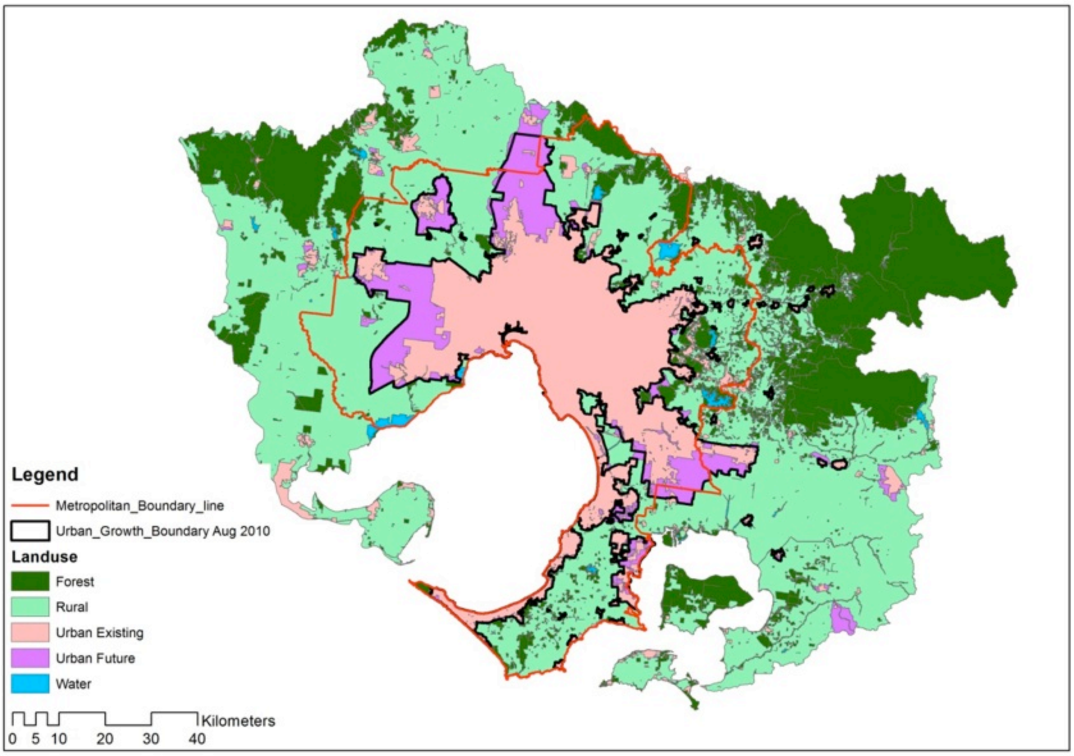


Figure 5-4: Landuse layer developed for 20 year template project

Layer Name: Landuse (developed by MW for New bays catchment model) – 2012

Description: This Landuse layer has been assembled from two sources; Detailed_landuse_BBW_DSS (portE2 layer, section 2.1) and GraceGIS 20-year template layer (section 2.4). It has 4 classes, namely, Forest, Rural (pasture/grass land), Urban and Water. These classes were ground truthed with 2009 aerial photos. Urban landuse has been extracted from GraceGIS layer. This layer has improved urban, improved forested landuse in Bass, Lang Lang and Bunyip areas.

Layer Name: Updated VLUIS layer from DEPI

Description: This layer is in preparation.

Layer Name: Farm Dams data

Description: MW confirmed existence of two datasets for farm dams.

1. Dam areas digitised from aerial photos for the Woori Yallock, Werribee, Little River and Maribyrnong catchments by SKM, and
2. DSE farm dams data for other catchments.

Layer Name: Wetlands and water bodies by GraceGIS

Description: GraceGIS developed a wetlands and water bodies layer for MW using LiDAR based depression model and aerial photos.

Possible options for developing a consolidated landuse layer

- Collect latest DEPI landuse data and use that as a base.
- Check the accuracy of the other existing landuse layers before you can use them to update the base layer.
- Using latest aerial photos to perform quality checks and adjustments as required.
- Develop a final consolidated and topologically consistent landuse layer by keep original DEPI classes as well as new classes for WSFD.

Gaps in available spatial data: It is likely that the above consolidation will inadequately characterise degree of stock access to streams, which is likely to be a strong driver of stream degradation associated with rural land use. A program of data collection of this variable, perhaps initially as a pilot to assess its importance to stream condition, is recommended.

5.1.3 Digital Elevation Models

LiDAR based elevation model exists for almost all the MW region. For those missing areas (mostly rural areas and undulating terrain) other DEMs with cell size ranging from 5-10m are available, which can be used to fill the gap.

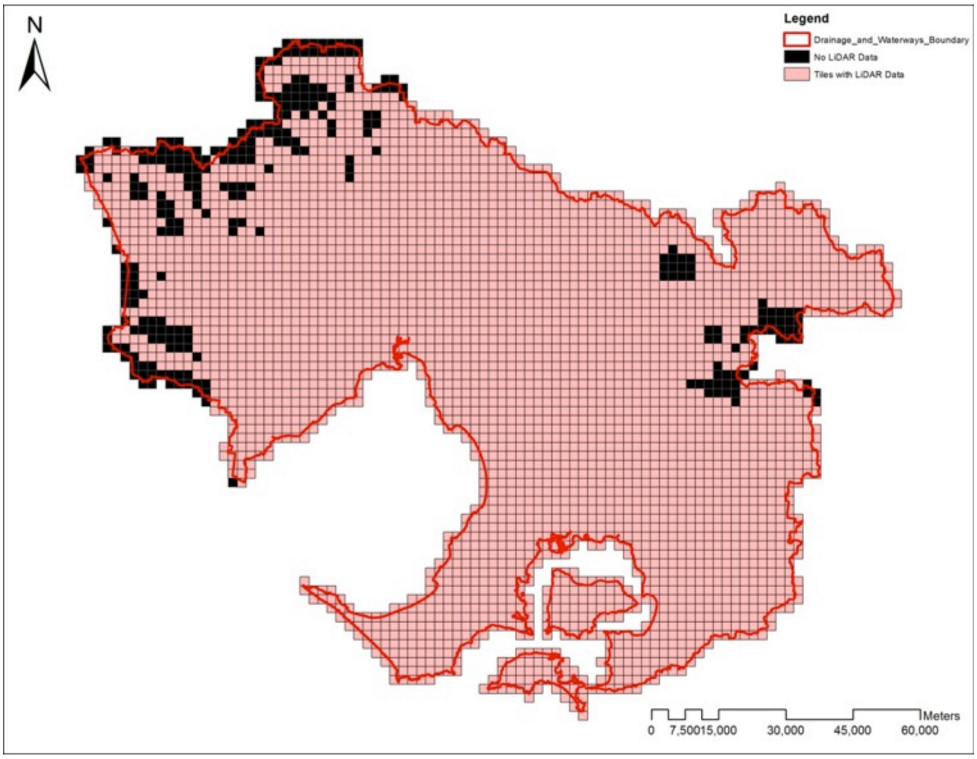


Figure 5-5: Map showing LiDAR data availability for MW region

5.1.4 Hydrologic Data

There are 4 layers to form the drainage network for the MW area, namely:

- DR_Natural_Waterway_Centreline
- DR_Channel_Centreline
- DR_UGround_Centreline
- DR_Waterway_Connector

As shown in Figure 5-6 and Figure 5-7, they form a connected drainage network.

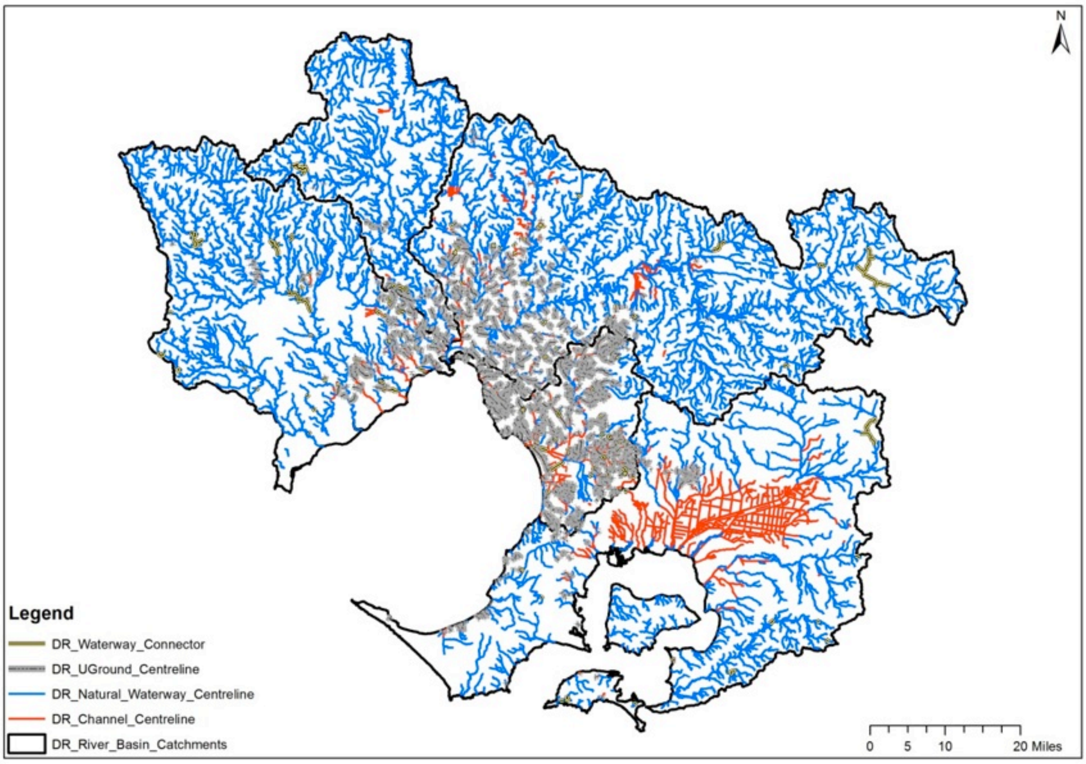


Figure 5-6: **Map showing drainage network for MW area**

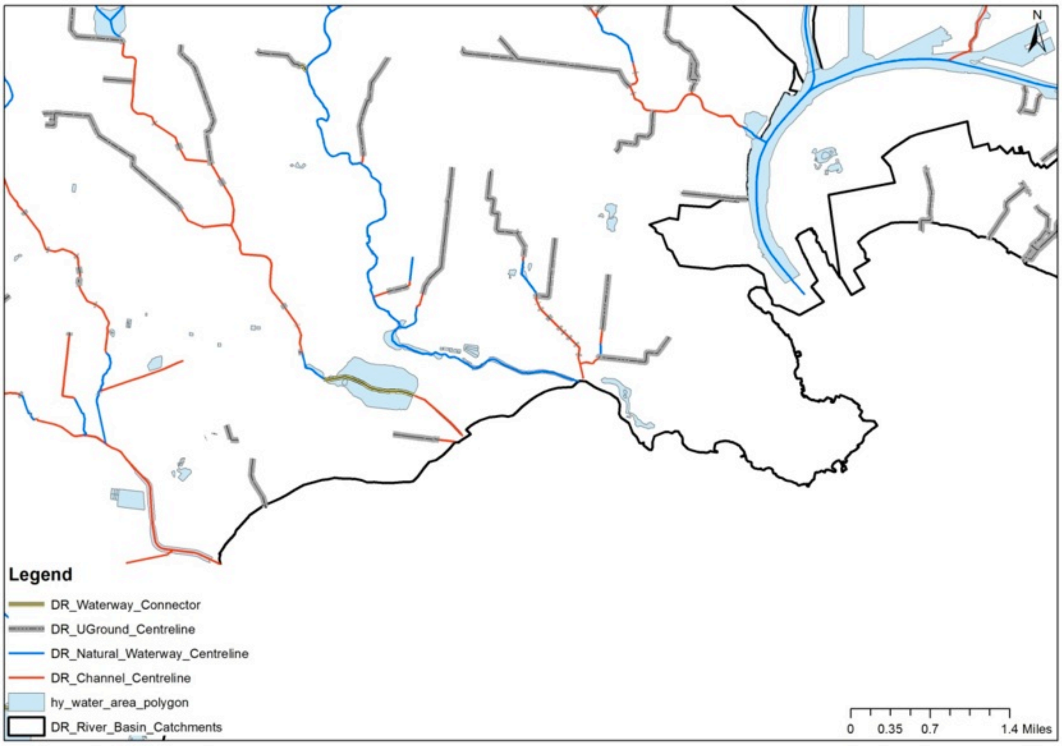


Figure 5-7: Natural waterways, Channel centreline, Underground pipes and water bodies connector together they form a connected drainage network

Options for improvement: Above MW waterways is to be developed. Where to begin a realistic stream network is an issue and a method need to emerge to fix this. The authors are working on this to identify a defensible method to identify the beginning of the stream.

5.1.5 Water Quality

Water quality data sets are reliant on the location of the monitoring sites, which are currently being corrected. Figure 5-8 shows the water quality site locations. Figure 5-9 shows a typical display of water quality records.

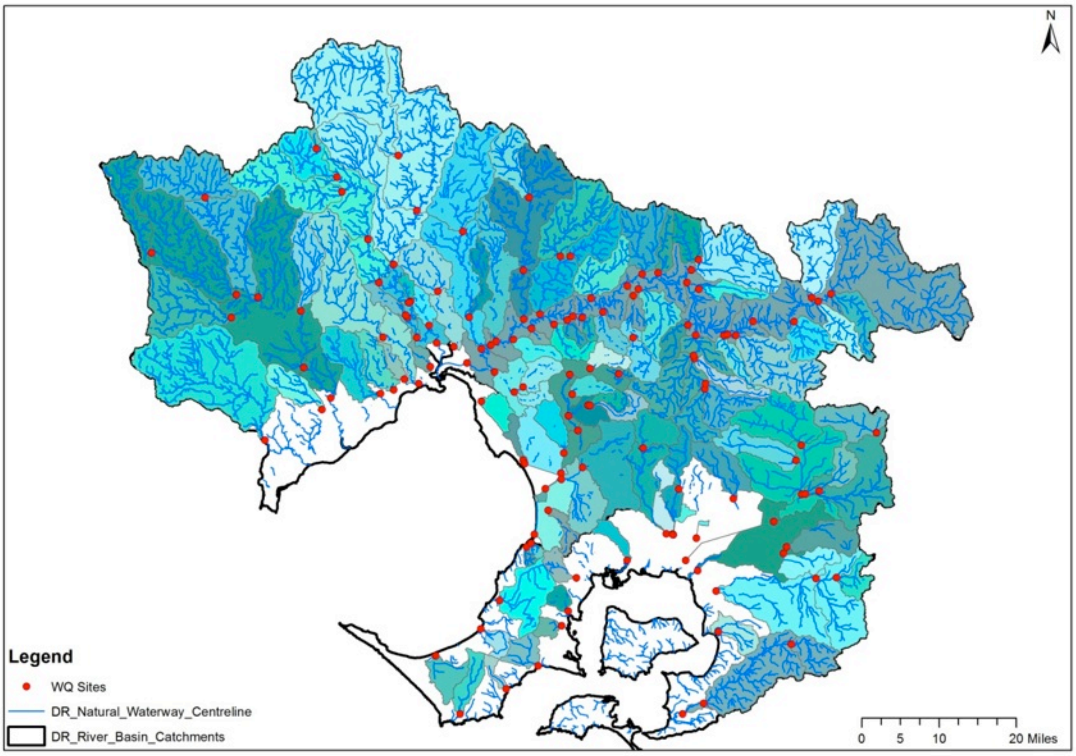


Figure 5-8: **Map showing MW Water Quality sites and their catchments**

Table

WQ Sites

COMPLETE_S	SITE_CODE	InlineBudD	STREAM	LOCATION	MAP_REF	EASTING	NORTHING	New_to_DB
MAARU0010	MAARU		Arundel Creek	at Annandale Rd	MEL 14 K1	309475.91	5825138.96	
MABAR0005	MABAR	BAR	Barringo Creek	at Wooling Rd	ESMAP 596 J11	289878.13	5856932.43	Y
MADEE0309	MADEE	DPW	Deep Creek	at Kennedys Lane	ESMAP 598 G12	306876.06	5855540.18	
MADEE0625	MADEE	DPW	Deep Creek	at end of Kinnear rd	MEL 365 D3	310721.62	5844020.37	
MADEE0868	MADEE	DPW	Deep Creek	at Bulla Rd	MEL 177 A6	305968.92	5832817.79	
MAJAC0152	MAJAC	JKN	Jacksons Creek	at u/s Sunbury-Riddells Rd	ESMAP 620 F7	295177.33	5847962.56	
MAJAC0342	MAJAC	JKN	Jacksons Creek	at bridge upstream Sunbury Rd	MEL 382 G5	300612.14	5838004.43	
MAJAC0398	MAJAC	JKN	Jacksons Creek	at Organ Pipes NP, at walkway ~200 u/s Rosette Rock	MEL 3 C3	302908.97	5829002.62	
MAMAR1294	MAMAR	MRB	Maribyrnong River	at Arundel Rd	MEL 14 H2	309055.09	5824895.9	
MAMAR1311	MAMAR	MRB	Maribyrnong River	Brimbank Park Ford (upstream Taylors Creek), Keilor	MEL 14 H8	308712	5821784	
MAMAR1346	MAMAR	MRB	Maribyrnong River	Canning Street Ford, Avondale Heights	MEL 27 B8	310712	5817584	
MAMAR1401	MAMAR	MRB	Maribyrnong River	end of Newsom St. 500m d/s of Ascot Vale MD	MEL 28D11	314861.29	5816482.51	
MARID0079	MARID		Riddells Creek	at u/s Gisbourne-Kilmore Rd	ESMAP 620 E4	294167.67	5850992.76	
MASTE0026	MASTE		Steele Creek	Rose Avenue, Niddrie	MEL 27 J2	313212	5820084	
MASTO0017	MASTO		Stony Creek W	Bena Street, Yarraville	MEL 41 J11	313562	5811384	
MATAY0018	MATAY		Taylors Creek	at walkway d/s Green Gully Rd	MEL 14 G8	308411.95	5822246.54	
WBCHE0015	WBCHE		Cherry MD	U/s of Kororoit Creek	MEL 54 E5	308167.18	5808893.06	
WBKOR0227	WBKOR	KRT	Kororoit Creek	Millbank Drive, Deer Park	MEL 25 D7	303732	5817644	
WBKOR0278	WBKOR	KRT	Kororoit Creek	Racecourse Road, Altona	MEL 55 C8	311112	5807964	
WBLAV0069	WBLAV	LVT	Laverton Creek	at track off Valente St, D/s Kayes Drain, U/s weir	MEL 53 J10	305920.22	5806687.87	
WBLER0150	WBLER		Lerderderg River	at O'Brien Rd	ESMAP 617 G8	266717.32	5846759.12	
WBLER0323	WBLER		Lerderderg River	at at Bacchus March Rd	MEL 334 H9	277733.24	5825976.06	
WBLIT0407	WBLIT	LTL	Little River	at You Yangs Rd	ESMAP 730 J7	279135.62	5796182.66	
WBLOL0049	WBLOL	LOL	Lollypop Creek	at at u/s Black Forest Rd	MEL 205 A8	291018.11	5802539.43	
WBPAR0154	WBPAR	PRW	Parwan Creek	at at Parwan	MEL 339 D8	272170.89	5821721.48	
WBSKE0092	WBSKE		Skeleton Creek	Ayr Street, Laverton	MEL 53 B12	303212	5805924	
WBYAN0092	WBYAN	TLN	Yangardook Creek (=Toolern Creek)	at Bridge Rd	MEL 343 A5	286612.97	5823085.89	
WEWER0100	WEWER		Werribee River	at Old Melbourne Rd, Ballan	VICR 294 H3	255501.87	5835207.91	
WEWER0353	WEWER		Werribee River	at end of McGregor Ct	MEL 333 G8	273232.4	5826439.88	
WEWER1337	WEWER		Werribee River	at Cobbledicks Ford Rd	MEL 227 B10	287210.07	5811386.76	
WEWER1394	WEWER		Werribee River	at Black Forest Rd	MEL 205 F2	292839.73	5804978.33	
WPARA0063	WPARA		Ararat Creek	at Nar Nar Goon- Longwarry Rd	MEL 319 J10	376610.11	5784015.34	
WPBAL0104	WPBAL	BLC	Balcombe Creek	Uralla Drive, Mt Martha	MEL 145 C11	327952	5762784	

0 (0 out of 136 Selected)

WQ Sites

Figure 5-9: Typical attributes of WQ sites

Grace Detailed-GIS Services developed sub-catchments for the existing water quality sites (Figure 5-8).

Options for improvement: Some locations were reported to be away from the natural waterways network, which need to be amended.

5.1.6 Ecological Data

Description: Macroinvertebrate data from biological monitoring programs in the Melbourne region (including data from MW and EPA Victoria) is well curated, consisting of >6,000 samples, collected from >850 sites since 1992 (Figure 5-10).

A similarly large (but longer-term) record of fish collection data has been collated, but requires substantial curation (under way) to allow its use for a wide variety of purposes.

A similarly large record of platypus collection data is also available.

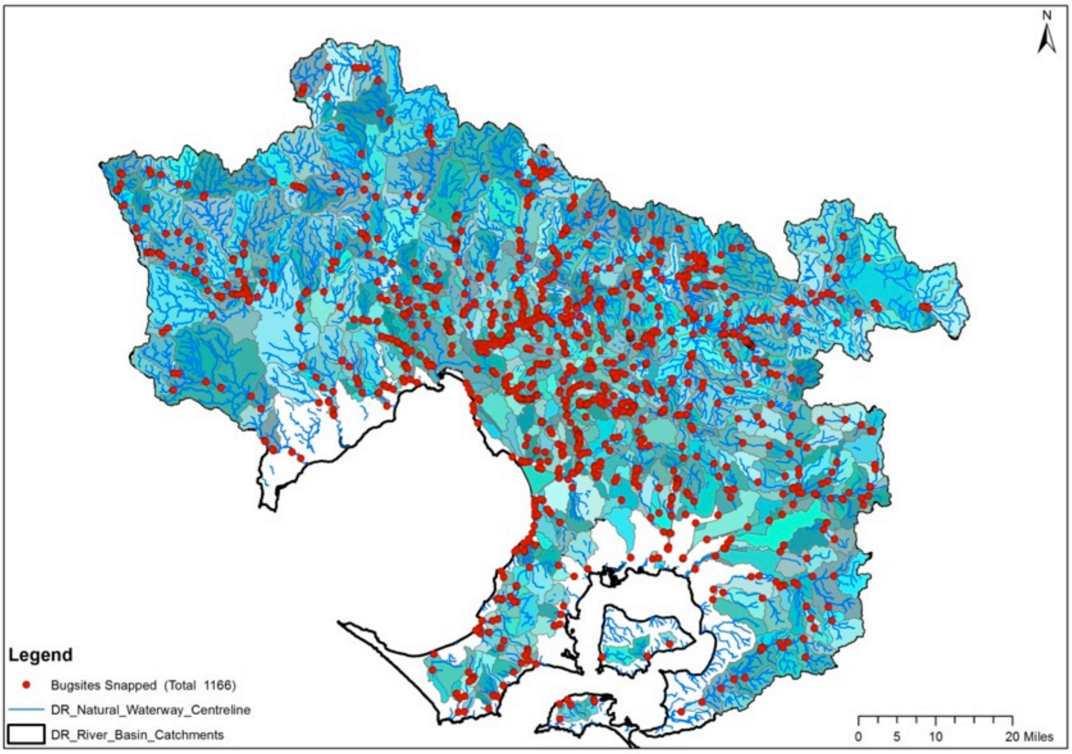


Figure 5-10: Map showing MW Bug sites and their catchments

5.1.7 Recommendations

The recommendations for improvement of the current spatial data set are provided below:

- **Land use:** it is likely that land use data consolidation will inadequately characterise degree of stock access to streams, which is likely to be a strong driver of stream degradation associated with rural land use. A program of data collection of this variable, perhaps initially as a pilot to assess its importance to stream condition, is recommended.
- **Digital elevation models (DEM):** LiDAR based elevation model exists for almost all the MW region. For those missing areas (mostly rural areas and undulating terrain) other DEMs with cell size ranging from 5-10m are available, which can be used to fill the gap.
- **Hydrologic data:** the 'above MW waterways' layer is to be developed. Where to begin a realistic stream network is an issue and a method needs to emerge to fix this. The

authors are working on this to identify a defensible method to identify the beginning of the stream.

- **Water quality:** some locations were reported to be away from the natural waterways network. These need to be amended.

5.1.8 References

Walsh, C. J., Webb, J. A. and Danger, A. (2013). Data preparation: collation of biological data, and determination of land-use and other predictor variables. In: Walsh, C.J. and Webb, J.A. *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.* Melbourne Waterway Protection and Restoration Science-Practice Partnership Report 13-1. Department of Resource Management and Geography, The University of Melbourne

5.2 Development of improved and adaptive spatial land use data

Authors: Elizabeth Morse-McNabb (DEPI)

5.2.1 Overview

MW has identified 12 rural land use classes it would like to include for enhanced catchment modelling to predict sediment and nutrient loads in rural areas. The classes are:

1. Dryland grazing (pasture)
2. Dryland Dairy
3. Dryland Perennial Horticulture
4. Irrigated Dairy
5. Irrigated grazing (pasture)
6. Irrigated Annual Horticulture
7. Irrigated Perennial Horticulture
8. Softwood Plantation forestry
9. Hardwood Plantation forestry
10. Native Woody Vegetation
11. Rural residential/small landholders (0.4 – 20 hectares)
12. Intensive animal production

The Victorian Land Use Information (VLUIS) data set has been created by DEPI. It maps each cadastral parcel across the state for land tenure, use and cover type and therefore can be used as a source of information for MW's land use needs, both for modelling and for other applications such as land use planning. The VLUIS dataset covers both public and private land; urban through to natural land use environments and captures annual changes in land cover types.

Previous spatial land use information used by MW has been based on the land use data that pre-dates the VLUIS data known as the Catchment Scale Land Use Map; this was also produced by DEPI. The 'Review of spatial data for the MW region for potential use in understanding the impacts of land uses' by Joshphar Kunapo (University of Melbourne) identifies three land use datasets (section 5.1.2) that incorporate some or all of the data from an original refresh of the Catchment Scale Land Use Map (Detailed_LandUse_BBWW_DSS layer). Whilst the Catchment Scale Land Use Map is useful as a reference during the time of production, it should not be used for current studies as it is now at least 10 years old.

5.2.2 Rural Land Use Classes

The VLUIS dataset has three tiers of land information and a water register based water activity that can be combined to produce the 12 classes required by MW. The section below describes the components of the VLUIS dataset that could/will contribute to each of the 12 MW classes. Alternative breakdowns could also be tailored for MW's requirements if required.

- Dryland grazing (pasture): will include areas that do not have an active water use licence and have a 'livestock grazing' (apart from dairy because it is a separate class) or 'mixed farming and grazing' land use.
- Dryland Dairy: will include areas that do not have an active water use licence and have a land use code of '525 – Livestock Production – Dairy Cattle'.
- Dryland perennial horticulture: will include areas that do not have an active water use licence and have a land use code of either; 'Orchards, Groves and Plantations' and 'Vineyard'.
- Irrigated Dairy: will include areas that have an active water use licence and a land use code of '525 – Livestock Production – Dairy Cattle'.
- Irrigated grazing (pasture): will include areas that have an active water use licence and have a 'livestock grazing' (apart from dairy because it is a separate class) or 'mixed farming and grazing' land use.
- Irrigated Annual Horticulture: will include areas that have an active water use licence and 'Market Garden – Vegetables', 'plant/tree nursery' and 'commercial flower and plant growing (outdoor)' land use classes.
- Irrigated Perennial Horticulture: will include areas that have an active water use licence and have a land use code of either; 'Orchards, Groves and Plantations' and 'Vineyard'.
- Softwood Plantation forestry: will include areas with class '570 – Softwood Plantation'.
- Hardwood Plantation forestry: will include area with class '571 – Hardwood plantation'
- Native Woody Vegetation: will include most (not water) classes in the land use codes beginning with 9 for 'National Parks, Conservation Areas, Forest Reserves and Natural Water Reserves'.
- Rural residential/small landholders (0.4 – 20 hectares): will include areas with class '117 – Residential Rural/ Rural Lifestyle'.
- Intensive animal production: will include areas with land use codes beginning with 54, 'Livestock – special purpose fencing, pens, cages, yards or shedding, stables' and includes classes such as poultry (egg and broiler) production, piggeries and horse studs. It will also include codes beginning with 58, 'aquaculture', where they exist.

5.2.3 Areas of Improvement Required for a Rural Land Use Map

- Annual and perennial horticulture – accuracy
  - In the case of annual and perennial horticulture, confidence in VLUIS data depends on the location, i.e. known horticultural areas are reliably mapped but small isolated farms may not be. Desk-top interpretation of current aerial photography could be used to check the annual horticulture class and improve where necessary.
- Dairy farms – accuracy
  - Dairy farms have been re-mapped in west Gippsland using a collection of EPA and DEPI project datasets. Aerial photo interpretation of this area would improve accuracy.
- Native Woody Cover – within parcel accuracy

- Large areas of woody and non-woody land cover can be highlighted using the land cover component of VLUIS. However, further refinement of areas that are identified as non-woody will be needed from the MW 'treed' layer.

5.2.4 Key findings

Change detection

In the Port Phillip and Westernport Catchment most land use change appears to be occurring on the fringes of urban areas, changing from a rural land use class to a rural residential class (or subdivisional land before being further subdivided into small house blocks). It is difficult to see the detail at the whole catchment scale; however, large area changes in land use classification from a primary production land use code to rural residential land use code are clearly visible to the north of Melbourne (Figure 5-11).

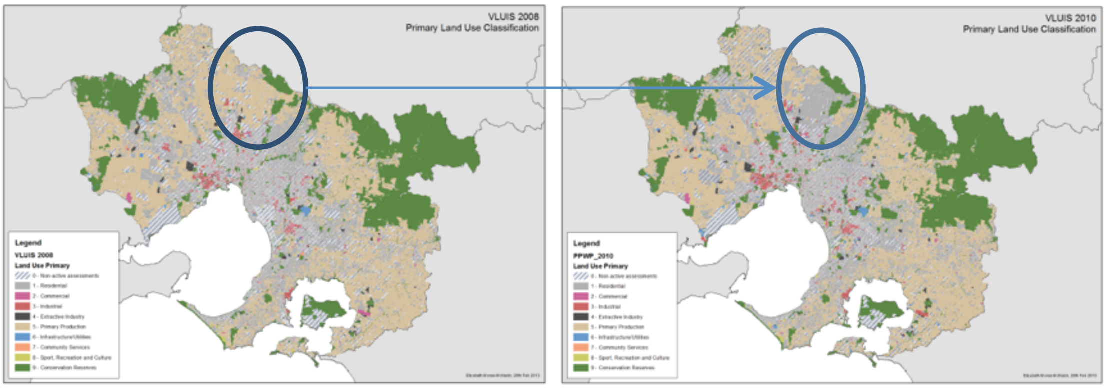


Figure 5-11: Most changes from a rural land use to a residential land use in the area highlighted have happened over a 4 year period. In 2006 the area was classed as 'mixed farming grazing', in 2008 it was classed as 'rural lifestyle' and in 2010 as 'residential use development land', with 2012 cadastres and photography showing houses being built in small subdivisions.

The changes shown in Figure 5-11 need a combination of regular land use data updates and regular cadastral updates to identify changes in land use and the proportional changes across the catchment. These two aspects (land use class and subdivision) are difficult to sequence because cadastral change is constant and land use classification is only captured every second year through the Valuer General Victoria (VGV) general revaluation process. The VLUIS dataset combines the land use class (from VGV general revaluation) with the relevant cadastre year, taken in the same month as the VGV general revaluation.

Data Updates

Updating data will not be difficult once the initial VLUIS translation (see options below) has been done. Generally speaking the update interval for land use data depends on the intended use and outcomes required from the data. In a catchment such as Port Phillip and Westernport where land use is rapidly and extensively changing, frequent updates (2-3 yearly), would be desirable from a land use planning perspective. For catchment modelling purposes, updates in the order of 5 yearly would probably be sufficient.

The timing of data updates should be based on MW reporting, planning and project requirements. It is important to allow adequate time to collect any new input data and validate for accuracy. Very frequent (i.e. yearly) updates will require exponentially more resources to ensure that in the limited time available to create the data there is also time and capability to validate for accuracy.

Accurate land use data relies on many other datasets for validation and therefore the cost to update a land use dataset should also include aerial photography purchase, interpretation and analysis. Ideally a spatial database should be designed with future edits and updates in mind, how these will be included (i.e. over write old data or add temporal layers) and when. Development of such a 'system' for MW should be done outside the constraints of any one project to ensure it can meet all user's needs.

5.2.5 Recommendation

The new MW land use product should use the VLUIS 2010 data as the base, and include (either by integration or interoperability[1]) the most current impervious/pervious data layer, the most current treed extent, MW's hydrological data and dams and water bodies from the Corporate Spatial Data Library.

Two options are possible for the creation of an appropriate base rural land use layer for MW across the Port Phillip and Westernport Catchments. The costs outlined below are for a once only update to the land use data. Ongoing maintenance and updates of land use data will require further analysis and planning (discussion below).

Option 1

- A simple translation of VLUIS land use and cover codes to match the 12 MW classes. There would be no translation of residential, commercial etc. land use classes and therefore the data would only be useful to this rural land use project.
- Validation of annual horticulture and dairy farm properties using aerial photography interpretation.
- The data would be supplied by DEPI to MW as a single layer that can be incorporated with other existing MW data (such as impervious/pervious and treed mapping) by MW. Indicative resourcing and costs are provided in a separate document.

Option 2

- A complete translation of VLUIS data (land tenure, use and cover) based on all MW requirements, which would therefore include urban, rural, treed, water and infrastructure classes. This would allow the data to be used for many more projects across MW. The data would be supplied as a single layer that can be incorporated with other existing MW data as in option 1.
- Validation of annual horticulture and dairy farm properties using aerial photography interpretation.
- The data would be supplied by DEPI to MW as a single layer that can be incorporated with other existing MW data (such as impervious/pervious and treed mapping) by MW. Indicative resourcing and costs are provided in a separate document.

[1] An interoperable system links data sets but does not integrate them into one static dataset.

5.2.6 References

Department of Primary Industries (2010) Victorian Land Use Information System, State Government of Victoria, Melbourne

5.3 Development of consistent spatial soils data

Authors: David Rees (DEPI) and Mark Imhof (DEPI)

5.3.1 Overview

MW requires land use and soils information for a range of applications including land use and management planning and other decision-making such as quantifying nutrient loads through catchment modelling into Port Phillip and Westernport Bays. Improving land use information has been dealt with in a complementary report by Morse-McNabb (2013).

There have been a number of legacy soil and landscape survey reports completed in the region dating from 1942-2002. Each has covered parts of the region and been completed at a range of scales and survey intensities, see Victorian Resources Online: http://vro.dpi.vic.gov.au/dpi/vro/soilsurv.nsf/searchcatchment?CreateDocument. There has not been a whole-of-region consolidation of this mapping into a consistent 1:100,000 scale product, as has occurred in a number of other Catchment Management Regions. We recommend that there is a need for a consistent soils product that can be used for a number of purposes, of which the need for modelling is the key focus for this report.

In addition to the legacy soil and landscape survey work, MW recently contracted a review of soils information work (Annett and Spry, 2012). This work assessed the extent and availability of relevant, existing soil data and information to be used for assessing the risk of soil erosion as assessed by the Land Use Information Management (LIUM framework). The report concluded that for the purposes of LUIM the existing base of soils data and information was sound and there was no need for undertaking additional soil survey work.

Whilst the existing soils information was assessed as suitable for coarse-scale assessment using LUIM, the same cannot be concluded if MW wants to make investment decisions on individual farms and through assessing the effectiveness of farm management practices linked to water quality outcomes in the Bays, such as has been commenced in the Rural Lands Program through the use of the Rural Lands Metric.

The report ‘Review of existing modelling options to assess the impacts of rural land management on water quality’ (Roberts, Beverly and Barlow 2013, see section 6 in this report) outlines potential options for improved hydrologically-based modelling. Options 1 and 2 do not make use of soils/land use information adequately, whereas Options 3 and 4 can utilise such information. This report is based on premise that Options 3 or 4 are preferred for modelling.

On this basis, soil/landform mapping at 1:100,000 scale minimum would be useful as a basis for hydrological modelling and other uses. This level of coverage is already available in a number of Victorian catchment regions.

5.3.2 Soil attributes required for hydrological modelling.

Modelling of land management practices require soils information to parameterise the model to represent hydrological behaviour. Modelling requirements for hydrological models (such as the *Howleaky* model commonly used by DEPI and in Queensland’s Great Barrier Reef catchments) is outlined below:

- Soil depth layer
- Ksat – hydraulic conductivity (mm/d)
- Air dry Moisture
- Wilting point
- Field capacity
- Saturated Water content
- Plant Available Water Content (PAWC) for total soil depth
- Water Holding Capacity (WHC) per layer
- Bulk density
- Curve Number (CN) bare
- CN reduction
- Soil Crack state
- Maximum Infiltration into cracks
- Stage1 Soil Evap_U mm
- Stage2 soil Evap_Cona
- USLE_K metric
- Runoff
- Drainage
- Evaporation
- Transpiration.

The above attributes are those required to assess soil-water movement. Other factors such as inherent nutrient levels would also be useful both in terms of biomass potential and hazard (salinity).

By delineating the soil type of an area many soil factors can be estimated using a look-up table based on national data (McKenzie et al, 2000). Whilst useful this does not apply specifically to Victoria and would be associated with greater error than investing more effort into adequate soil attribution.

5.3.3 Currently available soils coverage

Available soil/landform studies are shown in Figure 5-12 with additional comments made for each of Westernport and Port Phillip outlined below.

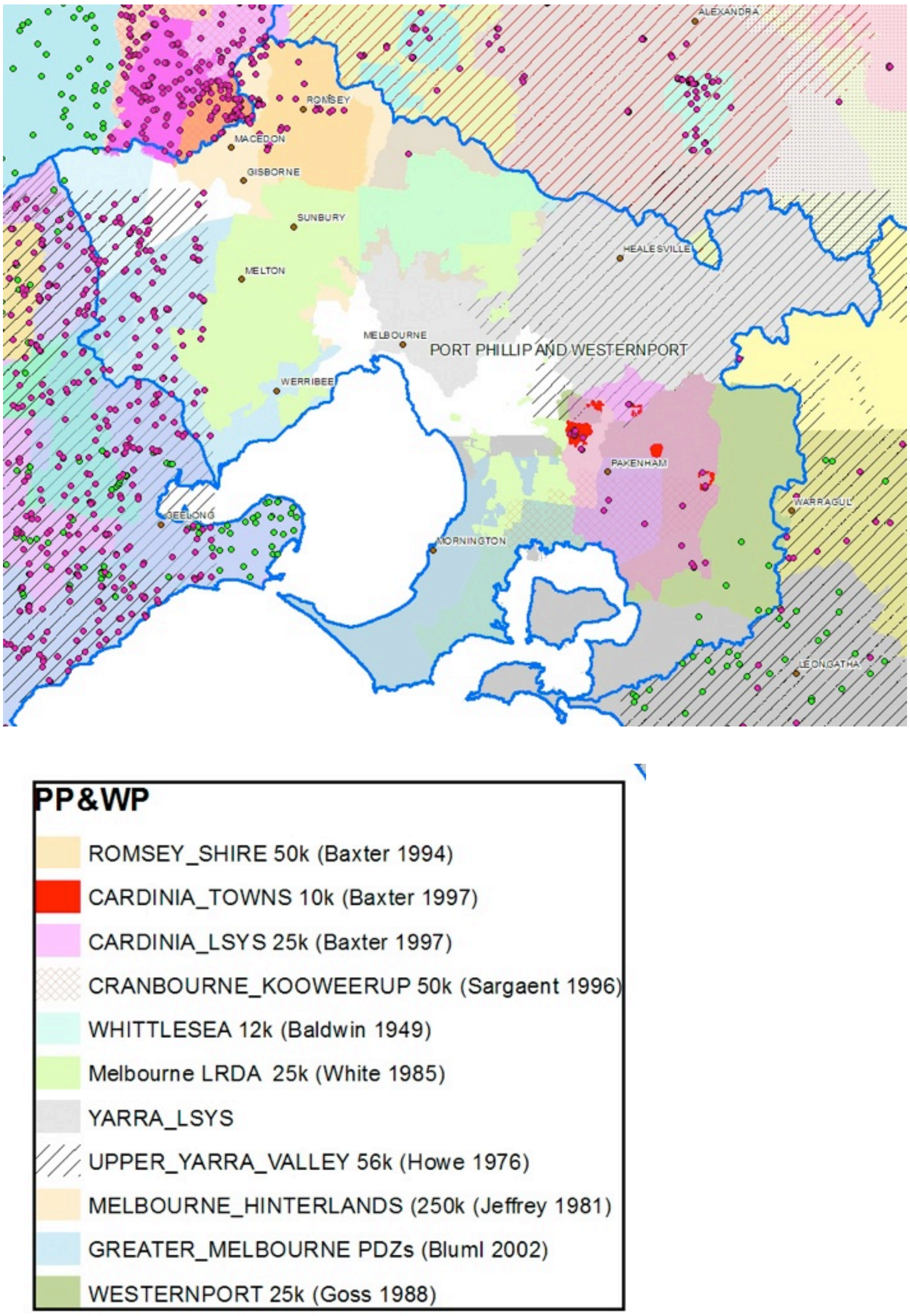


Figure 5-12: **Soil/landform studies in Port Phillip and Westernport catchments.**

Westernport

For Westernport the major sub-catchments are the Eastern Mornington Peninsula; and eastward to the catchment boundary including, French and Phillip Islands.

In broad terms, freehold land from Mornington Peninsula eastward and south of the latitude of Cheltenham is covered by consistent mapping at 1:100,000 scale with some at 1:50,000 in the Cranbourne to Koo-Wee-Rup area. Public land comprising some of the upper catchment areas is neither mapped nor sampled. Despite a range of studies carried out, the freehold land is best characterised by the coverage as shown on the DEPI VRO website, based on work by Sargeant and Imhof et al (1996, 2013).

While there are examples for most units on VRO in terms of soil pit photos and profile descriptions, there may be a need for further examples, particularly if a finer scale (resolution) is required (such as 1:50,000). More specific soil physical data may be required for the proposed project than currently exits.

Port Phillip

For Port Phillip the broad sub-catchments are the Bellarine Peninsula, Werribee, Maribyrnong, Yarra, Dandenong and the Mornington Peninsula. The Bellarine and Mornington Peninsulas have existing 1:100,000 mapping, Werribee and Dandenong only have consistent catchment coverage of 1:250,000 scale (there is some 1:25,000 scale information for Werribee but limited close to Melbourne). The Yarra catchment has finer scale coverage (1:60,000 scale) however there is currently very limited soils attribution and this would need to be rectified to enable use for soil-water modelling. The area to the north of Melbourne has intermittent mapping at 1:100,000 or finer, with a consistent coverage at 1:250,000. Associate information (attributes) are scarce, especially those highlighted in Table1.

Below we have provided examples of the gap filling which would be required to provide consistent 1:100,000 coverage:

- **Yarra Valley:** More reliable data in this catchment would mean sampling the existing Land System units (i.e. 32 units in total). See Upper Yarra Valley and Dandenong Ranges study. In addition to soil pit descriptions (which each take 4 days work; identification of site/ permission, excavation, description, sampling, rehabilitation, part lab access component) there are costs associated with planning, travel, data compilation, synthesis, report preparation. One description per unit is token and will not provide any information around within-unit variability. Ideally there should be additional descriptions per unit for consistency checking, with potentially more sampling in strategic areas and less in other less-strategic areas.
- **West of Melton**: new survey of gap area, consolidation of 1:250 000 mapping. Compilation only = 4 weeks. Compilation and new gap survey= 5 months, enhanced mapping and compilation = 9 months
- **Shire of (Gisborne area):** Compilation 2-3 weeks. Compilation and new mapping compared with Romsey Shire = 4 months (limited mapping 2 months)
- **North of Melbourne and east of Sunbury**: Compilation only = 4 weeks, added survey (4 months)
- **Catchment 15 (Powelltown)**: compilation 2 weeks, added survey 2 months

5.3.4 Achieving consistent coverage for Melbourne Water catchments at 1:100,000 or 1:50,000 scale

More analysis of information would be required for areas northwest and west of Melbourne as there is a range of studies with limited specific information as well as gap areas in information. Some of the sources identified by the consultants are quite old and therefore some factors may not be adequately measured currently.

The options outlined below allow for different intensities and sophistication of data. The minimal requirement would seem to be to create a consistent as possible data suite of soil information across the Port Phillip and Westernport catchments at 1:100,000 scale.

Furthermore, whilst much of the available soil/landform data has been identified here, there still needs to be a decision made as to the degree of data generalisation and derivation that is considered acceptable for this exercise.

If most of the CMA were to be subject to further survey there would be savings compared with each surveying individual sub-catchments. Time assessments allow for one experienced field soil scientist, and half-time GIS operator.

Procedure

Clearly there is a cost involved with collecting more information and if finer-scale information is required (for example 1:50,000 compared with 1:100,000 scale) then the amount of effort required rises exponentially. Finer scale (1:50,000) information would be worth considering if finer scale assessment, such as consideration of riparian vegetation responses are required. Several options are outlined, depending on data and associated uncertainty and:

- The complexity of existing data would require resolving boundary issues resulting from differences in scale and purpose of previous surveys;
- Attribution or derived attribution of those polygons (map units) which needs knowledge of attributes required as well as their measurement;
- Data compilation and integration with existing datasets so that it can be presented in a useable form for use by non-specialists.

In broad terms the options are:

- **Status quo:** Use 'McKenzie look-up tables' to derive specific functions (as required by the *Howleaky* model)
- **Enhanced soil type definition:** Gather more information to better describe land systems and still use McKenzie tables
- **Enhance soil descriptions, improve mapping of soils and sampling:** to include specified factors (e.g. wilting point)
- **Enhance soil descriptions and sample for all data requirements including soil infiltration** (for two depths – i.e. surface and subsoil horizons).

In Table 5-2 the approximate number of key sites are proposed. For the intensive 1:50,000 scale, more field tests would be carried out than only morphology, particle size analysis (PSA) and exchangeable cations. Enhanced sites would be sampled for bulk density and infiltration (at two depths – i.e. surface and subsoil horizons). The refinement of factors to be sampled can be discussed once decisions on modelling type and intensity have been made. As discussed above, the number of sites for 1:50,000 scale mapping and attribution would ideally be four times that for 1:100,000 mapping and attribution.

Table 5-2: Minimum approximate no of key reference sites*

Area	Desk top (D)	D + 1:100K Low intensity	D + 1:100K High intensity	D+1:50K Low intensity	D+1:50K High intensity
West of Melbourne /Kilmore	nil	≥ 10	≥ 15	≥ 24	≥ 30 (enhanced)
North of Melbourne	nil	≥ 6	≥ 10	≥ 12	≥ 15 (enhanced)
Yarra Valley	nil	≥ 10	≥ 13	≥ 22	≥ 28 (enhanced)
SE of Melbourne (incl WP)	nil	≥ 10	≥ 15	≥ 24	≥ 30 (enhanced)
Total	nil	36	55	84	105

*Does not include check/inspection sites

Indicative resourcing and cost are provided in a separate document.

5.3.5 References

Annett, S. and Spry, S. (2012). 'Soils on land – not in waterways', information needs analysis, Final Report to Melbourne Water (RMCG, Melbourne, Victoria).

McKenzie, N. J., Jacquier, D. W, Ashton, L.. J. and Creswell, H.P. (2000). Estimation of Soil Properties Using the Atlas of Australian Soil. CSIRO Land and Water technical report 11/00.

Morse-McNabb, E (2013). Melbourne Water Land Use Data Requirement, Report to Melbourne Water as part of the Rural Lands Program Position Framework.

Roberts, AM, Beverly, C and Barlow, K (2013). Review of existing modelling options to assess the impacts of rural land management on water quality. Report to Melbourne Water as part of the Rural Lands Program Position Framework.

Sargeant, I.J. and Imhof, M.P. (1996, 2013). Major Agricultural Soils of West Gippsland –as published on the Victorian Resources Online website.

6 Landscape Modelling

Authors: Anna Roberts (DEPI), Craig Beverly (DEPI) and Kristen Barlow (DEPI)

6.1 Overview

This section discusses existing modelling options which links rural and land use impacts on catchment loads (nitrogen, phosphorus and sediment in particular). The approach needs to build on MW's investment to date, principally in MUSIC (for urban impact assessment) and also Source Catchments (rural land use impacts). The scope of the report has been thus constrained, and with the exception of adding the internationally recognised SWAT model, has not explored a wide range of modelling approaches.

The model options need to be capable of incorporating major soil and land use classifications that have significant impact in nutrient and sediment loss within the Port Phillip and Westernport catchments. Consideration of options also needs to include data limitations, calibration and monitoring information (see section 7 in this report) as well as the capacity to be linked to an economic optimisation framework. The report needs to address the requirements for achieving adequate coverage of minimum land use/soil types to be used for modelling as well as addressing considerations of MW developing in-house capacity or outsourcing for running developed models.

Below we present six modelling options, increasing in the level of complexity, and their capacity to address sources of sediment and nutrient impacts from surface and groundwater. For options 1-4, later options are mostly additional to the preceding options (except that option 3 does not require all of option 1 to be done). Option 5 is independent of other options, whereas 6 builds on option 1. Model comparisons are summarised in Figure 1 and Tables 1 and 2, followed by more detailed analysis of each model's strengths, weaknesses and other performance criteria. At the end of the report overall recommendations are provided.

6.2 Comparison and summary of models

The key characteristics and data requirements of each of the proposed options are summarised (Figure 6-1, Table 6-1 and Table 6-2). The transition from Options 1 to 4:

- Increases the predictive capability of the catchment modelling framework
- Increases spatial resolution
- Replaces the nutrient generation rate estimates with physics-based nutrient dynamic modules
- Increases the capacity to test BMPs and land management options
- Increases data requirements.

Options 1 and 2 do not make use of soils/land use information adequately whereas options 3, 4, 5 and 6 use soils and land use information (as per recommendations in section 5.2 and 5.3 using VLUIS and soil/landform mapping at 1:100,000). Note that discussions with MW suggest that rural land use needs to include categories of dryland extensive grazing, dryland dairying, irrigated pasture dairy, irrigated pasture other, annual horticulture, perennial horticulture, plantation forestry, native vegetation, rural residential and intensive animal production. Urban land use needs to include townships, industrial land and ‘other’.

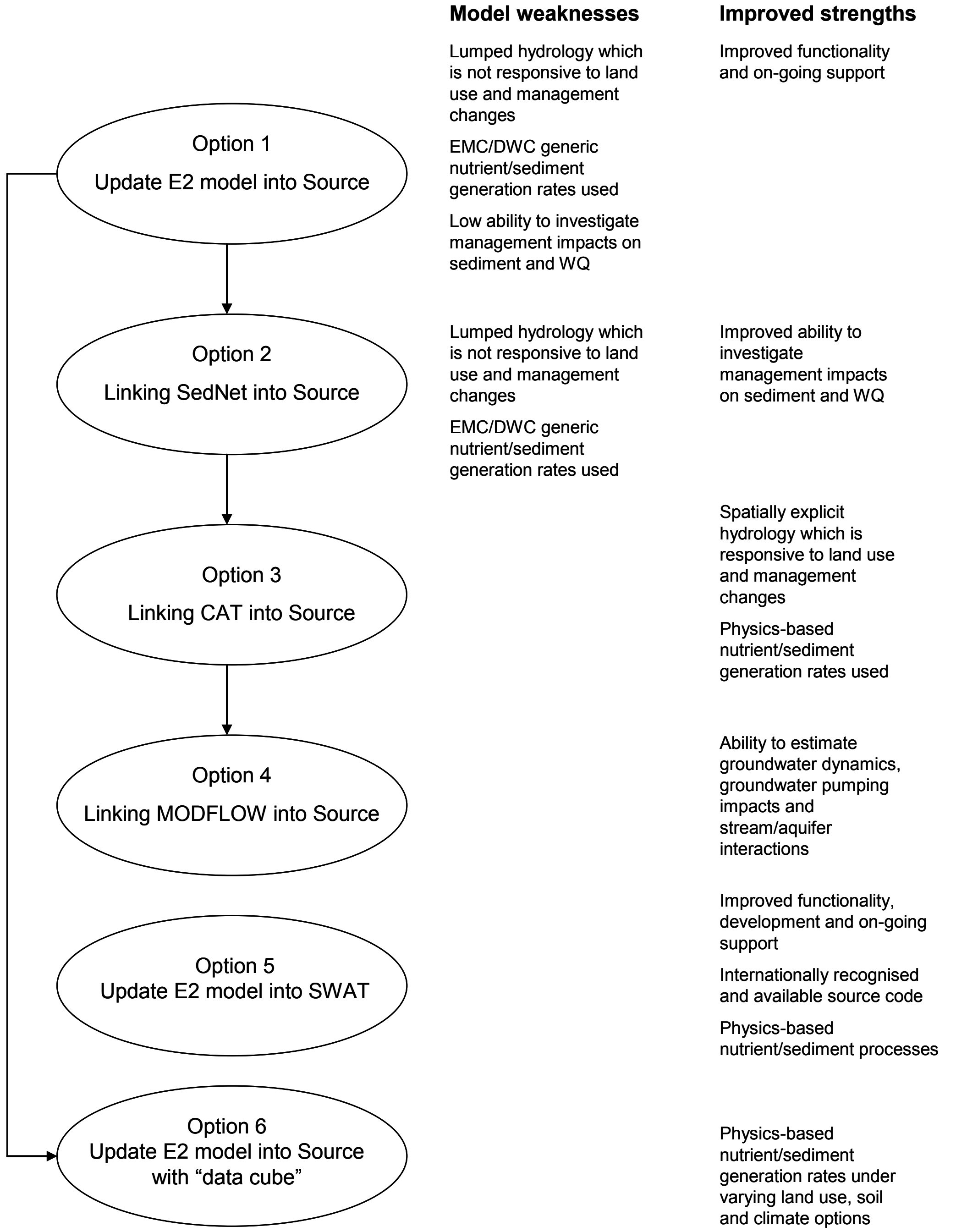


Figure 6-1: Summary of model weaknesses and strengths associated with each option

Table 6-1: Model characteristics for each of the proposed options

Desired Modelling Characteristic	Option 1 Translate E2 to Source Catchments	Option 2 Migrate SedNet into Source Catchments	Option 3 CAT into Source Catchments	Option 4 Develop links to Modflow	Option 5 Translate E2 to SWAT	Option 6 Translate E2 to Source Catchments with data cube
Type	Conceptual	Conceptual	Physics-based	Physics-based	Physics-based	Conceptual
Predictive capability	Limited	Limited	Very good	Very good	Very good	Limited
Scale	Lumped	Lumped	Spatially explicit	Spatially explicit	Lumped	Lumped
Time step	Daily	Annual	Daily	Daily/variable	Daily	Daily
Able to link with other models/frameworks	Yes (via plug-ins)	Yes (via plug-ins)	Yes (via plug-ins)	Yes (via plug-ins)	Yes (via plug-ins)	Yes (via plug-ins)
Runoff generation processes	RRL[1]	RRL[1]	Explicit[2]	Explicit[2]	Explicit[2]	RRL[1]
Ability to model dairy management	No	No	Yes	Yes	Yes	No
Ability to model grazing management	No	No	Yes	Yes	Yes	No
Ability to model crop management	No	No	Yes	Yes	Yes	No
Ability to model forest management	No	No	Yes	Yes	No	No
Nutrient generation/transport process[3]	EMC/DWC	EMC/DWC	N & P dynamics	N & P dynamics	N & P dynamics	EMC/DWC
Ability to account for fertiliser management	No	No	Yes	Yes	Yes	No
Ability to account for irrigation management	No	No	Yes	Yes	Yes	No
Sediment generation/transport - hillslope	No	Yes	Yes	Yes	Yes	No
Sediment generation/transport - gully	No	Yes	Yes	Yes	No	No
Sediment generation/transport - streambank	No	Yes	Yes	Yes	No	No
River routing, extractions and diversions[4]	Yes	Yes	Yes	Yes	Yes	Yes
Account for lag and attenuation	Yes	Yes	Yes	Yes	Yes	Yes
Groundwater	No	No	No	Yes	No	No
Account for groundwater pumping	No	No	No	Yes	No	No
Model documentation	Good	Good	Good	Good	Good	Good
Custodian	Licensed	Licensed	DEPI	USGS (freeware)	USDA (freeware)	Licensed

[1]RRL: rainfall-runoff libraries including AWBM and Simhyd which are calibrated simple bucket models.

[2]Explicit: runoff generation processes are explicitly modelled based on soil/water/plant interactions.

[3]Nutrient processes have been classified as either user defined generation concentration rates (EMC/DWC) or process based representation of soil/water/plant/fertiliser/animal interactions (N & P dynamics).

[4]River routing: River operations and management (including routing) assumed to be available by linking with Source Rivers.

Table 6-2: Data requirements for each of the proposed options

Model Data Requirements	Option 1 Translate E2 to Source Catchments	Option 2 Migrate SedNet into Source Catchments	Option 3 CAT into Source Catchments	Option 4 Develop links to Modflow	Option 5 Translate E2 to SWAT	Option 6 Translate E2 to Source Catchments with data cube
Land use	Yes	Yes	Yes	Yes	Yes	Yes
DEM	Yes	Yes	Yes	Yes	Yes	Yes
Time series climate	Yes	Yes	Yes	Yes	Yes	Yes
Time series stream flow	Yes	Yes	Yes	Yes	Yes	Yes
Time series water quality	Yes	Yes	Yes	Yes	Yes	Yes
Soil mapping	No	Yes	Yes	Yes	Yes	Yes
Soil profile attribution	No	Yes	Yes	Yes	Yes	Yes
Hillslope erosion mapping/estimates	No	Yes	Yes (with SedNET)	Yes (with SedNET)	Yes (with SedNET)	No
Gully erosion mapping/estimates	No	Yes	Yes (with SedNET)	Yes (with SedNET)	Yes (with SedNET)	No
Streambank erosion mapping/estimates	No	Yes	Yes (with SedNET)	Yes (with SedNET)	Yes (with SedNET)	No
Dairy management/practice	No	No	Yes	Yes	Yes	Yes
Grazing management/practice	No	No	Yes	Yes	Yes	Yes
Crop management/practice	No	No	Yes	Yes	Yes	Yes
Forest management/practice	No	No	Yes	Yes	Yes	Yes
Fertiliser management/practice	No	No	Yes	Yes	Yes	Yes
Irrigation management/practice	No	No	Yes	Yes	Yes	Yes
River extractions and diversions	No	Yes	Yes	Yes	Yes	No
Groundwater aquifer characterisation	No	No	No	Yes	No	No
Time series groundwater hydrograph data	No	No	No	Yes	No	No
Groundwater pumping schedules	No	No	No	Yes	No	No

6.3 Option 1: Enhance current approach (convert E2/WaterCast into Source Catchments)

Outline of approach

This option involves the translation of the existing PortsE2 model into the Source Catchment framework. An evaluation application of the Source Catchments framework was undertaken for the Yarra River catchment (eWater, 2010) with the key finding that the Source Catchments model provided a flexible tool for catchment modelling. Model enhancements embedded in Source Catchments offers improved functionality and value-adds the significant past investment in the PortsE2 model.

Strengths (what it can do)

Source Catchments offers a range of utility not available in the original E2 framework including (1) links to Source Rivers to account for river management/operations and river extractions and diversions, (2) numerous rainfall-runoff modules, (3) auto-calibration of rainfall-runoff modules, (3) links to the parameter estimation and sensitivity analysis module PEST and (4) capability to develop customised plug-ins to enable the linking of various external models which may also be of different construct. The plug-in capability significantly enhances the useability of the model and will be used to link the catchment modelling framework with other MW modelling packages such as MUSIC and the Stormwater Quantification Tool (SQWT). The model also has good technical support (fee-for-service arrangements) and is able to be used by a range of model users and non-specialists.

Weaknesses (what it can't do)

Source Catchments does not explicitly use soils and land use data, and thus the spatial variability of land use, soil type, slope and topography is not used at all to inform the model. Instead, a series of lumped hydrographic response units (HRU) are defined within sub-catchments derived based on digital elevation data. The hydrological response of each HRU is simulated using a simple bucket model in which the unsaturated zone is represented as a single store with connection to a deeper store that represents the saturated groundwater. The parameters that characterise each store are typically non-physical and are defined using the calibration process. The Yarra application adopted the SIMHYD rainfall-runoff model which requires nine parameters.

The adoption of a lumped hydrologic approach limits the ability of this framework to assess the impacts of agricultural management on water quality, sediment and nutrient transport. Additionally this model requires the user to define EMC and DWC generation rates to estimate nutrient and sediment delivery to streams. Previous studies have shown that these parameters are highly variable and that model predictions are very sensitive to these estimates.

The weaknesses of the Source Catchment model framework are:

- The parameters for the rainfall-runoff models are non-physical and require calibration to historical stream gauge data

- The SIMHYD rainfall-runoff model has been shown in past studies (DEPI Ovens study, Melbourne University Farm Rivers and Markets project) to poorly represent low flow conditions (primarily due to the adopted bucket model conceptualisation)
- The rainfall-runoff models have poor predictive capability as it is fitted to past historical conditions such that changes to land use extent and management invalidate the fitted non-physical parameters
- The catchment delineation process does not preserve spatial specificity as it adopts a lumped catchment representation
- The model is poorly equipped to represent land management changes, including BMPs, as soil/water/plant interactions are not explicitly modelled
- The model poorly describes connection to groundwater and stream/aquifer interactions. The impact of groundwater pumping cannot be simulated.

In the context of water quality studies, a significant additional weakness of the commercially available Source Catchment model framework is that it is not linked to SedNet and as such does not predict gully or streambank processes. However, links to SedNet have been developed and may be available to research partners including MW. This needs to be confirmed.

Linkage between this option and MUSIC

The MUSIC model can be linked using the plug-in application capability of Source Catchments. It is proposed that outputs from MUSIC be incorporated as inputs into nodes within the node-link network developed for the study area.

Inclusion of soil, land use and management

This option does not require or utilise revised soil mapping, soil attribution or land management information. Revised land use data would be utilised to redefine the hydrologic response units within each sub-catchment.

Calibration considerations

The model calibration is based on matching historical stream flow and water quality data. This data should have already been compiled for the pre-existing E2 model application but would need revision to extend the data set to capture the most recent data.

Potential to inform in-stream ecology

Output from the model will include stream flow and in-stream constituent concentrations and state for each day throughout the simulation period. As such, these predictions have the potential to inform the process of estimating the condition of in-stream ecology. Previous studies have used such an approach to assess stream and in-stream habitat condition.

Capability required to develop and modify the model to suit future needs

This option assumes that the migration from E2 to Source Catchments is relatively simple and mechanistic which could be undertaken using non-specialists. Ideally this option could be undertaken by MW staff but could easily be out-sourced. The recalibration is expected to be relatively simple given that the E2 models are available in the Source Catchment framework. This implies that the existing E2 model parameterisations are compatible with, and transferrable to, the Source Catchment framework.

The Source Catchment model is designed to be used by non-specialists and practitioners. It is recommended that MW foster and maintain in-house capability to run the model and undertake simple scenarios that are catered for in the existing framework. It seems strategically sound for an organisation responsible for managing sediment and nutrient impacts from rural and urban land uses to at least have the capacity to run scenarios itself.

If MW only wants the capacity to run models, and not further develop models (we'd argue that model development capacity could also be justified in an organisation the size of MW) then more complex scenarios could be evaluated by external providers (such as Melbourne University, DEPI or appropriate consultants) based on the benchmark model configuration held by MW. This would ensure that complex scenarios developed external to MW would be compatible with that held by MW and would be returned to MW for archiving and future development.

Summary

This approach alone is not recommended, being insufficient for the following reasons:

- Doesn't account for any spatial (soil, land use, management) variability
- Doesn't include sediments – only N and P based on user defined generation rates
- Cannot predict impacts from rural land use change (so cannot provide a defensible basis for future scenarios or investment)
- Cannot provide guidance on whether streambanks, gullies or land uses have the major impacts, only whole sub-catchments
- Groundwater impacts not included.

6.4 Option 2: Migration of SedNet into Source Catchments

Outline of approach

This option enhances the capability of the Source Catchment framework to include SedNet thereby enabling the estimation of streambank and gully erosion and nutrient transport processes. Previous studies (DEPI Avon Richardson, Vigiak et al. 2011 and Accountable Dairy) have identified that streambank and gully processes contribute significant sediment and nutrient loads. Ignoring these processes means that previous studies have attributed elevated contributions from hillslope and/or groundwater with the results that mitigation strategies have been misdirected. The original SedNet model adopted an annual timestep, though the CRC eWater has explored/developed a daily timestep version. As part of the approach, the various SedNet model configurations would need to be evaluated to develop the appropriate plug-in.

Strengths (what it can do)

This option will enhance the predictive capability of Source Catchments by enabling the estimation of streambank and gully contributions.

Weaknesses (what it can't do).

The major weaknesses identified in option 1 remain.

Linkage between this option and MUSIC

Straightforward, same as for option 1.

Inclusion of soil, land use and management

No, as for option 1

Calibration considerations

Straightforward, as for option 1.

Potential to inform in-stream ecology

This option aims to enhance the estimation of suspended sediments and sources of N and P by the inclusion of streambank and gully processes. As such, these improved predictions have the potential to better inform the process of estimating the condition of in-stream ecology.

Capability required to develop and modify the model to suit future needs

This option requires expertise of model developers and programmers. It is recommended that any module development be undertaken by appropriately skilled external providers with an understanding of the physical processes to be modelled and translated into a predictive tool (DEPI, Melbourne University). It is further recommended that the development and testing of plug-ins be undertaken jointly by external providers with relevant experience and MW staff. Once developed, the model could be run by MW

Summary

This approach enables contributions from gullies and streambanks to be discriminated from land use impacts. Whilst better than option 1 it is not recommended as sufficient because it:

- Doesn't account for any spatial (soil, land use, management) variability
- Cannot predict impacts from rural land use change (so cannot provide a defensible basis for future scenarios or investment)
- Groundwater impacts not included

6.5 Option 3: Integration of the CAT Model into SourceCatchments

Outline of approach

The Catchment Analysis Tool (CAT) has been developed by DEPI to assess the impacts of land management on catchment dynamics, including productivity, surface water and groundwater. CAT contains a suite of commonly used farming systems and forestry models which mean that contributions from different land use, soil type, landscape position and management practices can be accounted for. It has been developed and used for over 10 years in DEPI. CAT has been used to inform Victorian government policy and the approach has been published in the peer-reviewed literature (Beverly et al. 2011).

This option aims to replace the existing lumped rainfall-runoff model used in Source Catchments with the spatially explicit suite of farming system models contained in CAT. The farming system models have the capability to simulate soil/water/plant interactions on a daily time-step with consideration for livestock, irrigation and fertiliser management. This option would (1) significantly improve the predictive capability of the model; (2) enable testing of best management practices at the farm management scale; and (3) account for landscape position.

Note that the commonly used model called PERFECT (used as the basis for the Queensland Howleaky model which we have used extensively) could be used as an alternative to CAT, however PERFECT poorly describes pasture based enterprises, does not simulate forest systems nor does it explicitly include nutrient dynamics with feedback to plants.

Strengths (what it can do)

This option would eliminate the major limitations of the current SourceCatchments framework whilst preserving the SedNet and Source Rivers capabilities. Implementation of this option would result in a catchment framework with equivalent or superior capabilities to contemporary international models such as MikeShe, SWAT and Basins. The strengths of the model would include:

- The estimation of daily water balance and vegetation dynamics for each spatially explicit land management unit
- The estimation of daily nutrient dynamics for each spatially explicit land management unit thereby reducing the uncertainties associated with user defined EMC/DWC estimates
- The ability to test BMP for targeted land use and/or spatially explicit land management units
- The ability to estimate streambank and gully erosion processes and their contribution to in-stream suspended solids and nutrient loads
- The ability to incorporate river operations and management using the Source Rivers model capabilities.

Weaknesses (what it can't do)

An added consideration of this approach is the additional computational overhead and data requirements. However this is not a weakness as preliminary data sets are currently available for the study area and the computational overhead is acceptable given the enhanced predictive functionality and capability.

The major weakness relates to the characterisation of groundwater processes including stream/aquifer interactions, groundwater pumping and groundwater discharge to surface features.

Linkage between this option and MUSIC

Same as for option 1.

Inclusion of soil, land use and management

Yes, this is its major strength. Commonly available spatial data sets are used as inputs to the model and include soil classification maps, digital elevation data and land use. Previous studies have used Land use data classified using the Australia Land Use Mapping (ALUM) classification Version 6 (BRS 2006) (http://adl.brs.gov.au). The ALUM taxa describe land cover against which management strategies have been specified and are easily modified.

This data can be readily replaced with more recent information as it becomes available, including that incorporated in the VLUIS spatial data (section 5.2) and soils data (section 5.3).

Calibration considerations

The calibration strategy includes matching streamflow on a monthly basis (as per the lumped modelling approach), water quality on a monthly basis (as per the lumped modelling approach) in addition to comparing agricultural productivity, erosion rates, nutrient generation and cycling processes on an agricultural systems basis with field data and/or published data.

Potential to inform in-stream ecology

Outputs from this model include quickflow, sediment and nutrient load estimates generated at the farm management scale. As such, this approach enables predictions of inflows to stream segments within each sub-catchment at a finer scale than the lumped modelling approach. This has the potential to better inform the in-stream ecological impacts of land use and management changes on discrete stream segments at a scale much finer than sub-catchment.

Capability required to develop and modify the model to suit future needs

This option requires model developers and programmers but with training could be run by MW staff. It is recommended that any module development be undertaken by DEPI given their understanding of the physical processes to be modelled, knowledge of CAT and capability to translate enhancements into a predictive tool. It is further recommended that the development and testing of plug-ins be undertaken jointly by external providers with relevant experience and MW staff.

Summary

This approach only captures surface nutrient and sediment losses. It is the minimum recommended approach for MW to have a hydrologically based, spatially specific and predictive tool which is capable of being updated once new land use data becomes available in response to land use change or as finer scale information becomes available.

6.6 Option 4: Surface modelling approach fully coupled with groundwater model

Outline of approach

This option significantly enhances the catchment modelling framework through the incorporation of a fully distributed groundwater model as an add on to option 3. Whereas the current Source Catchment model considers groundwater as a simple store with pseudo connection to stream, a fully distributed groundwater model describes complex surface water/aquifer interactions, groundwater discharges and groundwater pumping. It is proposed to use the multi-layered, distributed groundwater model Modflow (USGS) and build upon readily available Port Phillip CMA region groundwater models which have been developed already in DSE.

Strengths (what it can do)

This option would eliminate all major limitations of the current framework whilst preserving the SedNet, Source Rivers and Modflow capabilities. Implementation of this option would result in a catchment framework with superior capabilities to contemporary international models such as MikeShe, SWAT, Visual Modflow, and Surfact. The strengths of the model would include:

- The estimation of daily water balance and vegetation dynamics for each spatially explicit land management unit
- The estimation of daily nutrient dynamics for each spatially explicit land management unit thereby reducing the uncertainties associated with user defined EMC/DWC estimates
- The ability to test BMP for targeted land use and/or spatially explicit land management units
- The ability to estimate streambank and gully erosion processes and their contribution to in-stream suspended solids and nutrient loads
- The ability to incorporate river operations and management using the Source Rivers model capabilities.
- The ability to simulate groundwater dynamics, including discharges to the bays, surface discharges, stream/aquifer interactions and groundwater pumping.

Weaknesses (what it can't do)

This option's only weakness is the additional computational overhead and data requirements, however as mentioned previously preliminary data sets are currently available for the study area and the computational overhead is acceptable given the enhanced predictive functionality and capability. It is proposed to access and enhance the pre-existing Port Phillip CMA groundwater model which encapsulates the Westernport region.

Linkage between this option and MUSIC

Same as for option 1.

Inclusion of soil, land use and management

Yes, as for option 3.

Calibration considerations

Same as for option 3 with the added calibration criteria of matching baseflows, groundwater hydrograph dynamics, surface discharges and depth to watertable.

Potential to inform in-stream ecology

Same as for option 3 but with more information regarding groundwater interactions and constituent exchanges with ecological assets. For areas where shallow groundwater has stream connectivity, this approach could substantially improve on the previous approaches in informing in-stream ecology.

Capability required to develop and modify the model to suit future needs

This option requires model developers and programmers. It is recommended that any module development be undertaken by DEPI given their understanding of the physical processes to be modelled, knowledge of Modflow, access to existing software that links CAT to Modflow and capability to translate enhancements into a predictive tool. It is further recommended that the development and testing of plug-ins be undertaken jointly by external providers with relevant experience and MW staff.

Summary

Given the importance of nitrogen losses in some catchments and the likely strong connection between surface and groundwater in a number of areas we would urge groundwater inclusion (option 4) from the outset instead of only option 3 if MW wants to consider water quality impacts holistically and considering the longer term pressures likely to be faced for rural and urban intensification.

6.7 Option 5: Adopt the Soil and Water Assessment Tool (SWAT) catchment modelling framework

Outline of approach:

This option proposes translating the existing E2 data sets into the Soil and Water Assessment Tool (SWAT) catchment modelling framework. The SWAT model is a continuation of thirty years development of non-point source modelling. In addition to the USDA Agricultural Research Service and Texas A&M University, input into the development and validation of this model includes US EPA, US Natural Resources Conservation Services and the US National Oceanic and Atmospheric Administration. SWAT was developed to predict the impact of land management practices on water, sediment, nutrient and agricultural chemical yields in complex watersheds with varying soils, land use, climate and management conditions. It is widely used internationally, freely available, with access to source code and is actively supported.

Strengths (what it can do)

SWAT adopts the same hydrological response unit approach as the E2/SourceCatchment models. However whereas the CRC eWater suite of models typically use a rainfall-runoff library to estimate soil/water/plant interactions at the broad scale, SWAT explicitly models these processes. As such, the SWAT approach enables the assessment of the likely impact of altered land use and land management conditions on catchment water, sediment, nutrient and agricultural chemical yields. The strengths of SWAT relative to the CRC eWater suite of models include:

- The model is physically based. The physical processes and interactions associated with water movement, sediment generation and transport, crop growth, nutrient cycling and river dynamics are explicitly modelled on a daily basis.
- The model explicitly simulates nutrient dynamics thereby removing the need to specify EMC/DWC for each land use.
- The model simulates in-stream routing and transformation processes.
- The model uses readily available inputs.
- The model is computationally efficient. Simulation of large catchments or management strategies can be performed relatively easily.
- The model is free and GIS based. This means that the model construction and simulations could be developed and maintained by GIS staff.
- The model is internationally recognised and supported. Numerous user groups and forums are available to support model applications.
- The source code is freely available. This is very important if modifications are needed to efficiently link with other software such as PEST (for optimisation), GAMS (for economic analysis, see section 7) or MUSIC. Whereas scripts can be developed if source code is not available to link input/outputs from various models, this approach is very computationally inefficient.

Weaknesses (what it can't do)

The weaknesses of the SWAT catchment framework in the context of the MW model requirements are:

- The model poorly describes connection to groundwater and stream/aquifer interactions. In the current version of SWAT the impact of groundwater pumping cannot be simulated. However SWAT is being further developed to link to the fully distributed multi-layered groundwater model MODFLOW. This version is scheduled for commercial release in 2013.
- The model does not predict gully and streambank processes. However, given that SWAT source code is freely available, incorporation of the SedNet algorithms would be relatively quick and simple by an experienced modeller. This is based on the assessment that the basic catchment delineation adopted by both SWAT and SedNet are compatible.

Linkage between this option and MUSIC

It is proposed that SWAT be modified to accommodate the input/output requirements of MUSIC. This task is readily achievable given that SWAT source code is freely available.

Inclusion of soil, land use and management

The SWAT model requires soil, land use and management inputs.

Calibration considerations

Same as for option 4.

Potential to inform in-stream ecology

Same as for option 4.

Capability required to develop and modify the model to suit future needs

This option requires model developers and programmers. It is recommended that any module development be undertaken by DEPI given their understanding of the physical processes to be modelled, knowledge of the SWAT model and source code and data sets, access to existing software that links SWAT to Modflow and/or SedNet and the capability to translate enhancements into a predictive tool. It is further recommended that the development and testing of plug-ins be undertaken jointly by external providers with relevant experience and MW staff.

Summary

This approach is highly recommended if MW is not investing in a catchment modelling group but is committed to supporting a GIS group.

6.8 Option 6: Enhance current approach (convert E2/WaterCast into Source Catchments) and incorporate data cube results

Outline of approach

This proposal enhances option 1 through the elimination of a key limitation regarding the Source Catchment model's ability to represent land management changes, including BMPs and the user nomination of EMC and DWC generation rates to estimate nutrient and sediment delivery to streams. Previous studies have shown that these parameters are highly variable and that model predictions are very sensitive to these estimates. This proposal requires the development of a series of look-up tables merged into a "data cube" of EMC and DWC generation rates derived for all environmental and land management conditions and/or scenarios represented in the catchment model. The tabulated generation rates would be derived using a suite of farming system models that describe soil/water/plant/animal interactions at the land management scale.

Strengths (what it can do)

Same as for option 1 with the additional strength of being able to predict EMC and DWC generation rates under varying land use and land management practices for specific soil, slope and climatic conditions.

Weaknesses (what it can't do).

Same as for option1

Linkage between this option and MUSIC

Same as for option 1.

Inclusion of soil, land use and management

Same as for option 1.

Calibration considerations

Same as for option 1.

Potential to inform in-stream ecology

Same as for option 4.

Capability required to develop and modify the model to suit future needs

Same as for option 1.

Summary

Whereas this approach is an advance on option 1 as it accounts for soil, land use, and land management variability, this approach is only recommended as a short-term strategy as it is limited for the following reasons:

- Cannot provide guidance on whether streambanks, gullies or land uses have the major impacts, only whole sub-catchments
- Groundwater impacts not included.

6.9 Overall Recommendations

The following recommendations are based on the assumption that MW wants to be able to account for, and predict, the impacts of land use and land management changes from urban and rural lands including updating of land use/management information as it becomes available. Three recommendations are proposed depending on available funds and commitment to maintaining in-house catchment modelling capability, and are outlined in Table 6-3 below.

Table 6-3: Recommendations

#	Scenario	Option	Description
1	Limited funding, and limited in-house catchment modelling capability	Option 5	This option can be achieved using existing in-house GIS expertise and addresses the limitations of the SourceCatchment model by removing the need to specify EMC/DWC estimates under various land use/land management change and BMP options. An added advantage is that SWAT is freely available, internationally recognised and under constant development.
2	Adequate funding but limited in-house catchment modelling capability	Option 5 with inclusion of SedNet	This option is an advance on recommendation 1 as it accounts for gully and streambank processes. However this option requires a level of funding to provide model development to link SWAT with SedNet.
3	Adequate funding and a commitment to develop and maintain in-house catchment modelling capability	Option 3, 4 or 5	If adequate funds were available and MW was committed to maintaining catchment modelling capability, then Option 3 is required as a minimum. This option comprises the incorporation of farming system models of greater complexity than Option 5 and which explicitly simulate forest management, animal interactions and pasture dynamics. Option 4 is recommended if groundwater impacts are sufficiently important. Option 5 is recommended if broad scale nutrient dynamics is only required as this model will be linked to groundwater. Whilst options 1 and 2 can readily link MUSIC with SourceCatchments, they do not account for soil and land management impacts and thus poorly predict future impacts.

6.9.1 References

eWater (2010). Yarra River Application Project Source Catchments Hydrology Calibration Report, Progress Report, Carty, R and Pierotti, S, eWater Cooperative Research Centre Technical Report, November 2010.

Beverly, C., Roberts, A., Hocking, M., Pannell, D. and Dyson, P. (2011). Using linked surface–groundwater catchment modelling to assess protection options for environmental assets threatened by dryland salinity in southern-eastern Australia. *Journal of Hydrology* 410, 13-30.

Morse-McNabb, E. (2013). Melbourne Water Land Use Data Requirement. Report to Melbourne Water as part of the Rural Lands Program Position Framework.

Rees, D. and Imhof, M. (2013). Development of consistent soils data for Melbourne Water catchments. Report to Melbourne Water as part of the Rural Lands Program Position Framework.

Vigiak, O., Newham, LTH., Whitford, J., Roberts, AM., Rattray, D., Melland AR. (2011). Integrating farming systems and landscape processes to assess management impacts on suspended sediment loads. *Environmental Modelling and Software* 26, 144- 162.

7 Economic Optimisation

Authors: Anna Roberts (DEPI), Craig Beverly (DEPI) and Kerry Stott (DEPI)

7.1 Overview

Without being able to discriminate between the contributions of rural and urban sources of sediment and nutrient pollution and compare the unit costs of reducing nutrient loads from major sources it is not possible to have a defensible basis for making investment decisions about how to most cost-effectively address water quality issues. A 'state-of-the art' tested and developed economic optimisation framework is outlined which utilises the outputs of catchment modelling (sediment and nutrient loads to Port Phillip and Westernport Bays) to be able to assess the cost-effectiveness of management actions.

A developed, tested and simple-to-use environmental investment framework (based on Benefit:Cost Analysis) which uses catchment modelling and economic optimisation as inputs is proposed. This will ensure that broader ecological costs and benefits based on current knowledge on ecological cause and effect relationships are incorporated. This is in lieu of a more detailed program of work on ecological responses and economic benefits of water quality improvement. This would provide MW with a defensible basis on which to develop business-cases based on benefit:cost analysis for investment in achieving water quality outcomes.

7.2 Scope

This scoping work has the primary aim of proposing a sound method (economic optimisation framework) for decision-making about where pollution reduction systems and management actions (both urban and rural) have the potential to achieve the greatest benefits relative to costs (cost-effectiveness) and considering the amount of sediment and nutrient reduction to Port Phillip and Westernport Bays (either collectively or separately).

Important secondary aims are to consider and discuss the extent to which broader ecological costs and benefits be considered and to outline a sound basis for developing business cases for investment to achieve cost-effective water quality outcomes (based on Benefit:Cost Analysis tailored for environmental applications).

The work proposed below uses the outputs of the modelling work proposed for MW (Roberts, Beverly and Barlow 2013).

7.3 Why is an economic optimisation framework needed?

Other parts of the developed world, such as the USA and Europe have recognised the importance of diffuse-source pollution (mostly from agriculture) for some time. Notable examples in North America include the Great Lakes, Chesapeake Bay, the Florida Everglades, the Gulf of Mexico and the Californian Central Coast. Europe also has many examples including the Black Sea. Closer to home New Zealand has problems in many rivers and highly valued Lakes including Lakes Taupo and Rotorua. In Australia the Great Barrier Reef, the Peel-Harvey Inlet, Gippsland Lakes, Corner Inlet, Port Phillip and Westernport Bays are amongst those with water quality issues that need to be addressed and where agricultural sources are an important component of the problem.

Without being able to discriminate between the contributions of rural and urban sources of sediment and nutrient pollution and compare the unit costs of reducing nutrient loads from major sources it is not possible to have a defensible basis for making investment decisions about how to most cost-effectively address water quality issues. MW and the Victorian Government will be increasingly exposed to public criticism as awareness about water quality problems emerge.

Development of defensible investment programs requires organisational readiness, appreciation of a multi-disciplinary approach and computer modelling (biophysical and economic) as important components. MW has to date focussed the majority of effort on urban and point source impacts on water quality, which is understandable given the organisational focus on water supply and engineering expertise. In addition, control of point sources can be technically easier to address than diffuse sources. MW's investment in the RLP signals an increasing appreciation that diffuse-source pollution from rural land needs to be included in decision-making.

Increasing organisational focus on linking rural and urban impacts on water quality and developing more defensible investment programs for public investment into water quality using an economic optimisation framework is proposed in this section.

7.4 What needs to be considered in the economic optimisation framework?

The economic optimisation framework will enable MW to have the capacity to assess achievement of individual or multiple pollutant targets at least cost, limiting activities to particular industry or rural sectors and/or assessing what the level of sediment/nutrient reduction targets possible for various levels of upfront and maintenance budgets. The elements that need to be considered within such a framework are listed below:

- Needs to build on biophysical modelling enabling inclusion of urban and rural source impacts including changing land use and management (this would come from the modelling approaches outlined by Beverly, Roberts and Barlow 2013 in section 6). Selection of the level of economic optimisation will be limited by the fineness of scale and land use/management options able to be modelled;
- Inclusion of N, P and sediments (with potential to add other pollutants if required) with the capacity to address achieving single or multiple pollutant load reductions;
- Ability to investigate differing scenarios (such as whether particular targets can be achieved and at what cost, as well as what can be achieved at least cost or under particular land use/management constraints or budget constraints);
- Ability to investigate combinations of measures (will be limited to the understanding of interactions that are known and can be represented quantitatively);
- Ability to assess the impacts of particular nutrient targets discharged into the Bay(s) as well as the consequences for water quality in particular sub-catchments;
- Sufficient consideration of farm heterogeneity – having single representative farm types is unlikely to be adequate (e.g. all dairy farms considered as a single type). The smallest number (e.g. 4-5 farm types representing from the most extensive to beyond the most intensive currently) of 'stylised' or 'representative' farm types in each industry is recommended to enable greater targeting of least-cost options to achieve particular nutrient load reduction targets;

- Careful consideration of whether both upfront and on-going maintenance costs are to be included. Given that water quality benefits take time, inclusion of short and long-term costs can have considerable impact on the choice of intervention. If upfront and maintenance costs need to be separated (along with budget constraints in initial and latter years), then a 'dynamic' model will be required. Current DEPI work (along with the published international work referred to in this report) has been based on a 'comparative static' model incorporating both upfront and on-going costs over a 20-year time horizon;
- Sufficiently flexibility to enable on-going adaptation as new knowledge becomes available.

7.5 Are eWater CRC tools a suitable alternative?

Given that MW is a partner in the eWater CRC, it is important to consider eWater products that are linked to models, namely, Insight and MCAT as part of the scope of economic optimisation work.

7.5.1 Insight

Insight has been developed to help organisations develop transparent decision-making and include the viewpoints of stakeholders involved. It is a software product and claims to provide a structured framework to place models, and other sources of knowledge into a decision–making context. It assists in decision support capability to eWater models, including generic capability in multi–objective optimisation, uncertainty, risk and multi–criteria assessment. A prototype is currently being linked to Urban Developer (a new tool from eWater to support Integrated Urban Water Management and Source IMS). This functionality is currently being trialled.

Insight helps with issues such as: Are the uncertainties in the model outputs well understood? What are the risks that different courses of action will fail? How can all possibilities be considered and select optimal solutions across many competing objectives? And how can scientifically verified or calibrated model outputs be considered alongside the diverse views and interests of many stakeholders?

Sensitivity and uncertainty analysis are important regardless of the modelling approach advocated. Insight may be useful if eWater products are used for biophysical modelling, subject to it performing well. The decision about which modelling approach should be made first, followed by decisions about the form of sensitivity, risk and uncertainty analysis.

7.5.2 MCAT (Multi criteria analysis tool)

MCAT (Multi Criteria Analysis Tool) is an investment decision support tool that optimises environmental expenditure using multi-criteria analysis and combinatorial optimisation techniques. It is a form of Multi Criteria Analysis with an optimisation and a budget constraint.

Below are some comments about MCAT, based on looking at the MCAT documentation on the eWater website (www.ewater.com.au) and also using a discussion paper by David Pannell (University of Western Australia), namely Pannell discussion 158 – 'Using the wrong metric to prioritise projects is very costly' – www.davidpannell.net:

- Whilst MCAT is designed to make things easy, this puts a lot of restriction on the structure of the model. Whilst cause-and-effect relationships will be addressed through the biophysical modelling, the structure of MCAT itself is restrictive in terms of what can be analysed;
- It uses a weighted additive approach. The recommended approach (i.e. economic optimisation linked to development of business cases using INFFER, based on economic theory and outlined in the final two sections of this report) uses a multiplicative approach. Pannell Discussion 158 indicates that the losses in potential environmental benefits using an additive approach when a multiplicative approach is required can be in the order of 55%;
- Users determine which variables are included and how those variables are to be weighted. In contrast, important variables are already included in INFFER, thus removing a further source of error and lack of transparency. Leaving out a couple of factors can mean a loss of around 50% of environmental benefits;
- MCAT is still under development and not yet published. Both the economic optimisation approach and the investment decision-making framework recommended have been published.

A stinging critique of the multi-criteria analysis approach in public policy (compared to Benefit:Cost Analysis) has also been written by Dobes and Bennett (2010) from the Australian National University. They suggest multi-criteria analysis is seriously flawed both conceptually and mathematically. Key criticisms include:

- Biases due to a lack of conceptual underpinning;
- Subjectivity, so non-replicable and unscientific;
- Breaches of the mathematical principal of dimensionality (ie adding apples with oranges).

Dobes and Bennett (2010) conclude that the continued use of MCA by public sector policy advisers and decision-makers is due, at best, to ignorance and at worst represents gross negligence in the provision of advice to Ministers, and possibly breaches Australian Public Service Values and the Code of Conduct. In conclusion, MCAT is insufficient and unsuitable to develop sound business cases for investment and address the risks MW might increasingly face in terms of defensible public investment into improving water quality.

7.6 Proposed economic optimisation framework

A contemporary approach based on one that has already been developed and tested in Europe (Cools et al. 2011) and more recently in North Central Victoria (Doole et al. 2013) and Gippsland (Roberts et al. 2012, Roberts et al. 2013) to address water quality problems is proposed. The approach enables assessment of cost-effectiveness and least-cost options to achieve water quality load reduction targets.

Locally the approach has been developed and tested in both the Gippsland Lakes and Corner Inlet catchments by DEPI. Whilst only rural impacts have been assessed in both Gippsland Lakes and Corner Inlet, urban impacts could have been included (urban impacts were held constant under both scenarios, based on available information and were a small contributor overall to the problem). Whereas the already published Gippsland Lakes approach only considered P inputs (Roberts et al. 2012), the Corner Inlet application has considered N, P and sediment (Roberts et al. 2013) and can be refined further.

The approach utilises the biophysical modelling (SourceCatchments or SWAT, as per Roberts, Beverly and Barlow 2013) and an optimisation method which is appropriate for this complex problem whilst being straightforward to implement for modellers.

A conceptual diagram is outlined (Figure 7-1) which shows how the biophysical and economic elements are linked – note that steps do not all have to be done in sequence and that whilst E2 has been used as the example, Source, SWAT linked to MUSIC can be used instead. Note also that the approach can also be adapted to coarse scale and lumped (e.g. Option 1 or 2 in Roberts, Beverly and Barlow 2013) or finer scale approaches (Options 3 and 4 which make use of land use and soils information).

The main elements of the program (assuming a comparative static model approach is required) are outlined below:

- Identify representative land use and soil types for rural land that are required (based on fineness of scale of modelling desired, important land uses and available information). Identify the relevant urban sources and how these should be broken into sensible units. Depending on the scale of modelling selected, this might require enhancement/updating of the relevant land use layer (as addressed in sections 5);
- For each major land use/soil combination identify the relevant management practices and estimate the effectiveness of management practices compared with current practice (these are likely to need to be assessed by a combination of modelling for urban sources and mostly expert opinion for rural land);
- Assess the equal annual costs (EAC) involved with each land use and soil type combination calculated relative to the baseline or 'Operating Profit'. The EAC for rural land uses is the annual net private benefit (+) or cost (-) of implementing each practice on the representative land uses x soil types. This includes the upfront and on-going costs, both of which are important to consider in long-term water quality investment comparisons. The Operating Profit is also known as earnings before interest and tax (or EBIT), is the net return to land, labour and total capital and a measure of the efficiency of resource use in alternative agricultural land uses. It comprises:
  - Gross Income (cash sales of produce plus non-cash changes in inventories)
  - Minus Variable Costs (expenses that change with the level of output)
  - Minus Fixed Costs or Overheads (i.e. expenses that are independent of the level of output such as permanent labour, owner-operator's own labour and management and depreciation on capital assets)
  - Consideration of the ongoing impacts, with future losses discounted.
- Costs should be assessed as actual costs likely to be incurred – for example, in the case of rural lands, costs should not be restricted to current incentives that might be available, but rather the full costs, which include the opportunity costs of lost production. This is very important because to include the possibility of assessing costs of ambitious water quality targets then high rates of landholder adoption will be required, and this is likely to be unachievable without compensating farmers for lost costs;
- Use a well calibrated biophysical model to generate current (called base-case) nutrient loads from relevant sub-catchments/hydrological response units (choice depends again on which modelling option is selected);

- Model the degree to which base-case loads can be reduced by combinations of the land use x soil type x management for each subcatchment. These will be used as inputs into the economic optimisation framework;
- Develop and run the economic optimisation framework (using GAMS General Algebraic Modelling System, Brooke et al. 2008) to capture the nutrient load reduction information described above and associated cost information. This enables assessment of the least-cost combination of abatement measures required to achieve particular nutrient load reduction targets, budget or land use scenarios. Depending upon the level of user friendliness and transparency required, input information can be linked to GAMS through a spreadsheet which makes modification easier for non-modellers to interrogate.

7.7 Incorporating broader ecological costs and benefits

The economic optimisation framework proposed covers the costs of attaining particular water quality targets based on reducing nutrient loads into rivers and Port Phillip and Westernport Bays (Figure 7-1). It is not able to consider broader ecological costs and benefits associated with achieving water quality improvements.

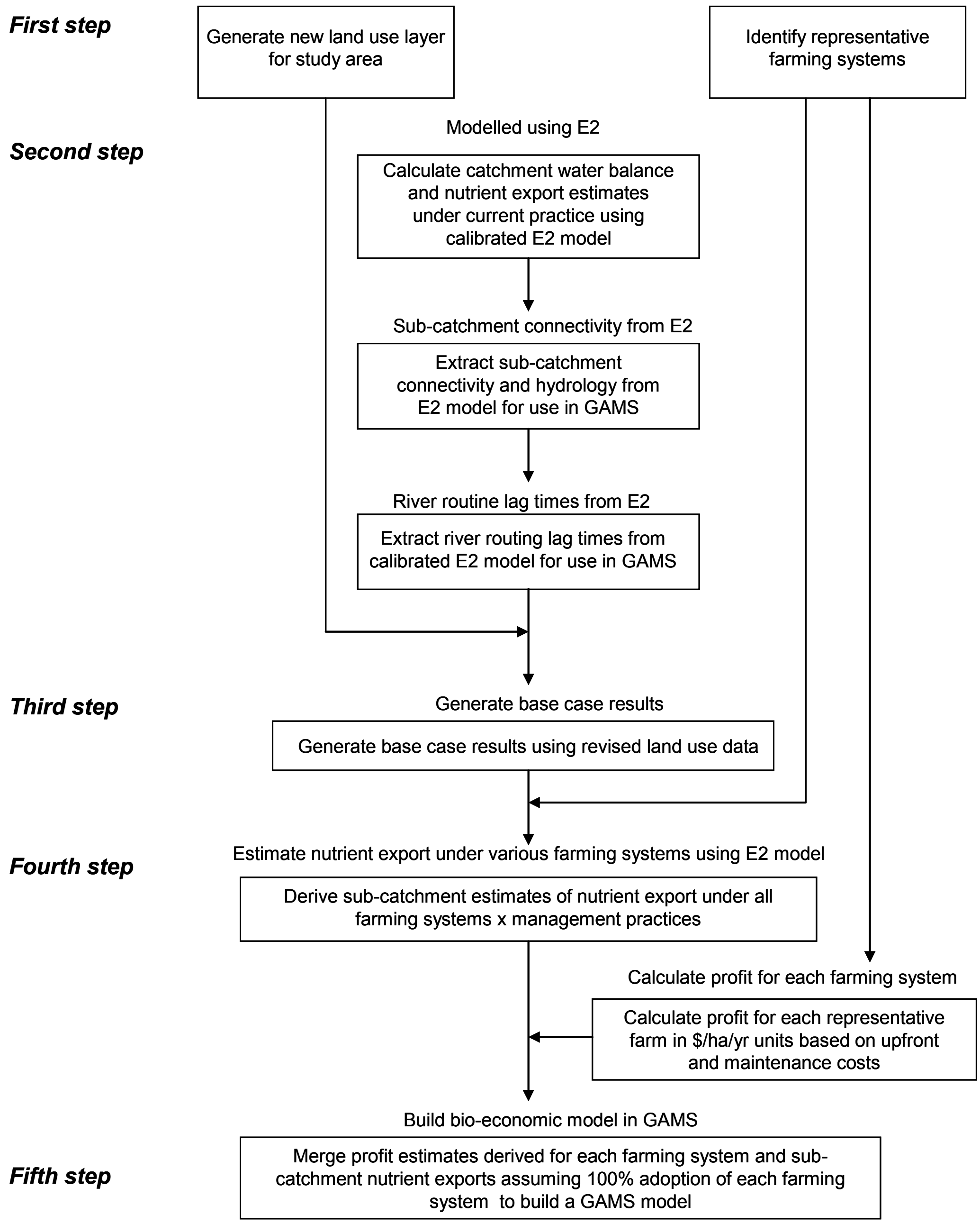


Figure 7-1: Conceptual diagram of the linkages between factors to be considered in linking catchment modelling loads to economic optimisation assessment. Note that there is an additional step to incorporate the outputs from the GAMS modelling into a benefit:cost analysis using INFFER (outlined later in the report)

7.7.1 Why can't broader ecological benefits and costs be better incorporated?

The biophysical outputs used from the catchment model are nutrient loads (nutrients or sediment measured in kg or tonnes/year). Ecological responses are often much more specific and subtle than the effects of simple average loadings. More adequate incorporation of ecological costs and benefits requires a greater level of complexity in factors. These include:

- Understanding of values of ecological assets (fish, water quality, seagrass, rivers and estuaries) and being clear about what ecological values are being protected;

- Understanding of cause and effect relationships between loads (if no additional finer scale research and monitoring is to be undertaken) and ecological responses including responses to flows, nutrient concentrations and water temperatures;
- Increased frequency of temporal monitoring of flows and concentrations to have a stronger basis for understanding cause and effect
- Better coupling, integration or using outputs from biophysical and ecological models.

Section 3 addresses ecological costs and benefits in more detail. Whilst it is recognised that these factors are important, the recommended approach is practical and pragmatic. Reliance on nutrient loads as the metric on which to assess costs associated with achieving water quality outcomes is practical given the paucity and coverage of adequate ecological response data.

7.7.2 What about a simple incorporation of benefits?

Assessing environmental benefits could be an entire work program in itself. A readily accessible overview of methods and their associated positives and negatives is available through four of David Pannell's discussion papers (Pannell discussions 217-220 www.davidpannell.net). Many of the methods are time consuming and costly. In the end, and regardless of the effort, all appear highly contestable. Given the lack of ecological response data, the high costs and uncertain benefits of investment in research into assessment of environmental benefits, there appear to be two main options:

- Don't incorporate environmental benefits in any future program;
- Use a simple method.

A simple method which incorporates both assessment of benefits and costs has also been developed. It is called INFFER (Investment Framework for Environmental Resources www.inffer.org). It has been published (Pannell et al. 2011) and has been well used across Australia on assets of various scales (see website for details). INFFER puts environmental value scores on assets. These scores are elicited from environmental managers using a table of well known environmental assets as examples and a scoring system that converts to dollar values.

There are higher work priorities than developing a program to only incorporate environmental benefits. Appropriate biophysical modelling and economic optimisation are much more important to address first.

7.8 Developing business cases for investment to achieve cost-effective water quality outcomes (INFFER)

The economic optimisation framework proposed gives MW the capacity to assess achievement of individual or multiple pollutant targets at least cost. An additional process is needed for the capacity to develop sound business-cases to justify public investment in water quality and compare the benefits and costs of different investment options. Examples include comparing whether investment on rural land generates greater benefits relative to costs than in urban land, or whether specified water quality targets can be met where the benefits outweigh the costs. With the economic optimisation framework as an input, INFFER analysis becomes straightforward.

INFFER has been specifically developed to help make better environmental decisions including development of sound business cases for cost-effective public investment, including addressing water quality problems (Roberts et al. 2012, Roberts et al. 2013). Benefits and costs are calculated through a formula (termed the Benefit:Cost Ratio or BCR, where ratios greater than 1 indicate that the overall benefits outweigh the costs). The BCR considers the major factors required to make sound and transparent decisions. These include:

- The value of the asset (environmental score outlined in the previous section);
- The impact of works undertaken to protect the value of the asset;
- The time lags until environmental benefits are attained;
- The risk of technical failure (that the works and actions wont generate the benefits claimed)
- Factors surrounding adoption of works and actions
- Whether the project delivery mechanisms are sound
- Socio-political risks
- Costs – upfront and maintenance
- Requirement for long-term funding to maintain the benefits

INFFER is being used currently to assess the benefits and costs of investment to improve water quality (N, P, sediment) in the Corner Inlet catchment and has been previously used in the Gippsland Lakes (Roberts et al. 2012). If development of sound business case investment is important to MW then the biophysical modelling and economic optimisation work recommended can be used as inputs to INFFER and would make such development simple and transparent.

7.9 References

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8 Guidelines for Design and Adoption

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8.1 Overview

The objective of this project area is to identify the drivers and barriers for landholders to adopt principles and practices in water sensitive farm design (WSFD). The key questions addressed include:

- What do we know about extension and adoption in agriculture and natural resource management, including principles for adoption and models?
- What are the drivers for adoption?
- What are the barriers to adoption?
- What instruments would support and facilitate uptake of systems and practices?
- What is the recommended approach to facilitate adoption?

A review of the literature identified key principles and models for extension. This review highlighted the need to understand the target audience including an analysis of diverse groups and different methods for delivery. The review also highlighted the need to understand the technology or practice that is being recommended and how it fits within the various farming systems to inform the design of effective extension programs.

Section 8.2 outlines a range of policy instruments and extension methods and models. Section 8.3 provides an overview of how this relates to the Rural Land Program and Section 8.4 describes recommendations for extension to facilitate the implementation of Water Sensitive Farm Design.

8.2 A review of extension and adoption

This section presents the theory and most recent thinking in relation:

- Facilitating change
- Understanding the target audience
- Drivers and barriers of adoption
- Policy instruments to achieve change
- Extension approaches
- Estimating the likely adoption of new technology.

8.2.1 Facilitating change

There has been extensive social research into understanding why farmers do or do not change or adopt certain practices and technologies (e.g. Black, 2000, Cary et al. 2002).

Adoption has been defined as '*the result of making full use of an innovation as the best course of action available'* (Rogers 1983). In agriculture, the term adoption has been used to define the uptake of agricultural practices and innovations and is targeted at the farmer or grower.

The adoption of particular management practices and technologies will depend largely on the:

- **Industry context** (e.g. industry profitability and limiting resources)
- **Farming context** (e.g. business fundamentals – equity, structure, succession, farming systems, irrigation infrastructure).
- **Personal attributes** (e.g. attitude to risk, propensity for change, motivations, values, skills, expertise).

Fundamental to facilitating change is understanding which aspects (contexts, attributes) are relevant and considered important for the target audience.

8.2.2 Understanding the target audience

Farming groups

It is important to recognise that there is significant social diversity among farmers, multiple methods to facilitate change and good reasons for non-adoption (Vanclay, 2004).

Extension programs therefore must consider the needs and circumstances of individuals and their different learning styles. The farming community is not homogeneous and extension programs need to be tailored to these different priorities, understandings, values, ways of working and problems (Vanclay, 2004).

Market segmentation is one method that has been used to describe groups of growers with similar needs and circumstances in relation to their farming context (Kaine et al., 2005). Extension activities and messages can then be tailored to the individual groups (Boland et al., 2006). This type of approach has been used to describe different farming styles for specific industries and regions. One example related to the Australian dairy industry (Waters et al., 2009) identified six groups based on aspects such as their business orientation, aversion to risk, knowledge and self-reliance, financial pressure, farming tradition and intergenerational orientation. These groups with similar context and attributes included (i) family first, (ii) winding down, (iii) love farming, (iv) established and stable, (v) open to change and (vi) growing for the kids.

Small Landholder Groups

A particular feature of the Port Phillip and Westernport catchments is a large number of small landholders or lifestyle properties. There has been considerable work undertaken to understand the specific needs of small landholders and develop extension approaches that may be more effective in achieving adoption (e.g. Guise et al., 2009; Hollier and Reid 2007).

Social research undertaken in Victoria (Hollier and Reid 2007) highlighted that the needs of small landholders differed to commercial farmers and information must be tailored to these needs. An analysis of the education needs and engagement preferences for the small lifestyle sector determined that small landholders had the following preferences towards education and training:

- One-on-one information, especially if extension providers visit the property

- Local information (e.g. Land for Wildlife staff, Landcare facilitators)
- Personal invitations to attend an activity
- Practical courses run by people who have been through the same experiences
- Opportunities to visit other farms (large or small) to assess the success of various approaches to land management and to build networks
- Recognition of small landholders as a distinct group, so programs can be targeted to them, and so they can form small farmer networks
- Specific targeting of education and training to absentee owners, including land management approaches that are not time consuming or costly
- Sufficient notice of events, especially for absentee owners; alternative communication channels; weekend access to training
- A coordinated approach so that all the relevant information for the sector can be sourced from one location.

Some negative reactions stemmed from:

- Extension providers not responding to questions and inquiries, or suggesting the landowners contact someone else; "it's not my job"
- Staff who were not perceived as being able to relate to the small farmer's situation, focussing too narrowly and lacking an holistic view of the system
- Perception of being treated unfairly; government extension being seen to help large farmers more than the small farmers, despite both being tax payers
- Activities being held during the week, which often results in difficulties for small, lifestyle landowners wanting to attend (the exceptions being retirees)
- Domination in education and training activities by larger farmers
- Activities that are perceived as not well structured nor practical enough
- Lack of recognition of small, lifestyle landowners' interests that may conflict with traditional agricultural management styles and no provision of alternative strategies (e.g. alternatives to synthetic fertilisers, poison baits or introduced pasture species).

Small landholder networks (e.g. equine groups) may differ from traditional farmer networks (e.g. production groups). A cluster approach can be effective when working with these landholders, with improved networks and awareness an important outcome.

Extension for small landholders (especially new landowners) can successfully target property planning or enterprise ideas/options, then lead to higher order capacity and implementation work. Understanding the individual context of small landholders (as with commercial farmers) will assist in designing strategies that have currency for these groups.

8.2.3 Drivers and barriers of adoption

Overview

Considerable research has been undertaken to understand the drivers and barriers to the voluntary adoption of farming practices and technologies. Frequently, a key premise of extension programs is that farmers actually want to change. For adoption to occur there must be a certain level of dissatisfaction with the current situation and the proposed or desired alternative must be seen to improve this. Understanding what is causing the dissatisfaction can be the key to success of an extension program. It is important to note that extension activities will only reach those landholders who are in a position to be receptive at the time the activities are delivered (Pannell et al, 2011).

Barriers to adoption can be motivational, technical, financial or biophysical (Erol, 2007):

- **Motivational** e.g. lack of direction from government, the wrong extension model, lack of confidence, lack of support and cultural resistance to change.
- **Technical** e.g. limited knowledge, advice and information, lack of clearly written materials, or lack of access to adequately skilled and trusted NRM advisers.
- **Financial** e.g. lack of money and incentive grants, the perception that costs outweigh benefits, lack of equipment and time.
- **Biophysical** e.g. variable seasons, poor productivity (because of salinity, acidity, and lack of trace elements), poor off-farm drainage and lack of suitable productive land. These barriers are very region-specific and vary according to production system.

The process of adoption and decision-making

One of the main theories of adoption is the innovation decision process developed by Rogers (1983). Rogers uses a complex process model of change, where an individual passes through the following steps (Figure 8-1):

i. Knowledge of an innovation

ii. Forming an attitude about the innovation

iii. Decision of adoption or rejection

iv. Implementation

v. Confirmation of the decision

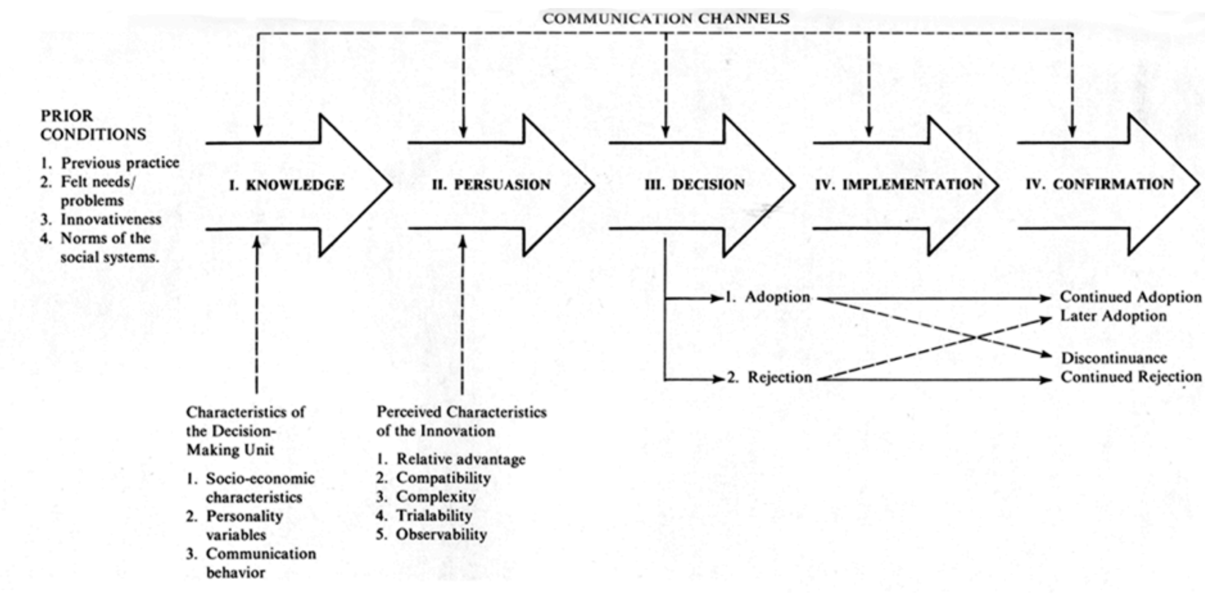

Figure 8-1: Model of stages in the innovation-decision process (Rogers 1983)

Jennings et al. (2011) use a similar model to describe the shift from awareness to enabling change:

awareness → knowledge → ownership → responsibility → commitment → trust = enabling change

For example, increased landholder awareness of river health and water quality issues (over a five year period 2002-2007), led to increased acknowledgement of the impact of management practices on soils. This in turn drove landholder behaviour (Curtis et al., 2008). This model is applicable when considering adoption of WSFD systems and practices.

Complex decisions

Making decisions about change can be an extremely daunting and complex task. As the rate of change increases, the ability to sift through information and adapt to the business situation becomes a valuable skill. Decisions are never made based on isolated pieces of information – rather they consider the whole farming system incorporating personal, financial, technical and environmental aspects.

It is critical to recognise that many farm decisions are complex where there are many difficult answers rather than simple (one right answer) or complicated (one difficult answer) (Snowden, 2003).

Supporting decisions about change involves understanding several important characteristics of the innovation including: relative advantage, compatibility, complexity, trialability and observability. Change can be considered if the practice and/or technology has a clear relative advantage and is trialable.

- **Relative advantage:** perceived superiority to the idea or practice that it supersedes and identification of a reason for change. This encompasses a wide range of factors including: the expected profitability over different time scales and in comparison with existing practices; the innovation's expected effect on and compatibility with the farm and the family's lifestyle, beliefs, values and self-image; environmental credibility; complexity and effect on the riskiness of production; and the adjustment costs in making the change (Pannell et al., 2006).
- **Trialability:** how easy is it to test and learn about prior to adoption (Pannell et. al., 2006). This is determined by two main factors: the risk and cost of trialing the innovation, including partial adoption; and the ability to attribute results of the trial to the innovation.

Farmers' reasons for non-adoption or partial adoption are legitimate, and relate either to their farming context or personal attributes (Vanclay, 2004). Research has shown that growers often have sound, logical reasons for not adopting an innovation and lack of awareness, limited information or inadequate knowledge is not necessarily barriers.

Botha and Coutts (2011) reviewed decision-making theory and project evaluations to better understand the decision-making processes. They suggested that a major driver is the ability of the decision maker to 'play' with the innovation, so that a decision can be made with confidence – that is, confidence that it will work for them – including how it fits with the farming system and their personal context. The stages in the adoption process are shown in Figure 8-2 below.

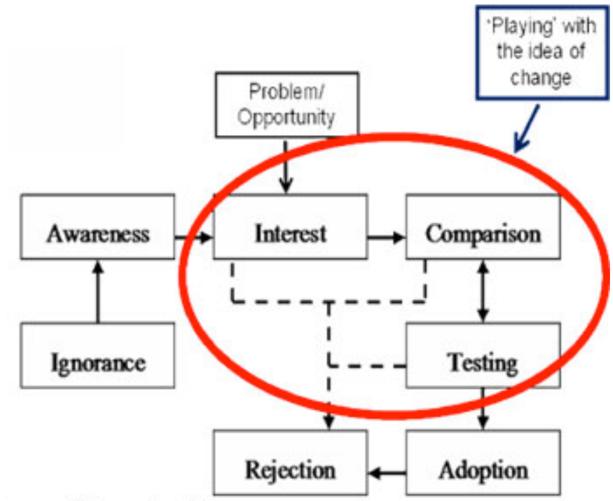

Figure 8-2: Stages of the adoption process (Botha, 2004 adapted by Botha and Coutts, 2011)

Motivation and capacity

Two other elements in the adoption process include motivation and capacity. Generally, for a new practice to be adopted, both of these elements must be present. Critically, where only one element is present, the practice or innovation is unlikely to be adopted.

8.2.4 Policy instruments to achieve change

There are many policy instruments that can be utilised to achieve change. Many landholder-based programs involve voluntary adoption although there are other mechanisms that can be applied.

A policy instrument is "*a method or mechanism used by government, government agencies as well as other institutions including business to achieve a desired effect*."

The State Extension Leadership network described 21 policy instruments (SELN, 2006). These have been grouped into extension based voluntary programs and other approaches highlighting the many opportunities for achieving an outcome.

Table 8-1: Policy instruments to achieve change (SELN, 2006)

Regulatory and Policies	Knowledge Management
1. Regulation, Enforcement and Compliance 2. Institutional Arrangements 3. Change other policies 4. Reasoned Inaction	5. Research and Development 6. Monitoring, Evaluation, Benchmarking and Adaptive Management 7. Assessment Procedures
Market Based	**Voluntary Regulation**
8. Direct Investment 9. Market-based Mechanisms 10. Economic Incentives	11. Self-Regulation 12. Quality Assurance processes, EMS and Eco-labelling
Agreements	**Marketing**
13. Common Law, Duty of Care, Stewardship 14. Covenants and MoUs	17. Public Relations, Marketing and Advertising

15. Formal Agreements 16. Conditionalities	18. Suasion
Education	**Voluntary Adoption**
19. Formal Education and Training	20. Extension 21. Participatory Approaches

Extension can be used on its own and/or in combination with other instruments.

Pannell (2008) developed a framework for selecting policy mechanisms and categorised mechanisms into five categories:

1. Positive incentives (financial or regulatory instruments to encourage change)
2. Negative incentives (financial or regulatory instruments to inhibit change)
3. Extension (technology transfer, education, communication, demonstrations, support for community network)
4. Technology change (development of improved land management options, such as through strategic R&D, participatory R&D with landholders, provision of infrastructure to support a new management option.)
5. No action.

Mechanisms are selected depending on the levels of public net benefits and private net benefits from the land-use changes being proposed (Figure 8-3). The RLP currently uses a mix of extension, positive incentives and technology change to encourage the adoption of WSFD systems and practices.

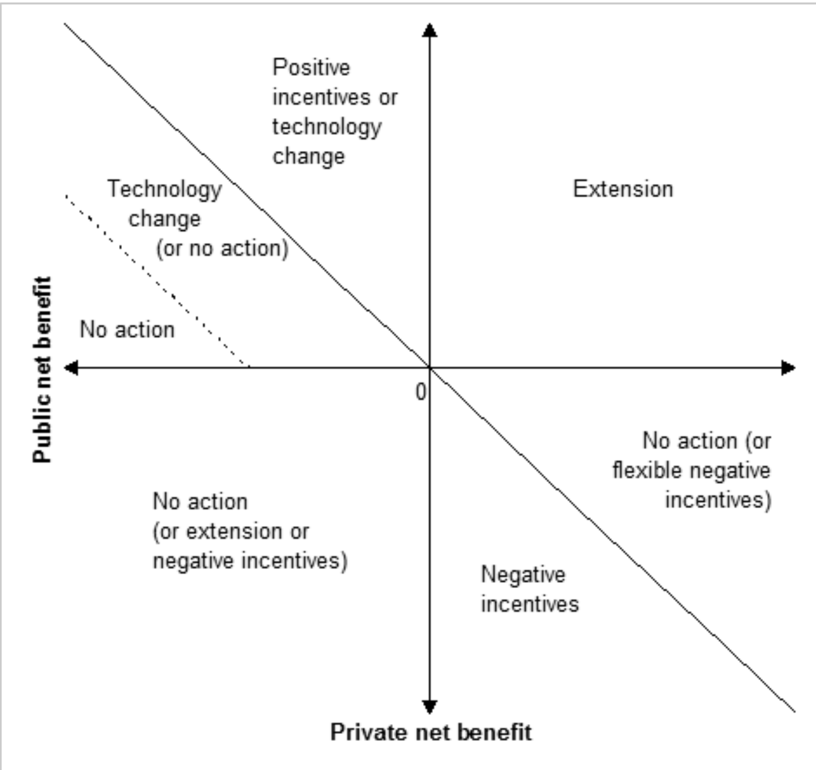

Figure 8-3: Policy tools for levels of public and private benefits (Pannell 2008)

The model uses the following rules, which build on the drivers and barriers for adoption discussed in section 8.2.3 above:

1. Do not use positive incentives for land-use change unless public net benefits of change are positive.
2. Do not use positive incentives if landholders would adopt land-use changes without those incentives.
3. Do not use positive incentives if private net costs outweigh public net benefits.
4. Do not use extension unless the change being advocated would generate positive private net benefits. In other words, the practice should be sufficiently attractive to landholders for it to be 'adoptable' once the extension program ceases.
5. Do not use extension where a change would generate negative net public benefits. (Rules 4 and 5 are referring to cases where extension is used as the main tool to achieve land-use change. Extension could also be used to support any of the other policy mechanisms, playing a supporting role, rather than being the main tool).
6. If private net benefits are negative (but not too negative), consider technology development to create improved (environmentally beneficial) land management options that can be made adoptable (with or without positive incentives).
7. If private net benefits outweigh public net costs, the land-use changes could be accepted if they occur, implying no action, or they could be penalised at an appropriate level, but not prohibited.
8. If public net costs outweigh private net benefits, use negative incentives.
9. If public net benefits and private net benefits are both negative, no action is necessary. Adverse practices are unlikely to be adopted.
10. In all cases, the suggested action needs to be weighed up against a strategy of no action.

8.2.5 Extension approaches

Traditionally the emphasis of agricultural extension has been based on transfer of technology i.e. linear 'top down' transfer of technology. Scientists typically developed agricultural technologies and knowledge and the task of extension agencies was to promote adoption of these technologies by farmers (Black, 2000). More recent extension has focused on engagement of individuals and approaches that assist them in making decisions.

Coutts et al. (2005) reviewed extension models involved in the building of capacity in agriculture. These models operated across industries and communities, with each playing key and complementary roles within a capacity building framework. Current extension projects utilise a range of extension models as a suite of complementary capacity building avenues.

Table 8-2: Types of extension models

Extension Model	Description	Contribution to Capacity Building
1. Group Facilitation/ Empowerment	This model focuses on increasing the capacity of participants in planning and decision-making and in seeking their own education and training needs based on their situation. They will often resource a facilitator to define their own goals and learning needs and realise these.	Platform for ongoing learning
2. Programmed Learning	This model delivers specifically designed training programs or workshops or both to targeted groups of landholders or community members to increase understanding or skills in defined areas. These can be	Specific topics and learning events

	delivered in a variety of models and learning approaches.	
3. Technology Development	This model works with individuals and groups to develop specific technologies, management practices or decision support systems which will be available to the rest of the industry or community. It often involves local trials, demonstrations, field days and on-site visits.	Development or integration of new approaches
4. Information Access	This model provides a range of information that individuals and groups can access at a time that suits them. It can be based in a library, information centre, on a website, or other centralised location.	Ongoing access to support information
5. Individual Consultant/Mentor	This model provides individualised one-on-one support. It may be a technical expert visiting and providing advice, diagnosis, and recommendations. It may be an ongoing facilitating mentor relationship which provides a sounding board for decision-makers.	Individual iterative support to make decisions about changes

The integration of elements of the five extension models is described by the Capacity Building Ladder, which can be used in the successful development of human capacity (Figure 8-4).

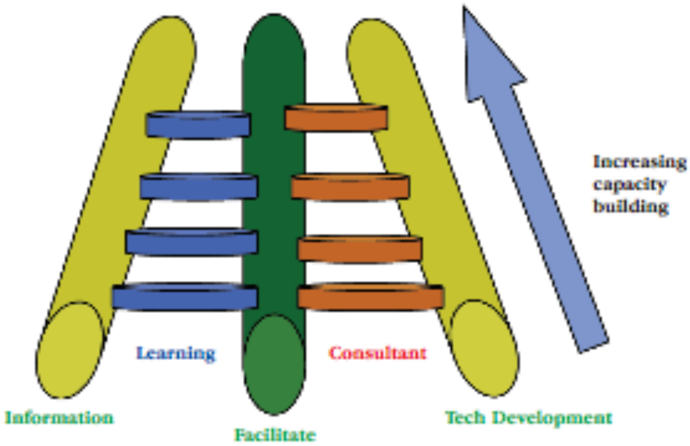

Figure 8-4: Extension models – Capacity Building Ladder (Coutts et al., 2005)

8.2.6 Estimating the likely adoption of new technology

The ADOPT (Adoption and Diffusion Outcome Prediction Tool) model, developed by the Future Farm Industries CRC, is being tested as an approach to estimate the extent and rate of adoption of new technologies (Kuehne et al, no date). The model includes a series of question based on four quadrants.

Table 8-3: Four main components of the ADOPT model

Population-specific influences on the ability to learn about the innovation	**Relative advantage for the population**
The ability of the target population to learn about the innovation – this is about learning the benefits or relative advantage. Constraints will slow the time to peak adoption, they do not affect peak adoption level. Factors include:	Is the advantage gained from adopting the innovation, sufficient to motivate the target population to adopt? Factors include: ▪ Enterprise scale ▪ Family succession/management horizon ▪ Profit orientation

▪ Group involvement ▪ Advisory support ▪ Existing skills and knowledge and ▪ Awareness of the technology in their district	▪ Environmental orientation ▪ Risk orientation ▪ Short-term constraints
Learnability characteristics of the innovation This is about the innovation and not the target population. Some innovations are easy to learn while others are more difficult. Factors include: ▪ Trialability ▪ Innovation complexity ▪ Observability	**Relative advantage of the innovation** The relative advantage of the innovation (not the perception of the target population). Factors include: ▪ Relative upfront cost of the innovation ▪ Reversibility ▪ Profit benefit ▪ Time for profit benefit ▪ Risk effect ▪ Environmental costs and benefits ▪ Time to environmental benefit ▪ Ease and convenience

This model incorporates the theory associated with relative advantage and trialability. The model is still being tested, and could be used to indicate the expected level of adoption, time to reach peak adoption and also highlights where efforts could be focused to increase adoption and adoption rates.

8.2.7 Review implications

Understanding the target audience – Different groups or segments of a community may be described by differences in their context and particular attributes.

Drivers and barriers of adoption - There are a number of issues that drive the adoption of practices and technology including the relative advantage and trialabilty. There is a need to understand the attributes of the technology and how they are perceived by landholders.

Policy instruments - Voluntary adoption, education and marketing are instruments that have been used by the RLP. Alternative policy mechanisms may be appropriate in achieving the desired RLP objectives. Consideration of the Public and Private benefits of RLP would assist in determining the appropriate mix of public and private tools, the role of regulation and the potential for market based instruments to achieve outcomes.

Extension models – A range of extension models should be used which are focused on the needs of the target audience and the attributes of the technology and/or practice. All of these models have been used in delivery of the RLP.

ADOPT – the adopt model can provided some useful insights into the likely adoption of WSFD treatments and practices.

8.3 Links to the Rural Land Program

This section provides an outline of the agricultural communities and provides principles for facilitating adoption in the RLP.

8.3.1 Agricultural communities

There are many sectors of the community that can be regarded as part of the broader agricultural community of the Port Phillip and Westernport region, and who can play a role in implementing the RLP including:

- Commercial farmers (primary producers)
- Lifestyle farmers
- Rural township dwellers
- Local councils servicing rural areas
- Social networks including Landcare groups, equine groups
- Industry specific groups including berry growers, dairy framers, horse breeders
- Government agencies such as DEPI, DSE, CMA, local government, fire authority, water retailers, public land managers
- Water diversion licence-holders.

8.3.2 Evolution of extension program for RLP

The RLP has developed from a pilot program to a mainstream component of MW. Prior analysis of many of the above aspects has led to the evolution of the RLP extension activities with a willingness to consider:

- Provision of incentives to individuals to conduct works
- Provision of incentives to landholders to develop capacity and property plans
- Development of catchment based ‘neighbourhood environment improvement plan’
- Utilisation of licence conditions as a tool to drive management of runoff based on water quality/quantity outcomes
- Employment of assessors to deliver the program
- Development of catchment health officers for MW
- Development of integrated NRM through collaboration with Landcare, NRM coordinators to link delivery of water quality and sustainable farming
- Establishment of local government partnerships with funding of rural land officers in local councils to deliver the RLP using a targeted approach
- Establishment of partnership with agricultural industry and marketing associations to incorporate water sensitive farm principles into codes of practice and quality/environmental assurance
- Identification of target catchments with intensive activities with landholders to implement a catchment action plan, including investment in treatment systems across the catchment
- Establishment of a tender/auction model whereby landholders submit proposals for works.

8.3.3 What extension activities are likely to work and why

There are a number of particular characteristics of the RLP including the audience and treatment systems that influence what extension activities will be successful. One approach to analyse these characteristics is the program ADOPT. Table 8-4 provides a framework to assess if there is sufficient knowledge about a particular innovation and the target audience to enable its adoption. Consideration of these aspects may provide insight into the expected uptake of an innovation.

Table 8-4: Components of ADOPT and implications for WSFD (Kuehne, no date)

ADOPT	Implications for WSFD
Learnability of Population	
▪ Group Involvement: What proportion of the target population participates in farmer groups? ▪ Advisory Support: What proportion of the target population uses paid advisors for advice relevant to the innovation? ▪ Relevant Existing Skills & Knowledge: What proportion of the target population will need to develop substantial new skills and knowledge to use the innovation? ▪ Awareness: What proportion of the target population would be aware of the use or the trialing of the innovation in their district?	This area highlights the difficulty in dealing with a highly diverse and fragmented population. It will require different methods to target specific clusters. It also means that there will be a general focus on awareness and capacity building for the entire population.
Learnability Characteristics of Innovation	
▪ Trialable: How easily can the innovation be trialled on a small scale before a decision is made to invest in full adoption? ▪ Innovation Complexity: To what extent does adopting the innovation involve complex changes to the farming system? ▪ Observability: To what extent would the innovation be observable to other farmers when it is used in a district?	Many of the proposed treatment systems are difficult to trial. Evidence of their effectiveness would greatly enhance their uptake and demonstrate how the system can fit within the existing farm practices. Many on-farm management practices can be assessed and may be adopted if they can be readily changed, are profitable and fit with other practices.
Relative Advantage for the Innovation	
▪ Enterprise Scale: On what proportion of the farms in the target population is there a major enterprise that could benefit from the innovation? ▪ Family succession/Management horizon: What proportion of the target population has a long-term (greater than ten years) management horizon for their farm? ▪ Profit Orientation: What proportion of the target population has seeking profit as a primary motivation? ▪ Environmental Orientation: What proportion of the target population has caring for the natural environment as a primary motivation? ▪ Risk Orientation: What proportion of the target population is highly averse to taking farm business management risks? ▪ Short-term constraints: What proportion of the target population is under conditions of short-term resource constraints?	For many landholders it may be difficult to determine the immediate benefit from the treatment system if profitability is the primary motive. However, appealing to alternative benefits such as environment, aesthetics values and future stewardship may influence the message delivered for specific audiences. The complexity of the treatment systems may also impact on those that are risk adverse and reluctant to change. The issue of short-term resource constraints should be addressed through the incentives program.
Relative Advantage of the Innovation	
▪ Relative upfront cost of innovation: What sized initial investment is required to adopt the innovation? ▪ Reversibility of innovation: To what extent is the adoption of the innovation able to be reversed? ▪ Profit Benefit: To what extent is the use of the innovation likely to affect the average profitability of the farm business? ▪ Time for Profit Benefit: How long would it take for most of the major profit benefits to be realised after the innovation is first adopted? ▪ Risk effect: To what extent would the use of the innovation expose the farm business to risk? ▪ Environmental Costs & Benefits: To what extent would the use of the innovation have on-farm environmental advantages or disadvantages? ▪ Time to Environmental Benefit: How long would it take for most of the major environmental benefits to be realised after the innovation is first adopted? ▪ Ease and Convenience: To what extent would the use of the innovation affect the ease and convenience of the management of the farm?	The extent to which profitability is considered will depend on the motivations of the individual and whether they are a commercial business or lifestyle landholder. Consideration of these aspects will influence the message that is delivered to specific groups.

8.3.4 Principles for facilitating adoption in the Rural Land Program

Based on the review of extension and adoption, ten principles for the implementation of the RLP were developed (adapted from InnoVeg program)[2]. These are:

1. Understand and respect the target audience
2. Acknowledge the importance of local knowledge
3. Segment the target audience and identify expected outcomes
4. Understand motivations for adoption of a practice/innovation
5. Ensure clarity of activities of WSFD program and alignment with partners/target audience
6. Utilise a range of extension methods/models
7. Consider range of different learning styles
8. Appreciate complexity of decision making and focus on capacity building
9. Utilise trusted service providers/partners with appropriate skills
10. Adopt a flexible and responsive approach based on evaluation and continuous improvement

8.4 Implications and recommendations for RLP

This section considers the findings from the review based around the key questions:

- What do we know about extension and adoption in agriculture and natural resource management, including principles for adoption and models?
- What are the drivers and barriers for adoption?
- What instruments would support and facilitate uptake of treatment systems and practices?

Based on our analysis we have provided recommendations to support the design and adoption of WSFD. The recommendations have been developed to address:

- Deeper understanding of landholders and their circumstances and needs
- Exploration of the characteristics of the treatment systems and management practices
- Analysis of relevant partners and their alignment with RLP objectives
- Major issues for the design and implementation of extension programs.

8.4.1 Landholder profiling

Landholder profiling should be undertaken to understand the different landholder groups, their needs, capacities and motivations. The design should carefully consider the criteria and methods used to classify landholder types (Emtage et al., 2007); the required spatial and temporal scales; and how to integrate single or multiple industries. Profiling work should consider targeting the 'hot-spots' where water quality issues are of greatest concern.

The process for profiling should include:

[2] RMCG (2012) InnoVeg Local Partnership Program - Coordinating collaborative & innovative industry development products, Project Number: VG09149 (HAL)

- Understanding landholders networks/clusters in a particular region – size, enterprise, social connections, primary income, industry affiliations
- Exploring the motivations and drivers and barriers for adopting WSFD practices and technologies recognizing very different contexts for individuals
- Describing the clusters of groups that have similar contexts and possibly motivations
- Focusing in particular on the specific needs of the lifestyle landholders
- Exploring how best to meet the objectives of these clusters including:
  - Identification of suitable policy instruments
  - How best to provide information and knowledge based on their current preferred sources
  - Appropriate extension tools and methods based on identified learning styles

Landholder profiling can vary in its scope and complexity of gathering information. In some instances there will be a depth of knowledge and understanding of landholder needs by local industry representatives or 'champions'.

8.4.2 Characteristics of recommended practices

The characteristics of the recommended technologies and practices will greatly influence whether they are adopted and how rapidly. These WSFD treatment systems may be considered complex and difficult to trial. It is also critical that there be consideration for how the practices and treatment systems fit with the existing farming system.

The following should be considered when exploring the characteristics of the treatment systems and practices:

- What is the general understanding of the issue? How relevant is the issue to the individual?
- Is there an understanding of the potential to use treatments systems and management practices to reduce the impact on waterways? What is landholder awareness of the need to implement the recommended practices?
- How confident are landholders that the recommended practices are effective? Is there evidence of effectiveness of practices?
- How easy is it to trial the treatments systems and practices in part or whole to determine whether they fit within the broader farming system.

8.4.3 Partnership analysis

Understanding the partners that are possibly involved in the engagement of landholders is critical to assist in the effective design and implementation of the program. It is recommended that further analysis be undertaken to:

- Determine partnerships involved in engaging with agricultural communities
- Establish pathways for engagement with specific clusters
- Explore objectives of similar programs and determine alignment with the RLP and possible synergies

- Assess appropriateness of delivery models for working with industry groups/clusters.

The partners analysis should include:

- State Government – DEPI, DSE, EPA
- Local Government – local councils
- Industry organisations

8.4.4 Extension program design and implementation

The extension program design and implementation will build on:

- Landholder profiling
- Description of the characteristics of innovation and
- Partner analysis.

The program design should also consider voluntary adoption, incentives as an appropriate tool, prioritisation, and partnership opportunities through the following key questions:

- Is voluntary adoption the most appropriate policy instrument to use? What other instruments may be useful?
- Are incentives a tool that will overcome barriers to adoption and do they represent good value for money? Are they critical for increasing the adoption of recommended practices? Can the implementation of incentives be sufficiently flexible to recognize the differing needs of different landholder groups?
- What will be the balance of capacity building across all catchments versus the focus on landholders in focal areas?
- How do we determine the focal areas and priority reaches?
- How do we target the needs of the specific landholder groups e.g. if labour and logistics is a barrier, coordination and organising volunteer groups may be effective?
- How do we provide extension activities that are targeted and yet provide value for money? There is a requirement for ‘horses for courses’ without being spread too thinly?
- What partnership opportunities exist that have synergies with the objectives of the RLP? How can these partnerships be utilized? Do the models for delivery that these partners use fit with the circumstances and needs of our target groups?
- How do we provide a participatory approach for landholders? How much do groups want self-guided versus directed activities?
- How well are our 10 principles for extension programs met? In particular are the providers of information/knowledge a trusted source?

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9 Guidelines for Policy and Regulation

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9.1 Overview

This section provides a summary of policy and regulation concerning management of diffuse pollution on rural (agricultural) land. The current and potential effectiveness of policy and regulation in Victoria is addressed, with some reference to experiences elsewhere. Recommendations are provided in regards to improving the effectiveness of policy and regulation and their application to increase their impact on reducing diffuse pollution from agricultural land.

The potential of a practice-change program based on voluntary participation to significantly reduce loads of nutrients and sediments to waterways is likely to be very limited, as indicated in other relevant research (Cary and Roberts, 2011). It is resource-intensive, and whilst the response has been positive, the program is likely to appeal most to a minority of landholders, such as those who are environmentally conscious and/or those with an advantage to be gained from environmental marketing. Many landholders would be unlikely to respond to the current approach for various reasons (lack of private benefits to landholders from adopting environmental practices, lack of management expertise or resources such as time or money to change from traditional practices, unwillingness, etc.). A higher level of commitment and resources, including appropriate policy change to better account for the off-site impacts of agriculture, will be required before the majority of landholders adopt practices to improve environmental performance (Ridley et al. 2003). The experience to date indicates that a more comprehensive and holistic approach to managing diffuse pollution from agricultural land is needed, including consistent policy and regulation for agricultural land uses.

9.2 The context for policy and regulation

In 2007, the Department of Primary Industries (DPI) led a review aimed at evaluating the effectiveness of agricultural management practices in reducing nitrogen and phosphorus export from farms to waterways. It concluded that the level of nutrient reduction in waterways achievable through improving nutrient and water management practices was highly context specific, depending upon some factors that can't be changed (such as annual rainfall, soil texture (surface and sub-surface), slope and distance to the watercourse), and other factors that can be changed such as management practices. The work acknowledged that the rationale or motivation for change is likely to vary greatly between farms, and recommended that a range of approaches ranging from education through to enforcement should be adopted to effectively drive change in management practices.

The DEPI report outlined four mechanisms to increase the adoption of change, but did not provide specific recommendations on which practices fell into which categories. The four mechanisms were:

- Farmer cost-effective (do-able now)
- Community based (do-able with public funds eg incentives, tenders)

- Industry and market based mechanisms (eg Environmental Management Systems EMS, codes of practice)
- Regulation and policy change (legislation, planning or licence conditions)

MW's RLP is based largely on the second approach. Several other government programs have also used this approach and some have also gone further, evaluating the potential for EMS (Cary and Roberts, 2011; Ridley et al. 2003a, 2003b; Seymour and Ridley, 2005; amongst others). This work, plus work outlining the fundamentals of practice adoption (Pannell et al. 2006) and consideration of the likelihood of adopting practices based on public and private benefits (Cary and Roberts, 2011; Pannell, 2008) confirm that environmental management practices are unlikely to be adopted at a scale to make a measurable difference to environmental outcomes.

In summary, work to date strongly suggests that a more holistic approach, including regulation, will provide greater outcomes for reducing nutrient input to waterways. This is consistent with work conducted in other parts of the world such as in the USA, where the need for a mix of approaches, including regulation, is already well recognised (Dowd et al., 2008).

9.3 Review of policy and regulations and their effectiveness

9.3.1 Legislation and regulations

In the absence of legislation specifically concerning water sensitive farm design, legislation and associated regulations and policies that address diffuse pollution from rural land to waterways will be considered in this discussion.

An overview of regulations is provided by Nelson (2005), in her paper discussing legislation related to integrated catchment management and its ineffectiveness in advancing sustainable water management. Roberts and Craig (2013) have also done work in this area, and Norton Rose have provided direct advice to MW. There is no single Act or government agency with the authority or responsibility to address diffuse-source pollution in Victoria, or indeed Australia-wide. Relevant Victorian Acts are the Environmental Protection Act (1970) and subordinate legislation of two State Environmental Protection Policies (1997 and 2003, addressing groundwater and surface waters respectively), the Water Act (1989) and the Catchment and Land Protection (CALP) Act (1994). Comments on each act are provided below, drawing upon the work done by those mentioned above.

The Environment Protection Act 1970

The *Environment Protection Act 1970* recognises the importance of "integrated environmental management" in prompting improved environmental health at the ecosystem level. The legislation mostly addresses point sources of pollution, including intensive agricultural enterprises like meat processing plants or broiler farms, where waste water disposal can be controlled through conditions on licences. However, the application of the Act to diffuse sources of pollution and their impacts on waterways is difficult, largely due to the standards of proof required for serving "pollution abatement notices" (Nelson, 2005, Norton Rose, 2012)

The State Environment Protection Policy (SEPP) Waters of Victoria, established under the Environment Protection Act, provides a mechanism for setting “water quality objectives” for different segments of waterways, recognising the “beneficial uses” to be protected for those segments. The accompanying “attainment program” for each schedule can outline the roles of landholders and management organisations in meeting the objectives, but is difficult to enforce. For example, the SEPP requires channels and drains to be designed and managed so that the water being transported has minimal impact surface water and groundwater (www.dpi.vic.gov.au), but enforcement of this requirement is difficult, with the responsibility for enforcement appearing to be blurred between the Environment Protection Authority (EPA) and the Catchment Management Authority.

The ineffectiveness of the SEPP is also evident in the low compliance rate with the water quality objectives for surface water. DEPI (2007) reports that nutrient concentrations at half the monitoring sites measured at three times greater than SEPP limits

The implementation of the policy framework to address diffuse pollution seems to be uncoordinated and cumbersome. For example, the SEPP refers to “Best Environmental Practice Management guidelines” to apply to management of wastewater on construction sites, but the enforcement of the guidelines is subject to their inclusion in planning schemes and permit conditions. This is then dependent on coordinated action between council local law officers and EPA officers to act on breaches of the code, requiring both political will and sufficient resources to be effective. No Best Environmental Practice Management guidelines for agricultural land use are referenced in the SEPP and, with the possible exception of the dairy industry, there are insufficient drivers for agricultural industries to urge farmers to adopt Best Management Practices.

The Water Act 1989

The *Water Act 1989* states some functions for MW in relation to the protection of water quality. There is some scope to address diffuse pollution under the powers, although it is limited by the requirement to be linked to a “water supply system”. The more general by-law making powers provide greater potential for addressing diffuse pollution, specifically under section 160 (Norton Rose, 2012). However, the requirement for a regulatory impact statement in the development of a by-law, and the relative low priority of addressing a non-core responsibility of MW, makes it unlikely that the powers to develop by-laws will be utilised.

The Catchment and Land Protection Act 1994

The *Catchment and Land Protection Act 1994* was established as the administrative structure for Integrated Catchment Management in Victoria, but Nelson (2005) notes that it is not well linked to water quality management or statutory land use planning. This may in part have led to the perception amongst management authorities that the environment is segmented into land and water and agriculture, rather than being viewed as one system. Nelson (2005) argues that statutory planning must be integrated with land and water management for the concept of Integrated Catchment Management to achieve its goals. She also suggests that legislation must provide a minimum level of catchment environmental protection that can be enforced. While the Catchment and Land Protection Act allows Catchment Management Authorities to develop statutory Regional Catchment Strategies, no minimal environmental standards are required.

A second criticism of the *Catchment and Land Protection Act* relates to the development of Special Area Plans, and their application to date being limited to Declared Water Supply Catchments (Nelson, 2005). Special Area Plans could be developed for other catchments, and provide directions and state actions for addressing land management problems in relation to waterway health. The development of Special Area Plans is resource intensive, and as public authorities are not obliged to implement Special Area Plans, there appears to be little political will for catchment management organisations to enable this aspect of legislation

In summary there are a number of current regulations covering agricultural land management practices, which are complex and largely ineffective at addressing diffuse-source water quality pollution. As noted by Nelson (2005), while an Integrated Catchment Management approach can attempt to address the adverse impacts of agriculture on waterways health in a holistic manner, the fragmented approach to Integrated Catchment Management in legislation means that the adoption of practices and regulation of activity is uncoordinated and the adoption of practices is more dependent on individuals' will rather than a collective movement for waterway protection. A holistic perspective is required, based on a recognition that ecosystem health for inland waterways is reliant on both water quality and water quantity, and in turn results from the complex interactions between surface water and groundwater, and between land use and land management. A holistic approach to improving waterway health needs to include regulatory reform to improve clarity and regulatory authority of institutions in administrating and enforcing action for reduced pollution to waterways, as well as non-regulatory components like education and incentives. .

9.3.2 industry Regulatory Standards

While there are several codes of practice operating in Victoria to protect the environmental impacts of intensive agriculture, they are restricted to enterprises that can be effectively viewed as sources of point source pollution. The Victorian Code of Practice for Piggeries 1992, the Victorian Code for cattle feedlots 1995, and the Victorian Code for Broiler Farms 2009, are linked to all planning schemes, and require protection of surface and ground water from waste water and nutrient runoff. The Dairy Effluent Management Guidelines are not linked to planning schemes, but their use by the EPA to work with dairy farmers not complying to the code and recognised as presenting risk to the health of waterways is supported by the dairy industry. Conversation with an EPA officer confirmed that limited resources and lack of political will means that this industry-endorsed approach to controlling diffuse pollution is limited to the dairy industry in selected geographical areas (anonymous (a), pers. comm. 2013). There appears to be very limited scope to extend the approach to other intensive animal industries, or to develop an industry-wide process for addressing diffuse pollution to waterways from agricultural land.

The Rural Land Program aimed to facilitate adoption of Best Management Practices in different agricultural enterprises. The document "*Water Sensitive Farm Design – A guide to reducing the impact of runoff to waterways"* outlines the key considerations for protecting water sensitive areas. The document is a tool for extending information, but can only encourage, not ensure or enforce, better management of runoff.

One avenue for driving action exists in the requirement for an irrigation and drainage plan to accompany new diversion licences of greater than 20ML. MW is currently developing a process to incorporate water sensitive farm design as a mean of addressing diffuse pollution from rural land in the licencing system it operates in the mid Yarra catchment. While this includes the Woori Yallock catchment, where the greatest number of licence holders are located, its limited application to the higher licence volumes, and the slow rate of licence transfers means its potential as a regulatory means of managing diffuse pollution is limited.

In summary, existing regulations barely address the problem of diffuse pollution from rural land, effectively being limited to dairy farms and licence landholders in the middle catchment of the Yarra River.

9.3.3 Current Reforms

The current conservative political climate suggests that there could be little scope or support to progress environmental policy reform in the short-term. However, given the long-term nature of water quality problems and reform, and the likelihood of increased waterway pollution from both urban and rural land given the high rate of changes in land use, it is in MW's interests to explore options for increasing the effectiveness of approaches to improving waterway health, and to be ready to act should the opportunity arise.

The discussion below outlines the three reforms currently underway with potential to increase focus on management of diffuse pollution, and comments on the reality of being able to act within the reforms:

- The draft documentation from a review of zones in the Victorian Planning Provision indicates that many land uses in rural zones will no longer be subject to permits, therefore limiting the ability for conditions regarding off site impacts of agricultural land uses to be included. However, there is still scope for development of local policy to better address diffuse pollution to waterways and promote practices for water sensitive farm design, placing the onus on MW to proactively work with councils in predominantly rural areas. While resource intensive, this option is certainly feasible, particularly given MW's work with local councils to date, for example, the current introduction of an Environmental Significant Overlay in the Yarra Ranges Planning Scheme, to apply within the catchment of Little Stringybark Creek.
- A review of the SEPP (Waters of Victoria) has commenced, with one of the aims being to better support the intent of the recently released *A Cleaner Yarra River and Port Phillip Bay: A Plan of Action*. The timelines for the review are uncertain, and there appears to be little opportunity to include reference to Best Practice Environmental Management for rural land. While MW can advocate for this inclusion, it is unlikely to be effective, as a significant amount of work is required to demonstrate the effectiveness of the guidelines and determine their impact on industry. Published work in Gippsland suggests that even if all practices were implemented the effects on reducing nutrient loads would be low (Roberts et al. 2012). Furthermore, given that SEPP is based on concentrations, this makes it very difficult to quantitatively assess the effects of practices on reducing nutrient inputs (Roberts and Craig, 2013).
- The water law review aims to rationalise the currently cumbersome nature of the Water Act 1989, consolidate it with the water industry act 1994, and streamline functions for all water authorities. It is planned to introduce new legislation to parliament in mid 2014. While MW can advocate for the new legislation to more comprehensively address water quality in conjunction with water quantity, and water management across a catchment rather than just within the waterway zone or storage basin, early indications are that this is unlikely to result in any change to promote management of runoff from rural land. It is

also expected that that the ability for water authorities to make local laws will be removed (anonymous (b), pers. comm.2013)

9.4 Linkage between regulation for diffuse and point source pollution

Water quality problems stem from pollution sources on both urban and rural land. To make informed decisions regarding intervention works to address diffuse pollution, data on the contributions from different sources is essential (as recommended in section 6). Furthermore, without being able to compare the unit costs of reducing nutrient loads from the major urban and rural sources it is not possible to have a defensible basis on which to make investment decisions about how to most cost-effectively address water quality issues, as been proposed as part of this work program (Roberts, Beverly and Stott 2013). Our comments below are predicated on the assumption that quantitative modelling and economic optimisation are embarked upon by MW.

Roberts and Craig (2013) have recently reviewed Victoria's approach to diffuse-source water quality problems, using the more than forty years of experience from the USA to help provide some key lessons. In addition to their conclusions about the need for changes in regulations being required to improve clarity, power and regulatory authority of institutions, the following requirements are noted:

- Adoption of a source-based approach to enable regulation and enforcement (current reliance on water quality concentrations in the SEPP are ineffective. It is near impossible and not practical to assess contributions of point and diffuse sources against water quality concentrations, and it is also difficult to assess the regulatory effectiveness of the objectives)
- Creation of a legal mechanism for linking point and diffuse sources on a given water body
- A mechanism for holding government accountable if it fails to perform mandatory regulatory duties

Whilst MW is not responsible for creating such a legal mechanism, nor for holding government to be accountable, adoption of a source-based approach and linkage of point and diffuse sources through modelling, as proposed by Roberts, Beverly and Barlow (2013) provides important preparatory work for a time when there is a political imperative to address water quality.

9.5 Building on international experience in reducing diffuse source pollution

Other parts of the developed world, such as the USA and Europe have recognised the importance of diffuse-source pollution (mostly from agriculture) for some time. In Europe and the USA the importance of diffuse-source pollution (mostly from agriculture) has been recognised and is progressively being addressed. Typically, point source pollution has been much better addressed than diffuse source pollution, and this is also being experienced in Australia. Point source pollution is more visible and easier to regulate, and therefore is addressed before diffuse source pollution. As seen in the discussion above, a coordinated and complimentary set of tools is needed to effectively address diffuse pollution.

No country to our knowledge can claim to have successfully addressed the problem of diffuse source pollution. There is however much to be learnt from the experience and MW can avoid some of the mistakes made by others. The approach we advocate here builds on the international experience, particularly that of the USA, albeit recognising that Australians are much less litigious than Americans, and that there is yet to be the urgent political imperative to embark upon major regulatory reform.

9.6 Recommended approach for policy and regulation

Significant regulatory reform is not within the mandate of MW. MW can work collaboratively with the Victorian government to encourage the need for reform but in the absence of political will there are limited avenues at present for direct action.

The discussion in this section indicates several areas of work to improve the potential for policy and regulation to facilitate uptake of practices and works for reducing pollutant input to waterways. It should be noted that no option alone will be effective in addressing all aspects of diffuse pollution management, and nor will any option remove the need for education and incentive approaches. A suite of complimentary approaches is required to effectively address diffuse pollution across the broad spectrum of agricultural land use, ranging from education to incentives to industry standards to enforcement of regulations.

Some practical areas of work for consideration by MW include:

- Declaration of priority catchments under *Catchment and Land Protection Act 1994* to enable Special Area Plans to be developed. This option would be applicable to the catchment draining to sugarloaf reservoir for MW interests, an action which is nominated for inclusion in implementation plans for Water Plan 3. The development of a Special Area Plan would be complex given the many intensive land uses within the wider catchment, but the process of declaring the area and developing a plan may serve to better integrate planning for catchment health outcomes.
- Development of Best Practice Environmental Management Guidelines for agricultural land for referencing in the SEPP (Waters of Victoria), and ultimately in local planning schemes of relevant councils with predominantly rural land. These could be adapted from MW's "Water Sensitive Farm Design – A guide to reducing the impact of runoff to waterways". It may also be possible to promote the guidelines in planning schemes in the absence of them having any referenced in the SEPP. However, this approach is unlikely to have any impact, especially given that the application and auditing of guidelines or standards will be dependent on individual officers within individual councils.
- Development of a template for promoting water sensitive farm design within irrigation and drainage management plans linked to diversion licenses. The current trial in MW could be assessed and promoted to the water industry more broadly across the Port Philip and Westernport region, as a means of working towards goals for reducing nutrient and sediment inputs to the bays.

Each of the options listed above requires political will and commitment to implement, as well as significant amount of resources. While they may only partly progress the goal of better addressing diffuse pollution, they are worth pursuing to continue advocacy for change. Additional preparatory work can also be undertaken to underpin future policy and regulatory approaches. One key area of work would be to coordinate approaches to diffuse pollution across different land use types on a catchment basis, through developing appropriate catchment modelling tools (Roberts, Beverly and Barlow 2013), and an economic optimisation framework to guide investment into water quality (Roberts, Beverly and Stott 2013). These approaches are discussed in more detail in sections 6 and 7 of this report.

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10 Guidelines for Monitoring

Authors: Tim Fletcher (UoM)

10.1 Overview

This section discusses monitoring the effectiveness of on-farm practices and structural treatment measures to achieve water quality outcomes. Given the relatively sparse literature on the performance of on-farm practices and on structural treatment measures for the mitigation of hydrologic and water quality impacts on receiving waters, MW will need to undertake its own monitoring activities to measure effectiveness. The value of investments in monitoring depends strongly on the design of the monitoring programme. In this section, we summarise the important principles in the design and operation of monitoring programmes. Given the likely requirement to develop and refine models, we also provide guidance on this application, with a primary focus on the catchment-scale.

There is perhaps surprisingly little literature available specifically to guide the development of monitoring activities on farms or for measurement of agricultural land use at broader scales. There are however, a plethora of guidance documents on flow and water quality monitoring in general and there is no *a priori* reason why these cannot guide the development of monitoring programs for rural and farming situations.

An important caveat, however, is that *prior* to the adoption of particular guidelines, there needs to be a determination (and agreement) of what needs to be monitored. For example, there are many guidelines available on water quality monitoring, but if the objectives of a particular monitoring programme are to, for example, measure ecosystem impacts, identify changes to flow regimes or assess sediment contamination, then use of such guidelines in the initial stages of the monitoring design are likely to serve more as a distraction. Table 10-1 provides some examples of relevant guideline documents available.

Table 10-1: Examples of monitoring guidelines

Reference	Relevance
(ARMCANZ & ANZECC, 2000). National water quality management strategy: Australian guidelines for water quality monitoring and reporting.	Benchmark reference. Includes an excellent chapter on setting program objectives, as well as chapters on study design, field sampling, laboratory analysis, data analysis & interpretation. Nothing specific on rural or on-farm monitoring.
(Water, 2009). Water quality monitoring; a guidelines for field sampling for surface water quality monitoring programs. ISBN 978-1-921468-22-3.	Provides guidance on designing monitoring (why, what, where, when, how), data management, quality control reporting and data use. Applies to industrial, rural and urban land use.
(Fletcher & Deletic, 2007; H. Lee, Swamikannu, Radulescu, Kim, & Stenstrom, 2007; J. H. Lee & Bang, 2000; Leecaster, Schiff, & Tiefenthaler, 2002)	Four papers which provide useful guidance on monitoring, with a particular focus on statistical aspects.
(Fletcher & Deletic, 2008). Data requirements for integrated urban water management. UNESCO and Taylor & Francis	A comprehensive textbook emanating from the UNESCO International Hydrologic Program which outlines principles for the design of monitoring programmes, data collection, quality control and analysis, and use of data in decision-making. While the book has a distinctly urban focus, its principles are generic..

10.2 Important processes and principles in designing and operating monitoring programmes

The process of designing, implementing, operating and reporting a monitoring program generally involves the following considerations or steps (these are derived from Fletcher et al. (2008):

- Defining objectives
- Selecting which variables to be monitored
- Taking into account spatial and temporal considerations
- Assessing and managing uncertainty
- Selecting appropriate monitoring equipment
- Data validation and quality control
- Data handling and storage
- Use of data to provide information and knowledge.

These steps are described in Figure 10-1 and outlined in more detail in the following sections (note that much of this material is extracted from Fletcher et al., 2008).

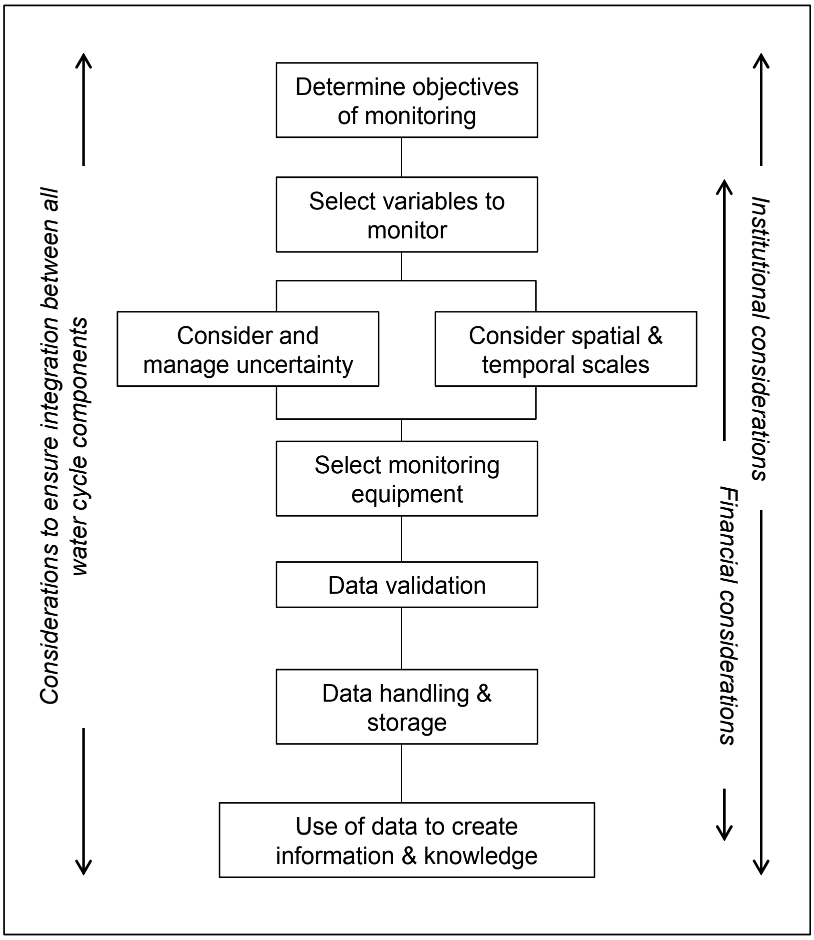

Figure 10-1: **Summary of considerations for data collection and use in integrated urban water management**

10.2.1 Defining the objectives of monitoring[3]

The natural tendency at the start of a monitoring program to jump straight into discussions about what variables will be monitored and what technologies will be used to monitor them. Such an approach is quite flawed and will likely lead to inferior monitoring design, or later disagreements within the group of stakeholders about what is needed. Given its fundamental importance, considerable resources should be given to the definition of objectives and making these specific, measurable, attainable, relevant and time bound (SMART). Appropriate dedication of personnel time, and gathering of information necessary to inform the process, should be built into the budget for monitoring design and implementation.

Monitoring objectives derive from the issue that is of concern, and from the *management objectives* that have been determined for that issue. In framing the monitoring objectives, one may ask some key questions, which are based on information needed to meet the management objectives. For example:

- What information and knowledge is currently lacking, that is needed to improve management of the issue, and its interaction with other aspects of the water cycle?
- Who will use the data, and how?
- What level of uncertainty in the result can be accepted?

[3] (Source: Fletcher & Bertrand-Krajewski, 2007)

- What level of resources do we need to undertake the monitoring?
- Over what scales are the data needed?

Questions about *how* the monitoring is to be undertaken are not of primary concern at this stage. Once the objectives have been established, design of the monitoring programme may show that the objectives cannot be met, and a review of the objectives and available resources will then be required. However, it is important that cost not be the primary consideration at the objective-definition stage, so that any gaps between the monitoring objectives, and the ability to meet them, are made explicit. Incorporation of financial constraints into the process of setting objectives will make it more difficult to objectively assess the consequences of reducing or increasing the resources available to meet the objectives.

Figure 10-2 summarises the process of defining objectives, involving five principal stages:

- Define the management issues
- Identify information requirements
- Collect existing information
- Create conceptual model of system and understanding
- Define the objectives.

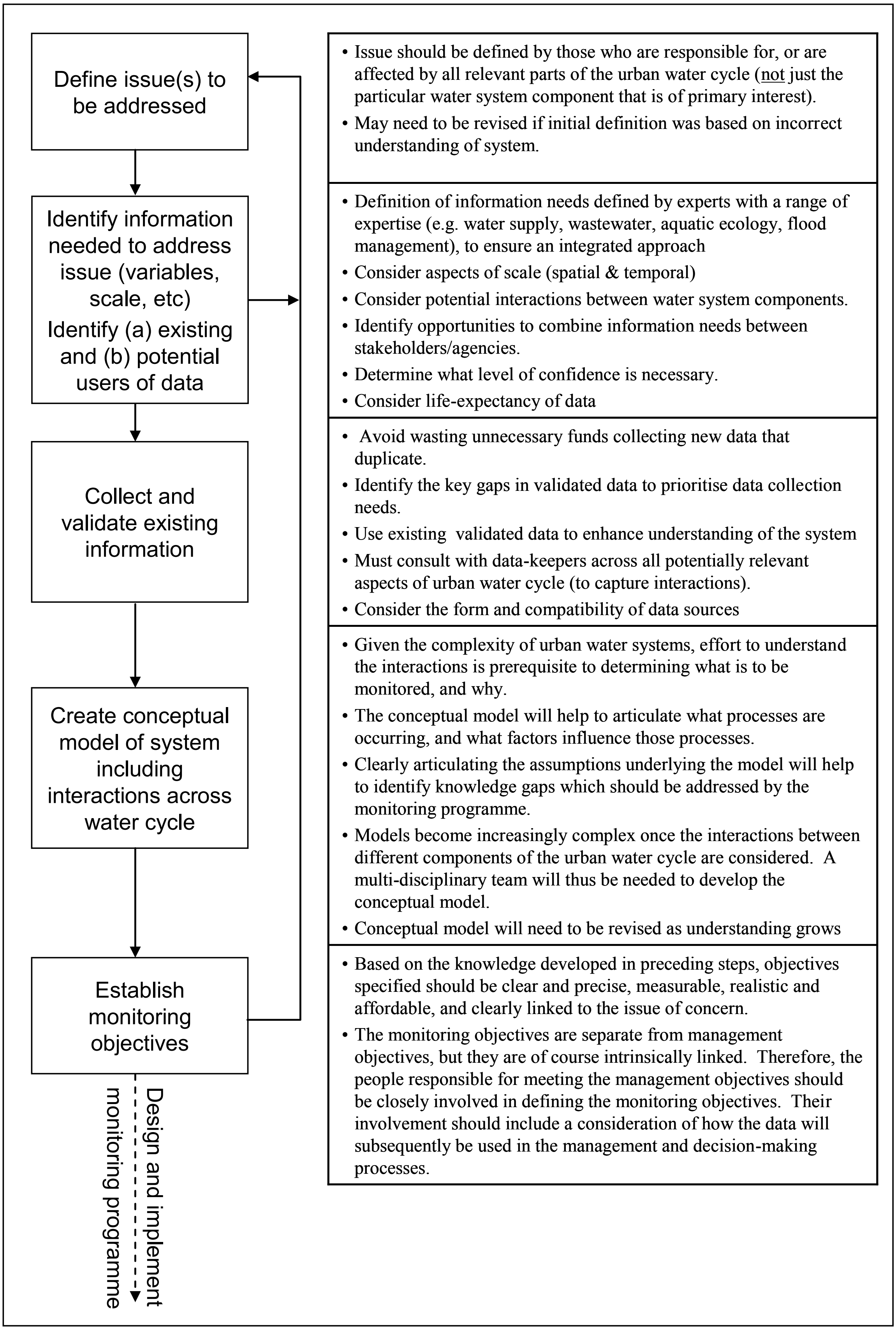

Figure 10-2: **Defining objectives for monitoring (Source: Fletcher & Bertrand-Krajewski, adapted from ANZECC & ARMCANZ, 2000)**

10.2.2 Selecting variables to monitor[4]

Once objectives have been specified, the variables to be monitored can be selected. These may include:

- Nature of the site or technology to be monitored (including its scale)
- Meteorology (e.g. rainfall)
- Water flow or level
- Water and sediment quality
- Ecological characteristics of the aquatic ecosystem.

Understanding the site conditions is important. For example, having an accurate definition of the catchment area will be critical to interpreting flow and pollutant load data. Where possible, high-resolution digital terrain data of the site should be collected. In the case where a particular set of on-farm practices or treatment systems is to be measured, then information on these should be collected, including their size and layout, design parameters, age and condition, as well as maintenance history. In particular, understanding the physical dimensions of any treatment system is very important, since it will inform the measurement of flows, etc. Therefore, use of 'as-constructed' rather than 'as-designed' specifications is critical.

Where rainfall is to be measured to inform, for example, measurement or modelling of flow, particular attention should be paid to the scales of measurement. For example, a raingauge two kilometres away from an individual farm is highly unlikely to provide reliable estimates of rainfall from which to predict runoff on the farm. The smaller the site of interest, the closer should be the raingauge, with the effect in practice that dedicated raingauges should normally be installed for each monitoring site.

Selection of flow and water quality variables to manage will obviously depend on the objectives. For example, is the aim to measure only surface runoff contributions or to capture total flow contributions, including surface and subsurface contributions? The answer to this question will fundamentally change the required monitoring. Similarly, the choice of water quality parameters – including nutrients, sediment, pathogens, heavy metals or other toxicants, and the need to measure their concentration or load, depends on the monitoring objectives.

Importantly, given MW's responsibility as custodian of waterways, monitoring resultant impacts on ecosystems is important; further guidance on this can be obtained from Breil et al. (2007).

10.2.3 Spatial and temporal scale considerations[5]

Suitable temporal and spatial scales are an important consideration for design of monitoring. For example, a waterway with a large catchment (made up therefore of many individual properties) will be extremely unlikely to show any water quality or ecological response to interventions on a single (or even a few) properties.

[4] (Adapted from: Deletic & Fletcher, 2007)
[5] (Adapted from: Bertrand-Krajewski, Fletcher, & Mitchell, 2007)

Temporal variability: The choice of appropriate monitoring time scale and time step depends on both the temporal dynamics of the phenomena to be monitored. The *sampling theorem* (also called the Shannon or Nyquist theorem) indicates that, in order to observe phenomena and effects occurring with a frequency F, one has to make measurements with a frequency at least equal to $2 \times F$. If, for example, the objective is to evaluate daily variations, measurements have to be made at least twice a day. An example of the influence of sampling frequency on uncertainty is given in Figure 10-3. A pilot campaign may be necessary to identify the appropriate temporal resolution of sampling. Another consideration in determining the temporal resolution of sampling is the potential use of the data for modelling. For example, the performance of a grass swale in MUSIC is best modelled using a 6-minute timestep and so sampling data needs to be of a resolution able to inform the calibration of such a model. Of course, the temporal resolution of sampling during dry weather and storm events may be quite different, due to differences in dynamics during these periods.

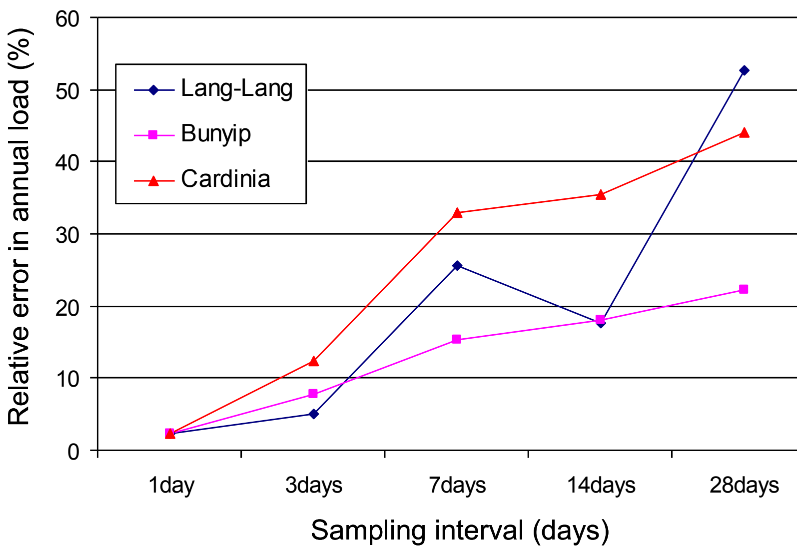

Figure 10-3: **Influence of sampling interval on error in calculated load of TSS (Fletcher & Deletic, 2007)**

Spatial variability: The phenomena of interest in rural and farm landscapes will often be spatially distributed, with for example diffuse and point-sources of pollutants within an individual farm, along with a network of drainage and receiving waters. It is also important to recognise that spatial influences on the representativeness of samples occur not only at large scales. Even at very small scales, spatial heterogeneity may distort sampling results; for example, with a drainage line or constructed system the velocity of flow and the quality of water (e.g. sediment concentrations) may vary significantly; only pilot investigations will reveal the extent to which such influences are likely for a given system of interest.

10.2.4 Assessing and managing uncertainty

Understanding the quality of data is essential for sensible use of monitoring results. Take the example where alternative treatment systems, such as a simple sedimentation basin and a vegetated buffer strip are monitored for their ability to reduce sediment concentrations. Monitoring may show the sedimentation basin reduces suspended sediments by 65% on average, while the buffer strip was on average 56% effective. This outcome may lead to allocate future RLP funds only to sedimentation basins, excluding funds for buffer strips.

However, if the uncertainty of the measurements was quantified, showing in fact that the sedimentation basin achieved a removal of somewhere between 55 and 70%, while the buffer strip was somewhere between 52 and 60%, it could be argued that the two systems gave statistically similar performance, justifying funding either option, depending on site considerations.

Bertrand-Krajewski and Muste (2008a) provide a very thorough description of methods for assessing and reducing the uncertainty of monitoring programmes. The following paragraphs, adapted from their chapter in Fletcher & Deletic (2008) summarise recommendations for uncertainty analysis during monitoring and for incorporating uncertainty into decision-making.

A preliminary uncertainty analysis should be done before the main measurement campaign commences. This procedure allows corrective action to be taken to reduce uncertainties (to within the limits determined by the objectives). This preliminary uncertainty analysis is based on data and information that exist before the test, such as calibration histories, previous tests with similar instrumentation, prior measurement uncertainty analysis, expert opinions, and, if necessary, special tests. The results can be used to determine what corrective measures, if any, should be undertaken. Post-test analysis then validates the pre-test analysis, provides data for validity checks, and provides a statistical basis for comparing test results. Once the sources of uncertainty have been identified, their relative significance should be established based on order of magnitude estimates. A "rule of thumb" is that those uncertainty sources that are smaller that 1/4 or 1/5 of the largest sources are usually considered negligible.

The challenges facing measurements and modelling of the flow, water quality and aquatic ecosystems should be contemplated in the wider perspective of risk-based decision support. Firstly, a high degree of measurement uncertainty is not necessarily an undesirable outcome, and undoubtedly is preferable to no indication of reliability at all. Secondly, measurement uncertainty should be viewed as a source of risk, as is traditional in other fields of engineering, and should be used to establish and achieve an acceptable failure probability in terms of water quality and quantity status, rather than be used to criticise the measurement approach. Thirdly, it is worth noting that, in the context of decision support, we are not justified in investing resources in monitoring and estimating uncertainties unless this will be instrumental in the decisions that need to be made.

10.2.5 Selecting monitoring equipment

The selection of monitoring equipment is a critical step in monitoring and typically involves a trade-off between confidence and cost. In selecting sensors, the following should be taken into account (adapted from Prodanovic, 2008):

- Accuracy and repeatability: these are fundamental to measuring with confidence. Of course, measurement accuracy and cost can are often (but not always) in conflict. The required level of accuracy should be identified as part of the objective setting. Another important consideration is to ensure compatibility in levels of accuracy between sensors. For example, there is little value in measuring flow with great accuracy to measure pollutant loads, if the pollutant concentrations are then measured with single grab samples for an event.
- Stability: while a particular sensor may be accurate after calibration, drift of sensors is a common problem. Drift may happen as a gradual evolution over time (this is particularly

common with pressure-transducer type water level sensors) or involve diurnal variation with temperature (common in many sensors include soil moisture probes, ultrasonic depth probes, etc). In the case of thermal drift, manufacturers will commonly provide correction curves, but it is advisable to check these independently.

- Resolution: it is important to understand whether the resolution of the sensor is capable of delivering the resolution required by the agreed objectives of the monitoring.

While these technical considerations are important, it is as least as important that the equipment selected is suitable to the users! Sensor networks that can only be used by highly trained experts may be appropriate in some cases, but it will, particularly in the case of the RLP, generally preclude involvement from landholders, etc. Another important consideration is the maintenance and download frequency of the sensor. Having to attend weekly to download data or change batteries will have a major impact on the cost of the project; in such a situation it may be cheaper over the life of the project to pay for equipment with greater data and battery capacity. Similarly, with the increasing move to wireless technology, the installation costs can be significantly reduced. Wireless sensor networks may allow centralised logging of data.

10.2.6 Data validation

Verifying the quality of collected data is critical! Undetected false data could have major impacts on investments and decisions. Bertrand-Krajewski and Muste (Bertrand-Krajewski & Muste, 2008b) provide a step-by-step process for validation. The basic principle is that "all measurements should be considered to be wrong until there are sufficient and objective reasons to prove otherwise".

Data validation should be carried out at two levels:

1. Local (or internal) validation: whereby the validation data is obtained with one individual measurement, at a point by one or more sensors. This analysis verifies the intrinsic validity of recorded data. This validation level is usually associated with the detection phase, but often the diagnostic phase is also needed.
2. Global (or external) validation: data validation is carried out by taking measurements with several sensors, in different points, and/or comparing the data with models or alternative observations. For example, upstream and downstream data along a river reach or rainfall volumes and measurement volumes downstream a catchment can be compared for this purpose. This validation level is usually associated with the diagnostic phase, but detection aspects are also involved.

Data validation can also be made either (i) off-line or (ii) on-line, with the latter typically used for real-time control systems. The following sections focus specifically on on-line validation.

After the validation, the following data and information must be stored:

- The initial raw data series (this must *never* be discarded).
- The validated data series: containing only the validated values that will be subsequently used for monitoring, legal purposes, design, diagnostic studies, modelling, etc. In some cases, a validity index (or data quality index) is estimated for each value.

Based on these basic principles, the following eight principles are given by Bertrand-Krajewski and Muste for data validation:

- Data validation shall be made systematically for all monitoring programmes (it is not an optional specification)
- Always check and validate all data from all types of measurements used in the monitoring programme (structural and functional data, static and dynamic)
- Validation should include two phases: (i) detection phase, (ii) diagnostic phase
- Validation should be made at both local and global levels
- Validation can not be made independently of its operational and environmental context
- Validation is not pertinent without rigorous and periodic calibration of the instruments and correct estimation of measurement uncertainties.
- Validation can be made off-line or on-line, depending on the monitoring purposes.
- Validation actions shall be recorded for memory, transmission, further diagnostics and reversibility.

Bertrand-Krajewski establish a number of tests that can be used to assess data validity, including (i) sensor status (working or not), (ii) whether data are within suitable measurement range, (iii) whether sensor was maintained according to standards at the time of the measurement. A conclusion of this section is that dependent on the importance of the data, having redundant sensors can be worthwhile (for example measuring water level with two separate sensors, in order to be able to cross-check one against the other or to be able to use the second data to provide information in the case of the failure of another.

10.2.7 Data handling and storage

The handling of data is critical to the success of a monitoring programme, yet is often poorly implemented. A well-documented system of data storage, access and retrieval should be in place and this should include meta-data (e.g.. data about the properties of the system being monitored. There should be clear indication of which data are validated and which are not. Data should preferably be stored in a format which is easily accessible and with suitable documentation to allow potential users of the data to extract and use it.

10.2.8 Using data to provide information and knowledge

In this section we briefly discussion of potential applications of data collected. Within the RLP, one could envisage the following typical uses of data:

- Calculation of pollutant concentrations and loads emanating from a given land use
- Measuring the effectiveness of a given treatment measure
- Quantifying the state of receiving water ecosystems (measured for example through ecosystem composition or function)

Importantly, these uses should have been envisaged <u>before</u> the collection of the data (because they should drive the type of data collection).

10.3 Using monitoring data to inform the calibration & validation of farm-scale models

Ultimately, the collection of data within the Rural Land Program and in particular the Water Sensitive Farm Design initiative aims to develop predictive capacity. That is, we wish to be able to predict the flow and quality of water emanating from different land uses and the performance of runoff retention and treatment measurements aimed at protecting receiving waters. In this section we outline the type of data required for farm-scale modelling, and particularly the performance of runoff retention and treatment systems constructed on an individual farm.

The MUSIC model will be used throughout this section as our example model as:

- MUSIC shows potential as an on-farm model and is already widely used already within MW (for urban purposes), giving potential for translation.
- It also shows potential for linking with catchment-scale models (see section 6).
- Initial investigation shows that a model using the algorithms in MUSIC could be appropriate for on-farm application (see section 6.9).
- Regardless, the principles remain broadly similar for any model.

10.3.1 Data for modelling the hydrologic, water quality and ecological impacts of given land use at farm scale

Measurement of runoff behaviour from an individual farm will be difficult (because apparatus able to measure runoff rates from a broad paddock will be very expensive and difficult to install). Therefore, it may be more useful to work either at (i) plot scale (for example collecting runoff data from a small plot, contained by installation of diversion structures) or (ii) sub-catchment scale, where there is a relatively homogenous land use. This latter option is most likely to be feasible, involving less disturbance to the landholder, being easier to install and allowing an integrated measure of the land use effect, but it does depend on finding a sub-catchment with homogenous land use. We recommend that sub-catchment-scale monitoring could be used to calibrate rainfall-runoff models of particular catchments.

A similar argument applies for water quality monitoring; measurement at the plot-scale will give more understanding of water quality processes occurring at the paddock-scale, but monitoring of concentrations (combined with flow) in a sub-catchment (stream) will give an integrated measure.

We therefore recommend collecting water quality concentrations of all pollutants of interest during both dry weather and storm events, in order to populate the "Dry Weather Concentration" and "Event Mean Concentration" parameters of models such as MUSIC. Dry weather sampling can be undertaken on a regular basis (e.g. monthly), while event sampling should ideally include discrete samples taken through an event; this requires an auto-sampler. Alternatively, grab samples during events can be taken, as long as enough events are sampled to gain a suitable representation of the site mean concentration (see for example Fletcher & Deletic, 2007; Leecaster, et al., 2002). Enough sampling is required to provide a *statistical distribution* of the Dry Weather Concentration and the Event Mean Concentration. The sampling campaign must therefore be long enough to provide these distributions (typically mean and 95% confidence intervals); this will typically be at least 12 months of monitoring.

10.3.2 Data for modelling effectiveness of on-farm technologies (point)

Monitoring of on-farm technologies for the calibration and validation of models needs to consider the nature of the model's algorithms. We will again consider the case of MUSIC. For most treatment systems (but not all), MUSIC uses the *Universal Stormwater Treatment Model*, made up of an algorithm to deal with hydrodynamics (the Continuously Stirred Tank Reactor model) and another to deal with the treatment of pollutants as they pass through the system (the k-C* exponential decay model). These are described below.

Flow hydrodynamic behaviour – the continuously stirred tank reactor (CSTR) model

The treatment effectiveness of a stormwater treatment measure depends upon the flow behaviour in that system. The most effective treatment will occur where the entire treatment surface area is engaged, and there are no stagnant zones, nor flow short-circuiting through preferential flow paths. Flow conditions approaching plug flow will be conducive to effective treatment, since all 'parcels' of inflow will be subject to equal detention time.

- The degree to which flow hydrodynamic conditions in a stormwater treatment measure depart from an idealised plug flow condition can be modelled by appropriate selection of the number of CSTRs (N). A single CSTR (such as a small pond with low aspect ratio) will result in a pollutant hydraulic residence time distribution represented by an exponential decay function (strongly right-skewed), where the peak discharge concentration occurs almost immediately after dosing, and concentration then reduces with the effects of dilution. Conversely, as the number of CSTRs in series increases, the residence time distribution becomes more like plug flow (such as may be observed in a long vegetated swale), and the time-lag of the peak discharge concentration is closer to the nominal detention time (given by Volume/Discharge).

Water quality behaviour – the first-order kinetic decay (k-C*) model

MUSIC uses the two-parameter first order decay function (Eqn. 1), which expresses the rate at which pollutant concentration moves towards an equilibrium or background concentration (C*), with distance along the treatment measure, as a linear function of the concentration.

$$q\frac{dC}{dx} = -k(C - C^*) \qquad \text{(Eqn. 1)}$$

where	q	=	hydraulic loading rate (m/yr), defined as the ratio of the inflow and the surface area of the system
	x	=	fraction of distance from inlet to outlet
	C	=	concentration of the water quality parameter
	C*	=	background concentration of the water quality parameter
	k	=	areal decay rate constant (m/yr)

The parameters k and C* are lumped parameters representing the combined effects of a number of pollutant removal mechanisms. A high value of k results in a rapid approach to the equilibrium concentration C*, and hence a higher treatment capacity (provided that C* is less than the inflow concentration).

To calibrate these two algorithms requires inflow and outflow data from the given treatment device at a suitable timestep. For example, MUSIC can work at timesteps down to 6 minutes and such small timesteps are necessary to accurately predict the performance of small systems likely to be found on farms, because of their short detention time. This will require an autosampler and flow measurement at the inlet and outlet of the treatment system. An example of the type of data used in treatment calibrations is shown in Figure 10-4.

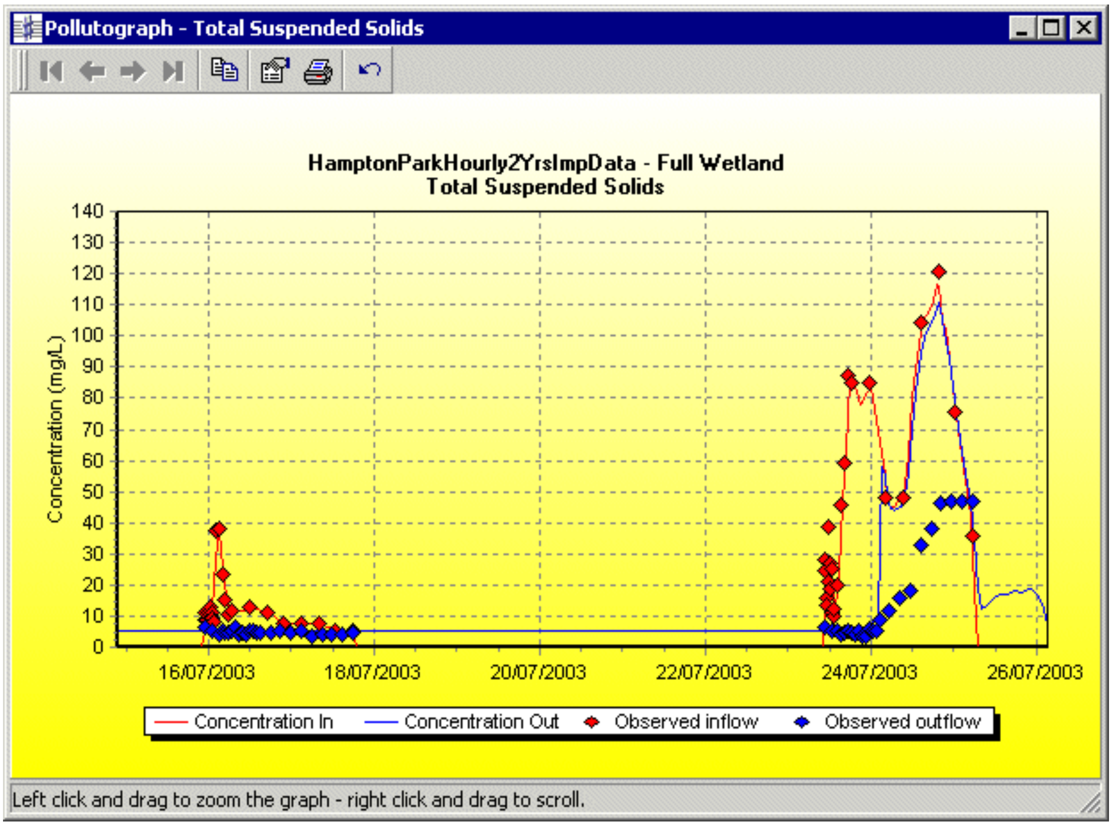

Figure 10-4: Example of calibration of MUSIC to observed inflow and outflow data (Source: Duncan & Fletcher, 2006)

10.3.3 Data for modelling effectiveness of on-farm practices (diffuse)

Monitoring in order to populate models which predict the effectiveness of on-farm practices (e.g. changes in the rate or timing of fertiliser or herbicide application) is perhaps the most difficult challenge. Given that it is unlikely that simultaneous changes in such practices will occur across an entire sub-catchment, monitoring will most likely be required at farm-scale. Unfortunately, because such changes in practices will be typically spread across a wide area, monitoring the resulting flow and water quality will be difficult and potentially resource intensive. This is in conflict with the hypothesised high cost-effectiveness of such measures. In addition, there is considerable farm-scale variability making the extrapolation of data to the catchment scale difficult.

A suitable response to this conflict may be set up contained paired plots within a farm, one where standard practice is applied and another where the 'improved practice' is applied.

However, there are important cost and scalability considerations involved with this technique. In a model such as MUSIC, such practices could either be represented using the Generic Treatment Node (see Figure 10-5) or simply by modifying the Dry Weather Concentrations and Event Mean Concentrations.

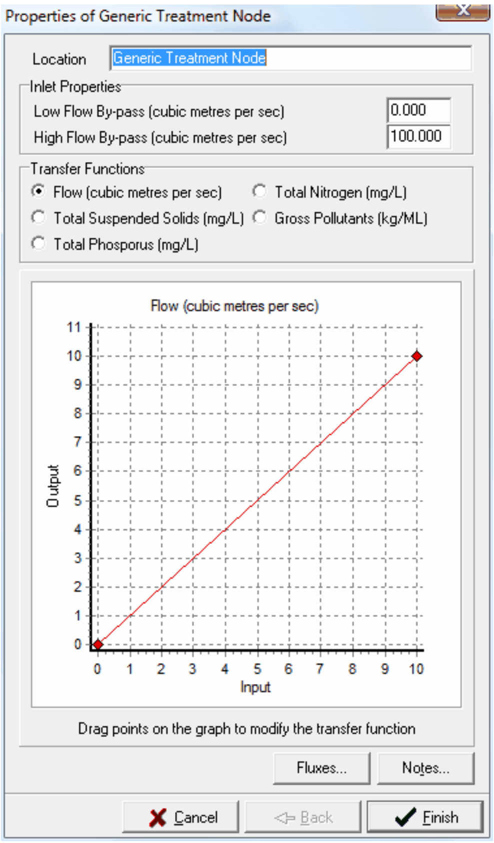

Figure 10-5: Generic treatment node in MUSIC can be used to represent effectiveness of on-farm practices

10.4 Recommended approach to monitoring

It is recommended that the process of designing, implementing, operating and reporting a monitoring program to assess WSFD treatment systems should involve the following considerations or steps (derived from Fletcher et al. (2008):

- Defining objectives
- Selecting which variables to be monitored
- Taking into account spatial and temporal considerations
- Assessing and managing uncertainty
- Selecting appropriate monitoring equipment
- Data validation and quality control
- Data handling and storage
- Use of data to provide information and knowledge.

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11 Summary of Recommendations

Authors: Various, collated by Anne-Maree Boland (RMCG) and Carl Larsen (RMCG)

11.1 Protection of aquatic ecosystems from the impacts of rural land use

- Conduct targeted research projects to assess, at smaller scales than existing studies, in-stream ecological response to different agricultural land uses
- Identify through consolidation and analysis of existing GIS data, the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration
- Ensure that the parts of the landscape that provide the greatest potential for natural retention and transformation of contaminants (small drainage lines) be protected, and used as natural treatment systems as a first priority. Management of the region's small streams and drainage lines will require an understanding of hydrologic and water quality processes beyond annual loads of pollutants.

11.2 On-farm pollution reduction systems and practices

For on-farm management practices:

- Use the guidelines of section 4.2.6 and local expert opinion if available to choose management practices that will be effective for the given problem at the given site
- Monitor a representative sample of treated sites to improve knowledge of treatment effectiveness under local conditions.

For structural treatment measures:

- Use existing urban models (i.e. MUSIC) to obtain indicative results and relative performance of structural treatment measures appropriate to the site, and select measures accordingly. Modify model parameters to account for any known differences in water quality descriptors (particle size distribution, dissolved versus particulate ratio, etc.)
- Monitor a representative sample of structural treatment measures to allow improved recalibration of urban models for local rural conditions.

11.3 Spatial characterisation

- Improvement of the current spatial data set requires:
  - **Land use:** to assess degree of stock access to streams, which is likely to be a strong driver of stream degradation associated with rural land use.
  - **Digital elevation models (DEM):** LiDAR based elevation model for the most regions or other DEMs with cell size ranging from 5-10m are available.
  - **Hydrologic data:** the ‘above MW waterways’ layer is to be developed with where to begin a realistic stream network an important issue.
  - **Water quality:** some locations were reported to be away from the natural waterways network. These need to be amended.

- The use of the VLUIS 2010 data as the rural land use base, and inclusion (either by integration or interoperability) of the most current impervious/pervious data layer, the most current treed extent, MW's hydrological data and dams and water bodies from the Corporate Spatial Data Library.
- Development of consistent spatial soils data with more analysis of information required for areas northwest and west of Melbourne. The minimal requirement would be to create a consistent as possible data suite of soil information across the Port Phillip and Westernport catchments at 1:100,000 scale and consideration of requirements for finer-scale information (for example 1:50,000 compared with 1:100,000 scale). In broad terms the options are:
  - **Status quo:** Use 'McKenzie look-up tables' to derive specific functions (as required by the *Howleaky* model)
  - **Enhanced soil type definition:** Gather more information to better describe land systems and still use McKenzie tables
  - **Enhance soil descriptions, improve mapping of soils and sampling:** to include specified factors (e.g. wilting point)
  - **Enhance soil descriptions and sample for all data requirements including soil infiltration** (for two depths – i.e. surface and subsoil horizons).

11.4 Landscape modelling

Three options for landscape modelling are provided below.

#	Scenario	Option	Description
1	Limited funding, and limited in-house catchment modelling capability	Option 5 (Adopt the SWAT catchment modelling framework)	This option can be achieved using existing in-house GIS expertise and addresses the limitations of the SourceCatchment model by removing the need to specify EMC/DWC estimates under various land use/land management change and BMP options. An added advantage is that SWAT is freely available, internationally recognised and under constant development.
2	Adequate funding but limited in-house catchment modelling capability	Option 5 with inclusion of SedNet	This option is an advance on recommendation 1 as it accounts for gully and streambank processes. However this option requires a level of funding to provide model development to link SWAT with SedNet.
3	Adequate funding and a commitment to develop and maintain in-house catchment modelling capability	Option 3 (integration of the CAT model in SourceCatchments), 4 (Surface modelling approach fully coupled with groundwater model) or 5	If adequate funds were available and MW was committed to maintaining catchment modelling capability, then Option 3 is required as a minimum. This option comprises the incorporation of farming system models of greater complexity than Option 5 and which explicitly simulate forest management, animal interactions and pasture dynamics. Option 4 is recommended if groundwater impacts are sufficiently important. Option 5 is recommended if broad scale nutrient dynamics is only required as this model will be linked to groundwater. Whilst options 1 and 2 can readily link MUSIC with SourceCatchments, they do not account for soil and land management impacts and thus poorly predict future impacts.

11.5 Economic optimisation framework

- Test the approach which utilises the biophysical modelling (SourceCatchments or SWAT, as per Roberts, Beverly and Barlow 2013) and an optimisation method which is appropriate for this complex problem whilst being straightforward to implement for modellers.
- A conceptual diagram is outlined which shows how the biophysical and economic elements are linked – note that steps do not all have to be done in sequence and that whilst E2 has been used as the example, Source, SWAT linked to MUSIC can be used instead. The main elements of the program (assuming a comparative static model approach is required) are described in section 7.

11.6 Extension design and adoption

It is recommended that the design and adoption of WSFD technologies and practices consider the following issues.

Table 11-1: Recommendations for extension design and adoption

Recommendation	Comment
Deeper understanding of landholders and their circumstances and needs	Landholder profiling should be undertaken to understand the different landholder groups, their needs, capacities and motivations. This profiling should target specific groups based on the expertise and existing knowledge established by the RLP team.
Exploration of the characteristics of the treatment systems and management practices	The characteristics of the recommended technologies and practices will greatly influence whether they are adopted and how rapidly. These WSFD treatment systems may be considered complex and difficult to trial. It is also critical that there be consideration for how the practices and treatment systems fit with the existing farming system.
Analysis of relevant partners and their alignment with RLP objectives	Understanding the partners that are possibly involved in the engagement of landholders is critical to assist in the effective design and implementation of the program.
Major issues for the design and implementation of extension programs.	The extension program design and implementation will build on: ▪ Landholder profiling ▪ Description of the characteristics of innovation and ▪ Partner analysis. The program design should also consider voluntary adoption, incentives as an appropriate tool, prioritisation, and partnership opportunities. The program should be realistic about the potential for voluntary adoption to achieve the desired outcomes in contrast to more regulatory (non-voluntary) based programs.

11.7 Approach for policy and regulation

Several areas of work to improve the potential for policy and regulation to facilitate uptake of practices and works for reducing pollutant input to waterways have been identified. It should be noted that no option alone will be effective in addressing all aspects of diffuse pollution management, and nor will any option remove the need for education and incentive approaches. A suite of complimentary approaches is required to effectively address diffuse pollution across the broad spectrum of agricultural land use, ranging from education to incentives to industry standards to enforcement of regulations.

- Declaration of priority catchments under *Catchment and Land Protection Act 1994* to enable Special Area Plans to be developed.
- Development of Best Practice Environmental Management Guidelines for agricultural land for referencing in the SEPP (Waters of Victoria), and ultimately in local planning schemes of relevant councils with predominantly rural land.
- Development of a template for promoting water sensitive farm design within irrigation and drainage management plans linked to diversion licenses.

11.8 Approach to monitoring

It is recommended that the process of designing, implementing, operating and reporting a monitoring program to assess WSFD treatment systems should involve the following considerations or steps (derived from Fletcher et al. (2008):

- Defining objectives
- Selecting which variables to be monitored
- Taking into account spatial and temporal considerations
- Assessing and managing uncertainty
- Selecting appropriate monitoring equipment
- Data validation and quality control
- Data handling and storage
- Use of data to provide information and knowledge.

It is recommended that MW take a disciplined approach to each monitoring activity undertaken under the RLP, stepping through each of these components. Particular emphasis is recommended to the careful definition (and agreement among all stakeholders) of objectives of each monitoring programme.

12 Conclusions and Next Steps

Authors: Various, collated by Anne-Maree Boland (RMCG) and Carl Larsen (RMCG)

12.1 Conclusions

Overview

The development of the Position Framework by the partners has identified that WSFD is an important approach for the implementation of the Rural Land Program. Of particular importance has been the need to more carefully consider what the RLP aims to protect and how activities can be prioritised to most effectively manage these assets and values.

The partnership approach has also identified the significant capability in Water Sensitive Urban Design (WSUD), catchment management and agricultural best management practices (BMPs) and the need to integrate this expertise and knowledge for RLP.

This Position Framework identified how this knowledge should be applied and where there is a need for additional knowledge to be generated. This section provides conclusions for each of the components of work and suggestions for activities that need to be undertaken by RLP. A path to implement sections of the Position Framework by all partners is provided.

Understanding the impact of land uses

Some agricultural land uses, such as intensive horticulture and dairying, are likely to be larger sources of nutrients and pollutants than others. However, research to date has found that the loss of natural vegetation near streams and small drainage lines is a stronger determinant of ecological impairment of streams than any one agricultural land use. Thus, in the absence of considering cost-effectiveness, management of land near rivers, streams and small drainage lines should be a priority, and the implementation of treatment systems should conserve and use the natural retention properties of agricultural landscapes.

An immediate need to meet this objective is to identify the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration.

Effective management of the region's small streams and drainage lines will require an understanding of hydrologic and water quality processes beyond annual loads of pollutants. Targeted research projects are required to assess, at smaller scales than existing studies, in-stream ecological response to different agricultural classes

Effectiveness of WSFD systems and practices

Rural activities, and hence runoff characteristics, are variable to the extent that optimum management strategies will always be site dependent. Specific strategies cannot be ranked in a way that will be generally applicable over the wide range of land uses in the area of interest.

Where land use and other local conditions are known, a short list of likely best performing management practices can be established, but the resulting improvement cannot be predicted accurately due to a lack of monitored data.

Models developed in the urban area for structural treatment measures are likely to be suitable in structure for application in the rural area, but their fit to rural conditions needs to be recalibrated.

An effective and efficient management program is likely to comprise several components of different forms. There is a need to validate models describing effectiveness of treatment systems in the rural area.

Spatial characterisation

MW has access to a substantial range of spatial data that can contribute to the aims of the RLP. Consolidation of these data should be a priority, as well as the development of improved integration of existing digital elevation and hydrologic models with land use data to permit objective delineation of the drainage network.

Development of consistent soils and land use layers is critical for a range of uses for MW, including modelling of rural land use impacts. A consistent soil layer to 1:100,000 should be considered as a minimum soils data set and finer scale (1:50,000) information would be worth considering to assist with prediction of likely riparian responses.

An improved and adaptive spatial land use layer is also essential; without this the changes between rural and urban loads over time will not be able to be predicted. The Victorian Land Use Information System (VLUIS 2010) provides a contemporary basis for updateable land use changes and can include all specified requirements required by MW including changes in urban, rural, treed, water and infrastructure classes as well as any rural land use.

Landscape modelling

MW currently has limited basis to assess the impacts of rural land uses and management practices. Further investment in landscape modelling, including the capacity to link contributions from urban and rural sources, will provide a stronger basis for assessing the contribution of rural and urban management options. This enhanced understanding is critical, given the pressures for urban growth and rural intensification and the need to quantify rural land use/management sediment and nutrient loads.

Several landscape modelling options are available which can build on MW's success in developing and using the MUSIC model. The choice of landscape modelling investment should be made considering the fineness of resolution required and whether incorporation of groundwater impacts is important, as this could be crucial to assess nitrogen impacts and to inform in-stream ecological responses. Additional considerations are whether MW wishes to retain some in-house capacity for using and/or developing models.

Given the importance of water quality issues facing Port Philip and Westernport Bays, it is recommended that MW maintain the capacity to run models and preferably to also develop them. Strengthening partnerships with research agencies (Department of Environment and Primary Industries, University of Melbourne) in model development would be desirable. As a minimum, translation of MW's existing E2 information into the internationally recognised, GIS-based and freely available SWAT model is recommended. Incorporation of the SedNet algorithms within SWAT would enable comparison of nutrient and sediment impacts from land management, waterways and gully erosion. Integration of the CAT model within Source Catchments provides an alternative option. Both the SWAT and CAT options provide the ability to link with groundwater models if required now or in the future.

Economic optimisation

The basis for investment decisions within RLP currently utilises minimal quantitative information for how to most cost-effectively address water quality issues. Assessment of the unit costs of reducing nutrient loads from major sources (rural and urban) linked to the outputs from the landscape modelling through a developed and tested economic optimisation framework is proposed as a minimum basis to assess the cost-effectiveness of management actions. Incorporation of economic optimisation information within an internationally recognised environmental investment framework (such as INFFER, based on benefit:cost analysis) would be relatively simple. Use of INFFER would also enable simple incorporation of broader ecological benefits and costs based on current knowledge of cause and effect relationships. Together these tools would provide a more robust and defensible basis for MW to justify investment decisions in either or both of rural and urban management options.

Guidelines for design and adoption

The review of the design and adoption of treatment systems for the RLP highlighted a number of key priorities for focus in the implementation of the next phase. This should build on the existing knowledge and partnerships established in the current RLP.

Of particular importance is the recognition of the diversity of landholders in the region and the potential for voluntary adoption to be an effective means of facilitating change for each of these groups. There will be a need to understand the motivations and circumstances of the targeted groups and be pragmatic about the likely use of WSFD treatment systems and modified management practices.

It was also acknowledged that others are involved in the establishment of sustainable management approaches and these partnerships need to be fostered. Once it is known what outcomes are to be achieved and who is the targeted group there are a number of fundamental principles to establishing an effective extension program. These principles were developed based on analysis of successful extension programs and include an understanding of the complex decision making process for landholders and the need to constantly adapt activities based on assessment of success.

Guidelines for policy and regulation

Current legislation and regulations do not provide a strong basis for addressing diffuse source pollution from rural land. In the immediate term there may be few drivers for exploring regulatory reform, but it is in MW's interests to explore options for increasing the effectiveness of a range of approaches to improving waterway health, and to be ready to act as appropriate.

In the short term there are several practical things MW can do or consider. The first is to work collaboratively with the Victorian government to encourage reform and incorporate aims for reducing diffuse pollution into relevant legislation and policy when possible. Second, declaration of priority catchments under *Catchment and Land Protection Act 1994* to enable Special Area Plans to be developed could be considered for the catchment draining to Sugarloaf reservoir. Development of 'Best Practice' Environmental Management Guidelines could be considered for agricultural land with reference to the SEPP (Waters of Victoria); these could be included in local planning schemes of relevant councils. Another activity could be to develop a template for promoting water sensitive farm design within irrigation and drainage management plans linked to diversion licenses. Preparatory work in development of landscape modelling and economic optimisation approaches is important to underpin future policy and regulatory approaches which may occur, as public concerns about water quality grow.

12.2 Recommendations

The following table provides a summary of the key areas for improvement and the associated recommendations. These recommendations have not been prioritised.

Table 12-1: Summary of recommendations provided for sub-project areas

Area	Recommendation summary
Understanding the impacts of rural land uses	▪ Conduct targeted research projects to assess, at smaller scales than existing studies, in-stream ecological response to different agricultural land uses ▪ Identify through consolidation and analysis of existing GIS data, the smallest drainage lines that a) are currently in adequately good condition to provide biodiversity values and retention and transformation of contaminants and b) those drainage lines that once provided those values, now lost, with the potential of restoration ▪ Ensure that the parts of the landscape that provide the greatest potential for natural retention and transformation of contaminants (small drainage lines) be protected, and used as natural treatment systems as a first priority. Management of the region's small streams and drainage lines will require an understanding of hydrologic and water quality processes beyond annual loads of pollutants.
Effectiveness of WSFD systems and practices	For on-farm management practices: ▪ Use the guidelines in the summary of effectiveness of on-farm practices (section 4.2.6) and local expert opinion if available to choose management practices that will be effective for the given problem at the given site ▪ Monitor a representative sample of treated sites to improve knowledge of treatment effectiveness under local conditions. For structural treatment measures: ▪ Use existing urban models (i.e. MUSIC) to obtain indicative results and relative performance of structural treatment measures appropriate to the site, and select measures accordingly. Modify model parameters to account for any known differences in water quality descriptors ▪ Monitor a representative sample of structural treatment measures to allow improved recalibration of urban models for local rural conditions.
Spatial characterisation	**Review of current spatial data:** improve the current spatial data including land use, digital elevation models (DEM), hydrological data and water quality site layers.
	Develop an improved and adaptive spatial land use data: use the VLUIS 2010 data as the base, and include most current impervious/pervious data layer, most current treed extent, hydrological data and dams and water bodies.
	Develop a consistent spatial soils data layer: 1:100,000 scale should be the minimum resolution, and finer scale 1:50,000 could be considered.

Area	Recommendation summary
Landscape modelling	Define a preferred position for catchment modelling to predict the impact of runoff from rural land. Consider the following catchment modelling options for further development: ▪ Adopt the internationally recognised SWAT catchment modelling framework. This option is likely to be best value if funding is limited and there is also limited in-house catchment modelling capability ▪ Include SedNet within the SWAT framework, which will be important if gully and streambanks are to be considered as well as paddock management options. This requires additional funding compared with the SWAT only option ▪ Integrate DEPI's CAT model within SourceCatchments, This option considers the surface modelling approach fully coupled with the groundwater model. A degree of commitment to develop and maintain in-house catchment modelling capability is required for this option.
Economic optimisation	Test an approach utilising the biophysical modelling (CAT/SourceCatchments or SWAT as outlined above) and an optimisation method, which is appropriate for this complex problem whilst being straightforward to implement for modellers. Bioeconomic modelling can be used as an input to an environmental benefit:cost analysis (e.g. INFFER) and would also be useful.
Guidelines for design and adoption	Identify geographical areas that are required to achieve RLP objectives and target specific landholder groups. Operating within this context it is essential to then: ▪ Obtain a deeper understanding of landholders and their circumstances and needs ▪ Explore the characteristics of the treatment systems and management practices ▪ Analyse relevant partners and their alignment with RLP objectives ▪ Analyse major issues for the design and implementation of extension programs.
Guidelines for policy and regulation	▪ Declare priority catchments under *Catchment and Land Protection Act 1994* to enable Special Area Plans to be developed. ▪ Develop Best Practice Environmental Management Guidelines for agricultural land for referencing in the SEPP (Waters of Victoria), and ultimately in local planning schemes of relevant councils with predominantly rural land. ▪ Develop a template for promoting water sensitive farm design within irrigation and drainage management plans linked to diversion licenses.
Guidelines for monitoring	Consider the following steps in designing, implementing, operating and reporting a monitoring program to assess WSFD treatment systems and practices: ▪ Defining objectives ▪ Selecting which variables to be monitored ▪ Taking into account spatial and temporal considerations ▪ Assessing and managing uncertainty ▪ Selecting appropriate monitoring equipment ▪ Data validation and quality control ▪ Data handling and storage ▪ Use of data to provide information and knowledge. It is recommended that MW take a disciplined approach to each monitoring activity undertaken under the RLP, stepping through each of these components. Particular emphasis is recommended to the careful definition (and agreement among all stakeholders) of objectives of each monitoring programme.

12.3 Next steps

The development of this Position Framework required the establishment and effective working relationship of the project partners. A final workshop was undertaken to review the work undertaken and the conclusions drawn for each of the components. This stage of the process highlighted the next steps required for each of the partners to improve our knowledge associated with Water Sensitive Farm Design and implement improved management of the assets through the RLP.

The following section describes some of the next steps for the different partners. This focuses specifically on:

- Development of an implementation plan for the RLP by MW, and
- Broader partnership approach with consideration of joint funding opportunities.

12.3.1 Implementation plan

MW will develop an implementation plan to guide the investment for RLP in WP3. This plan will be developed internally based on an understanding of potential integration of programs and possible constraints within MW. One example of possible convergence is the implementation plans in Sugarloaf Reservoir for MW water quality objectives and RLP outcomes.

Prioritising recommendations

The implementation plan will include the process of prioritising activities. This will be based on the objectives of the RLP rather than MW as a whole through the development of an RLP implementation plan for the next Water Plan period (2013-2018).

Three simple filter criteria can be used to assess WSFD treatments and practices. These include the effectiveness of treatment or practice, cost effectiveness, and implementation feasibility (how do we make it more feasible) as shown in Figure 12-1 below.[6]

Figure 12-1: Criteria for assessing WSFD treatments and practices

The prioritisation of recommendations could also include consideration of the following criteria:

Relevance

[6] Pers. comms. Tim Fletcher, University of Melbourne, 30 April 2013

- Contribution to RLP objectives: importance of the recommendation in the implementation for RLP for 2013 – 2018
- Priority for broader MW activities: extent to which other MW divisions (e.g. River Health, Environmental Flows, Urban Stormwater) would use and benefit from the activity

Resourcing

- Time to implement: time taken by MW staff or partners to implement the improvements
- Cost to implement: cost of implementing the improvements, including MW staff time
- Complexity of implementation: the number of internal and external stakeholders involved in the implementation of the improvements
- Risk involved in implementing: the risk to participation rates, perception of RLP and reputation of MW.

Higher priority recommendations will be those with high relevance and low overall resourcing requirements. Table 12-2 can be used as a project planning and management tool in prioritisation and phasing of recommendations.

Table 12-2: Prioritisation of recommendations

	RELEVANCE			RESOURCING				
Recommendation	**Contribution to RLP objectives**	**Priority for broader MW activities**	**Relevance rating**	**Time to implement**	**Cost to implement**	**Complexity of implementation**	**Risk involved in implementing**	**Resource rating**
Understanding the impacts of rural land uses								
Effectiveness of WSFD systems and practices								
Spatial characterisation: current spatial data								
Spatial characterisation: improved and adaptive spatial land use data								
Spatial characterisation: consistent spatial soils data								
Landscape modelling								
Economic optimisation								
Guidelines for design and adoption								
Guidelines for policy and regulation								
Guidelines for monitoring								

Rating scale: Very Low (1), Low (2), Medium (3), High (4), Very High (5)

12.3.2 Partnership approach

Significant benefits have been identified from the partnership approach and this potential needs to be developed further. From a MW perspective the partners (DEPI and UoM) add considerable weight to the body of evidence required for effective implementation of the RLP.

Next steps for the partnership may include:

- Development of a combined bid for ARC Linkage Grants (next round November 2013) with DEPI and UoM for the 2013-14 financial year
- Potential opportunities for regional DEPI integration with MW, although these are uncertain at this stage
- Inclusion of the Position Framework and WSFD and RLP activities into UoM planning the next two years of research
- Contribution to the review of the RLP implementation plan (broader than just the WSFD Position Framework). The RLP implementation plan would likely identify research gaps and potential collaborative opportunities with UoM and DEPI
- Exploration of possible high-level engagement with DEPI via a Memorandum of Understanding for Research (similar to UoM).

References

A consolidated reference list is provided by section of the Position Framework for the convenience of the reader. The reference list below refers to the key strategic MW references in sections 1, 2, 11 and 12.

Melbourne Water (2009) MW Rural Water Quality Program; Rural Land Pilot Programs Implementation Paper July, East Melbourne

Melbourne Water (2012) Draft Healthy Waterways Strategy; A Melbourne Water strategy for managing rivers, estuaries and wetlands, October, Docklands

Melbourne Water (2012) Draft Stormwater Strategy; A Melbourne Water strategy for managing urban and rural runoff, October, Docklands

Melbourne Water (2012) Water Sensitive Farm Design; A guide to reducing the impact of runoff to waterways, Docklands

Appendix 1: Setting Our Strategic Direction

Our Vision

Enhancing Life and Liveability

Water is central to living. It sustains the communities we live in, the natural environment we value and the economy we depend on.

Our Business Activities

Integrated water management	Contribute to a more sustainable, prosperous, liveable and healthy community by planning and delivering water supply, waterways and sewage services holistically
Service delivery	Provide services which are valued by our customers
Environmental stewardship	Protect the natural environment and ensure resource availability for future generations
Relationships	To be valued by our customers and stakeholders and a business of choice for our partners
Financial sustainability	Maintain financial viability and increase business value
Organisational capability	Strengthen the capability of the organisation to deliver better customer and community outcomes

Our Approach

Customer focused	Customer success is a measure of our own success. We gain satisfaction from striving to provide cost-effective products and services that meet or exceed customer expectations. This is achieved by listening to our customers to understand their needs, valuing their contribution and being responsive.
Commercial	We deliver services to our customers efficiently and maximise the value to our shareholder from our resources and investments. We will ensure our business is positioned to make the most of commercial opportunities and partnerships.
Innovative	We always look for better ways to do things. We enjoy working with others to deliver creative solutions that are valued by our customers and partners. We believe we can achieve better outcomes by sharing knowledge and ideas.
Sustainable	The long-term interests of the community and future generations are integral to our decision-making. We take an ethical and responsible approach and know the right solutions are created when environmental, social and financial goals are balanced.
Engaging	We engage our customers and stakeholders early to understand their perspective, share information and views, and encourage feedback to support our decision-making. We forge strong relationships and valuea transparent and honest approach.
Adaptable	We are open to change and flexible enough to embrace opportunities. We build resilience through sound planning, learning from our experiences and adjusting our approach when needed. We are prepared to make changes to achieve the best outcomes.

Appendix 2: Stormwater Strategy

Vision

Sustainable stormwater management supports prosperous communities, thriving landscapes and healthy waterways and bays.

20-year goal

Stormwater is collaboratively managed to protect and improve waterways and bays, resulting in multiple outcomes for the community.

Delivering multiple community outcomes

- Healthy waterways and bays
- Alternative water supplies
- Wellbeing and amenity
- Public safety

Approaches

Working together	Establishing and maintaining genuine partnerships with others in all that we do, sharing knowledge and building capacity, and communicating outcomes.
Better on-ground outcomes	Working closely with key land management partners to construct and maintain stormwater management assets in urban and rural areas.
Research and knowledge building	Building and sharing knowledge on the impacts of stormwater and most effective multi-benefit solutions.
Effective planning, policy and regulation	Supporting those involved in planning, policy development and regulation to achieve better stormwater management outcomes for the community.

Implementation Targets

IT1	Provide technical and financial support to our partners to deliver 125 structural and strategic stormwater projects over five years to achieve multiple community outcomes.
IT2	100 capacity building initiatives will be delivered under the Clearwater program.
IT3	A minimum of ten industry workshops aiming to reduce key industry gaps in stormwater management identified with partners will be delivered under the Clearwater program.
IT4	A minimum of 25 communication and education initiatives to raise community awareness on stormwater management will be delivered.
IT5	At least one alternative engagement model trialled to improve our understanding of the effectiveness of rural land management delivery methods.
IT6	Melbourne Water commitments under *A cleaner Yarra and Port Phillip Bay* action plan are delivered.
IT7	Provide technical input, data and support to agencies involved in litter program development and undertake litter removal from priority waterways.
IT8	Undertaken targeted disconnection projects to improve urban runoff management practices in priority areas through partnerships.
IT9	Undertake social research and community engagement to understand drivers and barriers to participation in stormwater management and waterways health initiatives to inform stormwater

	management program activities.
IT10	Nitrogen loads will be reduced by a further ten tonnes towards the Port Phillip Bay water quality target.
IT11	Construct a minimum of five regional stormwater assets that contribute to the protection of local waterways or improvement of receiving waters to provide multiple benefits to the community.
IT12	Stormwater treatment asserts are maintained on a prioritised risk basis so that they continue to deliver the required level of service in respect to hydraulic function, vegetation values and public safety to maintain achievement of nitrogen reduction targets.
IT13	100% of Melbourne Water's stormwater treatment wetlands are assessed for compliance with design requirements to inform prioritisation of rectification works.
IT14	Deliver 25 projects to reset and rehabilitate stormwater treatment wetlands to meet asset design requirements.
IT15	250 rural landholders will be engaged to increase action for reducing diffuse pollution from agricultural land.
IT16	Rural runoff management practices are refined and evaluation techniques are developed to assess performance in reducing pollutant loads discharged to waterways and bays, at both the farm-scale and catchment-scale.
IT17	Refine monitoring program by July 2013 and implement the program by July 2018: ▪ To improve understanding of ecological and public health risks from stormwater pollutants; and ▪ To inform the implementation of effective management measures.
IT18	Undertake research priorities identified in the Westernport Environment Science review to inform the development of water quality requirements for Westernport.
IT19	Improve our asset management and data sharing approach including effectively using our asset management information system to enable efficient planning and reporting of stormwater management activities.
IT20	Establish research partnerships to update stormwater management objectives and to improve stormwater technology and evaluation techniques.
IT21	Establish strategic research partnerships that foster knowledge sharing and collaboration and address Melbourne Water's strategic knowledge gaps in stormwater management.
IT22	Develop and implement a program of activities to improve the alignment of the stormwater policy and regulatory framework.
IT23	A minimum of two greenfield developments will commitment to implement stormwater management measures beyond existing requirements to protect high value waterways.

Appendix 3: Healthy Waterways Strategy

Vision

Healthy and valued waterways are integrated with the broader landscape and enhance life and liveability.

They:

- Connect diverse and thriving communities of native plants and animals.
- Provide amenity to urban and rural areas and engage communities with their environment.
- Are managed sustainably to balance environmental, economic and social values.

20-year goal

By 2033 the condition of waterways enables significant improvement in the health of environmental values and amenity in waterways.

Key Values

- Amenity
- Birds
- Fish
- Frogs
- Macroinvertebrates
- Platypus
- Vegetation.

Threats to Values

- Changes to natural water flows
- Poor water quality
- Vegetation clearing
- Urbanisation
- Climate change

Environmental Condition of Waterways

- Habitat
- Water Quality
- Flows
- Connectivity
- Physical Form.

Management Approaches

Themes	Management approach
Planning, strategy and guidelines	Review the Healthy Waterways Strategy by 2018, in accordance with Department of Sustainability and Environment guidelines.
Advocacy	Implement a program of advocacy for waterways and the values they support by seeking to collaborate and build meaningful relationships with stakeholders. The program will: ▪ Provide clear and transparent information on waterway health ▪ Develop an understanding of the opportunities and constraints to the community becoming mutual caretakers of waterways ▪ Develop programs targeted to improve the capacity of stakeholders and community members to provide effective care of waterways ▪ Develop appropriate standards and influence policy development for the protection and improvement of waterway values.
Enforcement	Develop a risk-based enforcement program to assess waterway and drainage enforcement issues and take appropriate action on identified high priority issues. The program will: ▪ Improve the process to identify and record potential enforcement issues ▪ Conduct a program of enforcement training for Waterways employees ▪ Develop a process to assess enforcement issues and identify high priority issues for action ▪ Work actively with stakeholders, other authorities and internally to ensure requirements of management arrangements such as leases and licences on Melbourne Water land are in place and understood.
Building stewardship and sharing knowledge	Encourage stewardship by sharing knowledge, actively learning, supporting community-based monitoring and increasing community capacity through delivery of grants, targeted programs and education to landholders, community groups and land managers.
Vegetation management	▪ Establish 802km of vegetation to the required level to support waterway values ▪ Manage 7579km of vegetation to the required level to support waterway values ▪ Construct 546km of stock exclusion fencing.
Habitat management	▪ Improve 193ha of aquatic habitat to the level required to support waterway values ▪ Remove 16 fish barriers ▪ Manage Sites of Biodiversity Significance as guided by the SoBS Strategy ▪ Manage high priority refuge sites as guided by Melbourne Water's Drought Refuge Plan.
Asset protection and renewal	Implement a risk-based program of asset protection and renewal to maintain in-stream connectivity, channel stability for community asset protection, 'systemic' river health outcomes and an appropriate hydraulic level of service. The program will: ▪ Develop a process for assessing risk to built and natural assets ▪ Develop strategic asset management plans for critical asset classes and site management plans for key sites ▪ Target vegetation establishment for waterway stability where appropriate ▪ Undertake bed and bank intervention as required ▪ Undertake desilting where appropriate ▪ Undertake vegetation management where appropriate.

Stormwater management	
Environmental water	▪ Environmental flows in major waterways and unregulated rivers will be improved by managing environmental entitlements in accordance with the Victorian Environmental Water Holder legislation and Melbourne Water programs respectively. ▪ Groundwater dependent ecosystems will be protected or improved by developing and implementing a groundwater dependent ecosystem program.
Diversion management	Diversions will be managed in accordance with rules specified in streamflow management plans, local management rules or drought response plans, and to meet the service requirement targets in Melbourne Water's customer charter for diversion services.

Actions

Building stewardship and sharing knowledge

- Provide incentives and support for individuals, community groups and local government for waterway management activities such as fencing, weed control, vegetation establishment and pest control

Stormwater management

- Deliver rural and urban runoff management programs to protect and improve key values in priority areas including:
    - Working with local government and the community to deliver on-ground works and planning activities to protect and improve waterways
    - Working with agricultural landowners to implement on-farm practices and on-ground works to reduce pollutants and runoff into waterways
    - Identifying key hotpots for ecosystem and public health, and facilitating an appropriate management response