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Conceptual requirements for an erosion-sediment model for the Motueka catchment

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Conceptual requirements for an erosion-sediment model for the Motueka catchment

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by

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Cover Photo: Sediment generation by landsliding and gullying during the Good Friday 2005 storm.

PREFACE

An ongoing report series, covering components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the data, with brief interpretation, can be used by managers, environmental groups and users of resources to address specific questions that may require urgent attention or may fall outside the scope of ICM research objectives.

We anticipate that providing access to environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

Introduction

Part of the goal of sediment investigations in the Motueka catchment is to contribute to the IDEAS framework by developing models of:

- sediment dynamics (generation, transport and storage) within the Motueka river system, and associated marine environment, and
- sediment impacts on freshwater and marine ecosystems.

The aim is to provide a model (or group of models) that would be linked to freshwater and marine ecosystem productivity models and provide a means of determining the cumulative ecosystem impacts of sediment at a range of scales, the degree to which sediment impacts can be mitigated, and/or the constraints that sediment dynamics impose for freshwater and marine fisheries management.

This report outlines the conceptual issues which need to be addressed in developing an erosion-sediment model for the Motueka catchment. It is based on analysis of sediment dynamics within the Motueka catchment resulting from the sediment source mapping that has been undertaken, and the findings of the review of the effects of fine sediment on river biota (Crowe and Hay 2004).

Erosion modelling

There are a wide diversity of approaches to modelling erosion and sediment yield, and a large number of existing models that simulate erosion (for example Merritt *et al.* 2003 review 17 existing models and their list is not exhaustive). These include:

- simple empirical models such as the Universal Soil Loss Equation (Wischmeier and Smith 1978) and Hicks *et al.* (1996) suspended sediment yield predictor, which are based on relationships between predictor and response variables derived from analysis of large empirical data sets;
- complex, spatially-explicit, process-based models such as WEPP (Flanagan and Nearing 1995), SHESED (Wicks and Bathurst 1996, Burton and Bathurst 1998) and EUROSEM (Morgan *et al.* 1998) which are based on simulating the physics of transport and deposition processes;
- hybrid models that use a combination of empirical and process-based approaches, such as SEDNET (Wilkinson *et al.* 2004) and TRACER (Coulthard and Macklin 2003). These are termed conceptual models by Merritt *et al.* (2003) and provide a general description of catchment processes based on transfers between storages, without including all the details of process interactions.

Few of these models deal with the full range of erosion processes (particularly landslide and bank erosion), and mostly they have been applied to small catchments (few hectares to a few tens of square kilometres). In addition none of them explicitly link sediment dynamics to the biological impacts of sediment. Consequently there is no clear obvious choice of erosion model to incorporate into the IDEAS framework. Merritt *et al.* (2003) and Summer & Walling (2002) provide useful recent reviews of erosion and sediment transport modelling.

Merritt *et al.* (2003) suggest that the choice of an erosion model needs to consider

- the objectives of the model user, including the ease of use of the model, the scales at which model outputs are required and their form;

- data requirements of the model, including spatial and temporal variation of model inputs and outputs;
- the accuracy and validity of the model including its underlying assumptions;
- the components of the model, reflecting model capability;
- hardware requirements.

Complex process-based models have become a major research emphasis in the last couple of decades because they offer the possibility that they can be used for extrapolation in space and time, unlike empirical models which are largely limited to application over their calibration range. Past hydrological modelling in the ICM programme with SWAT (Cao *et al.* 2004) and DHVSM (Davie *et al.* 2004), with which an erosion-sediment model might potentially be linked, fits in this class of modelling approaches.

However, Wasson (2002) questions the view that bottom-up process-based modelling is the best and only way to produce useful models for large complex catchments. He offers two reasons to support this view:

- models of the natural variability of rainfall infiltration, run off, erodibility, cover, channel characteristics, and sediment storage demand enormous data inputs. Such data are rarely, if ever, available for areas much larger than a few tens of square kilometres, and the cost of data collection is prohibitive in most countries. Highly parameterised models of the kind needed to exploit such data are essentially untestable, and while the accurate simulation of measured runoff and/or sediment yield may be obtained, it is not possible to know if it is because of correct model configuration or because of the tuning that is almost always needed to successfully simulate outputs.
- catchments are complex systems in which the dynamics are likely to be best understood by examining across-system organisation rather than concentrating on the parts from which a whole system view is constructed. The interaction of components produces results that generally cannot be simulated from the components; that is, the whole is emergent from a wide range of processes and interactions that are neither predictable from, or reducible to, the parts alone.

Similarly Merritt *et al.* (2003) suggest complex process-based models are limited by lack of reliable spatially distributed input data, lack of calibration data in space and time, over-dependency of model results on the experience of the user, and large computational requirements. They suggest a combination of empirical and conceptual approaches is needed to derive spatially distributed models of low complexity and plausible physical basis. Similarly, Wasson (2002) suggests emphasis in erosion and sediment modelling should be on modelling at the whole system level.

A conceptual approach to modelling erosion and sediment transport that addresses scale and cumulative effects issues, and focuses on separating environmental drivers of erosion and sediment yield from land use effects is outlined by Jakeman *et al.* (1999). It deals with natural complexity, spatial heterogeneity and sparse measurements, all significant issues for modelling erosion and sediment transport in the Motueka. Their modelling framework is characterised by:

- a set of generic models of key processes (e.g. rainfall-runoff, sediment generation, instream transport);
- incorporation of knowledge of the key processes and their interactions;
- being consistent in conceptual complexity and resolution (space and time) with the information content in the databases available to calibrate and drive the various models;
- links between spatially distributed generic model components to simulate cumulative effects at different locations in the catchment network.

Their model has two major components: an upland catchment model that simulates sediment generation from hillslopes and low order streams, and an instream sediment transport model that routes sediment from the outlet of upland catchments downstream and generates sediment from instream sources (processes of resuspension, bank erosion) and deposition). They suggest a central issue determining the precise prescription of an appropriate modelling framework is the information base that supports it.

Because there is a limited information base for the Motueka (both in terms of sediment generation and transport rates, and quantitative understanding of the biological impacts of sediment), and it is a spatially complex catchment, a high level modelling framework using a combination of empirical and conceptual approaches will probably be needed to derive spatially distributed models of low complexity and plausible physical basis.

Erosion processes in the Motueka catchment

A range of erosion processes are active in the Motueka catchment, some of which contribute sediment directly into the river and others transfer sediment from one store to another. Mapping of sediment sources has identified the key processes and their spatial distribution. Fig. 1 provides a conceptual outline of the key processes operating in the catchment with linkage indicated between the erosion processes and land use. It identifies the key erosion processes operating and the key sediment sources on hillslopes and in channels.

The erosion model needs to be able to simulate rates of landslide, gully and sheet erosion on hillslopes, and bank erosion from a variety of in-channel sources. The relationship between sediment generation and land use needs to be explicit, so scenarios for altered management and their impact on sediment generation can be explored. Specific requirements are to be able to simulate the potentially severe short-term impacts of forest roading and harvesting (by landsliding and sheetwash), the cumulative effects of erosion under pastoral farming (by sheetwash), and the contribution from natural erosion in the high rainfall areas of the catchment. The role of low frequency, high magnitude events also needs to be simulated. Current mapping is tending to suggest a high contribution from within-channel sources so accurate simulation of erosion from streambanks, channel bars and the channel bed is essential.

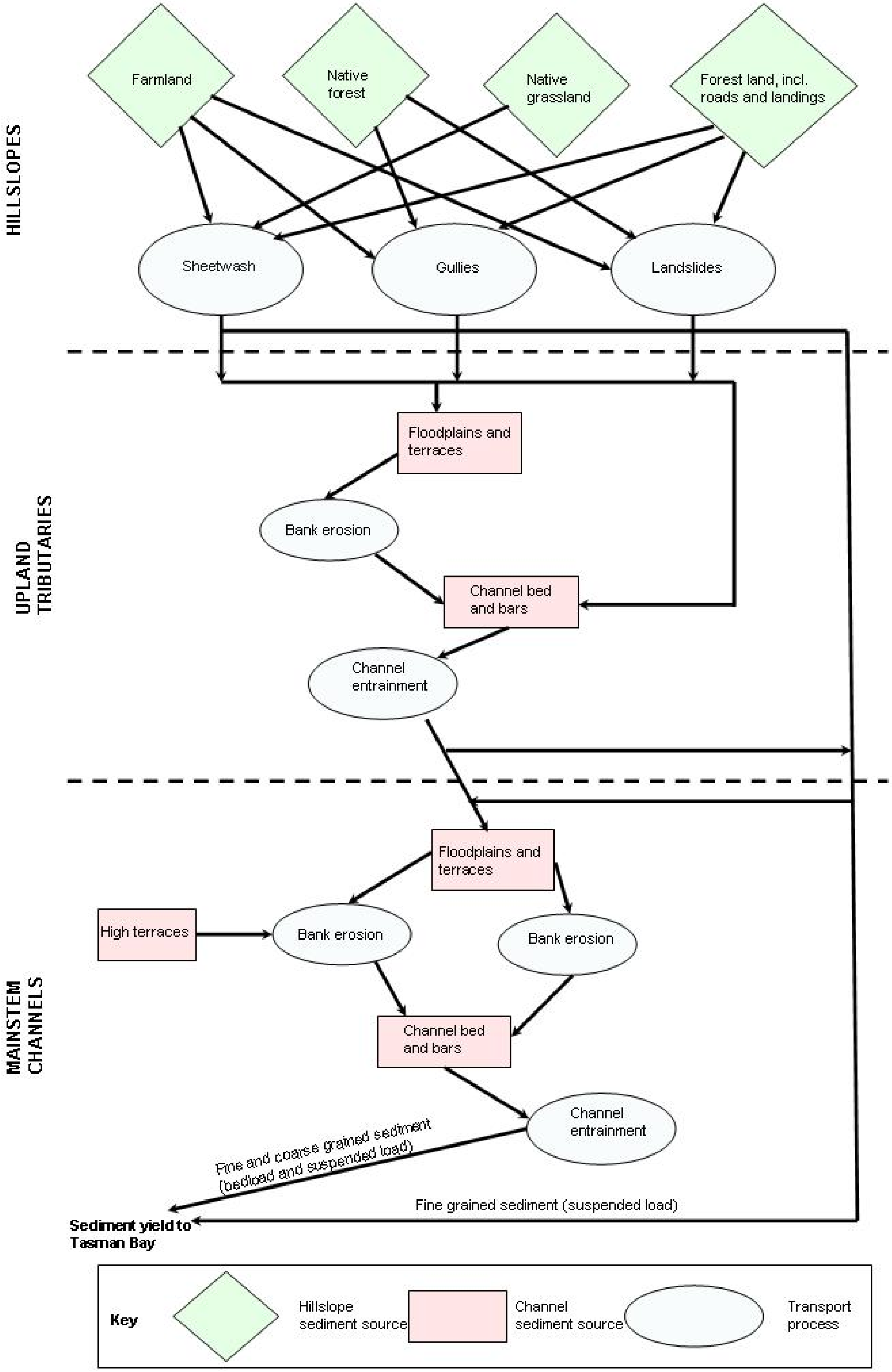

Fig. 1 Conceptual outline of sediment sources, transport processes, and sediment storages in the Motueka catchment.

The model needs to be able to simulate the entrainment and deposition of different sizes of sediment (from clay to boulder), the movement of waves of coarse sediment (both coarse granite sand and gravel) through the river system, consequent changes in sediment composition on the river bed, and sediment yield to Tasman Bay (by particle size class). Fine sediment (silt and clay) is probably the most important component of the load to simulate for evaluating the effects of sediment on marine ecosystems, whereas a wide range of sediment sizes will be important in freshwater environments (silt and clay affect water column characteristics, coarse sand to boulder size particles affect bed sediment composition and habitat characteristics).

It is likely that the requirements of an effective erosion model that can be used to evaluate sediment impacts on freshwater ecosystems may be different from those that are required to evaluate sediment impacts on marine ecosystems. For example, a simulation of total load (or storm load) to Tasman Bay at a prescribed time step, by particle size class, might be sufficient to link to existing models of marine ecosystem productivity and could probably be derived from the measurements of suspended load at Woodmans Bend. By contrast a model relevant to freshwater biological impacts will need to be spatially explicit and simulate sediment transport and deposition at both reach and catchment scale.

There is limited data available to support the modelling (Basher and Hicks 2003) including:

- short and long-term measurements of flow at 16 sites in the catchment;
- short-term measurements of suspended sediment, at large catchment scale, at Woodmans Bend, Motueka gorge, Motupiko at Christies bridge, Stanley Brook at Barkers and Wangapeka at Walters Peak;
- short-term measurements of suspended sediment at small catchment scale from Greenhill, Pokororo, Little Pokororo, Herring Stream and Big Bush;
- the spatial distribution of sediment sources is available from current mapping, but fluxes of material from the various sources are poorly known;
- very limited data on the spatial pattern bed sediment composition, and no data on temporal trends of bed sediment composition.

Biological impacts of sediment

Sediment, and particularly fine sediment, impacts on biota both when in suspension in the water column and when deposited on the river bed or sea floor (Crowe and Hay 2004). It can affect the whole food chain from primary producers to fish, as well as habitat characteristics, and the effects are often species and life stage-specific (see Fig. 2).

The biological response to sediment is influenced by a broad range of factors including the grain size of the sediment, the duration and frequency of sedimentation events, and the existing substrate (Crowe and Hay 2004). A key characteristic of a sediment model therefore is that it needs to be able to simulate these characteristics of sediment. Benthic invertebrates are particularly important in sediment impact assessment because they live in

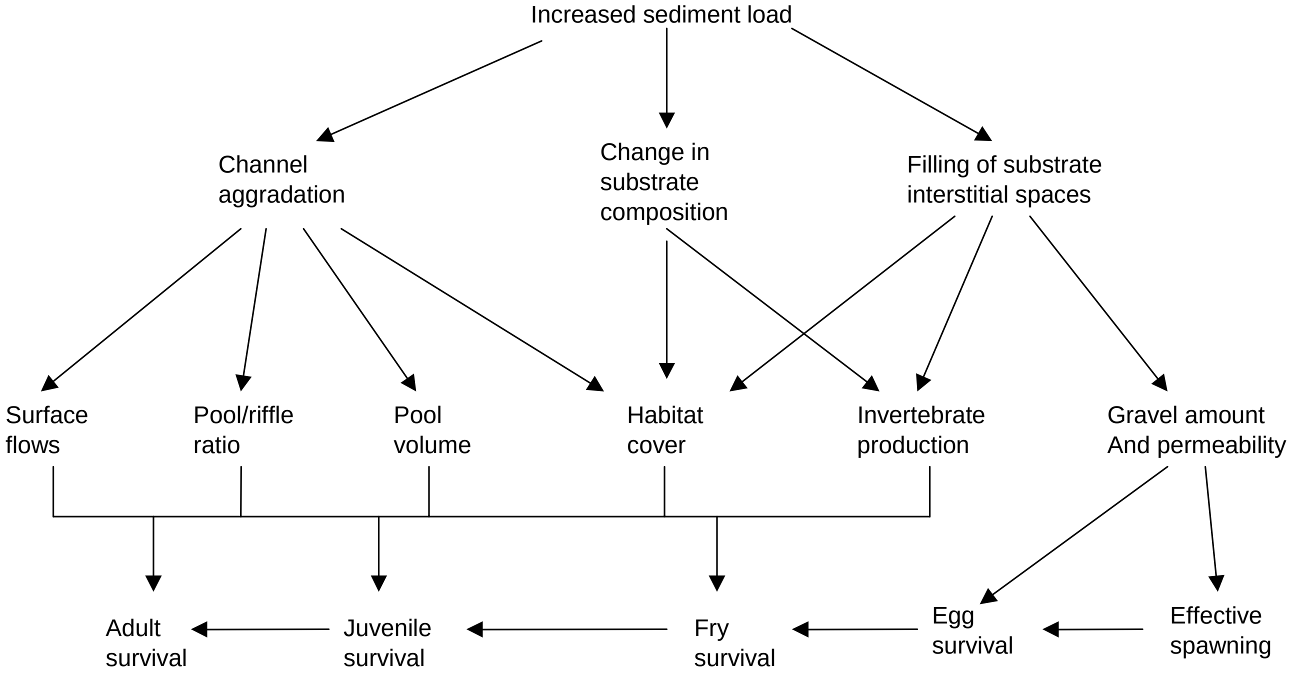

Fig. 2 Multiple impacts of increased sediment loads on trout and salmon populations (Reiser 1998).

and on the river bed or sea floor and therefore are likely to be affected by changes in sediment loading, while fish are mobile and might move to avoid localised sediment loading. This mobility implies that a model relating sediment impacts to biological effects needs to have a spatial context for simulating both direct at-a-site effects, and the adaptive response of higher trophic levels to changes in sediment load and bed composition.

In common with sediment modelling Crowe and Hay (2004) outline two possible modelling approaches: statistical models that fit relationships between predictor and response variables, based on large empirical data sets. (e.g., Jowett's (1992) "100 rivers" models), and mechanistic models that rely on a good understanding of the processes that cause biological responses to changes in sediment loading. Crowe and Hay (2004) suggest it would be relatively easy to develop predictive statistical models based on variables measured in the Motueka River but they may not apply in other catchments and the scale of prediction would probably be restricted to the reach scale or less, which limits their usefulness for whole catchment applications. Process-based models would be more widely useful than empirical models, since they should be more readily applicable to a range of river systems and at a range of spatial and temporal scales, although they would require a significant improvement in process understanding.

Prediction of sediment impacts on invertebrates has the potential to feed into existing predictive models relating invertebrate abundance to higher trophic levels (Crowe and Hay 2004). While there are published empirical quantitative relationships between sediment loading and invertebrate responses in the literature it is not possible to relate incremental changes in invertebrate density and composition to incremental increases in sediment loading and therefore research is required to provide this understanding for application to a sediment impacts model. Similarly, Crowe and Hay (2004) suggest a better understanding of the effects of different grain sizes within the fine sediment range, the effects of fine sediment on the hyporheic zone, and the way that sediment impacts interact with other factors are needed to develop predictive models based on a process understanding.

It is not clear to what extent the effects of sediment and effects of other variables moderating aquatic communities (*e.g.* nutrients, light, temperature, pollutants) are additive or more complex. If synergies exist between the impacts of these factors these interactions need to be considered in the development of predictive capabilities, adding an extra layer of complexity to the process understanding (Crowe and Hay 2004).

Conclusions

An erosion-sediment model for the Motueka that would be useful for management applications needs to:

- simulate the full range of erosion processes (landslide, gully and bank erosion and sheetwash);
- be spatially distributed to identify the key sediment sources in the catchment;
- quantify the relationship between sediment generation, land use, and other driving factors, so that management options for reducing sediment yield can be identified;
- be able to simulate
  - the entrainment and deposition of different sizes of sediment (from clay to boulder)
  - the duration and frequency of sedimentation events and consequent changes in sediment composition on the river bed
  - sediment yield to Tasman Bay
- be able to explicitly link sediment dynamics to the biological impacts of sediment.

Recent overseas whole-catchment modelling approaches suggest it might:

- use a combination of empirical and conceptual approaches to derive spatially distributed models of low complexity and plausible physical basis, suitable for modelling the whole hydrological-sediment-biological system;
- comprise a set of generic models of key processes (e.g. rainfall-runoff, sediment generation, instream transport, biological effects) ;
- be consistent in conceptual complexity and resolution (space and time) with the information available to calibrate and drive the various models.

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