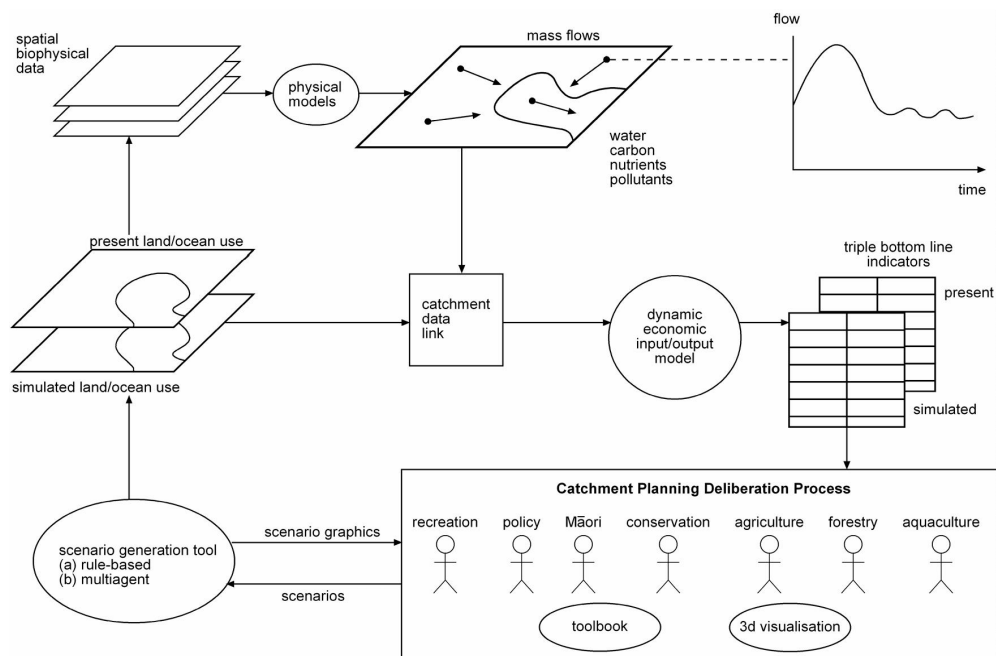


IDEAS - an Integrated Dynamic Environmental Assessment System for catchment planning



Prepared for

Stakeholders of the Motueka Integrated Catchment Management Programme



Manaaki Whenua
Landcare Research



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IDEAS - an Integrated Dynamic Environmental Assessment System for catchment planning

Motueka Integrated Catchment Management
(Motueka ICM) Programme Report Series

by

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Cover Photo: Schematic representation of the IDEAS framework

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.

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Introduction

“The purpose of IDEAS is to provide an Integrated Dynamic Environmental Assessment System within which modelling tools provide answers to real catchment questions about cumulative causes and effects of a mosaic of catchment developments. IDEAS is a strategic planning tool for testing “futures scenarios” involving a triple bottom-line approach, a collaborative learning development process, and assessment of cumulative effects in land and water management.” That was how IDEAS was described in the FRST program research proposal. This report outlines a proposed framework for IDEAS to meet these requirements.

Catchment planning – the deliberation process

IDEAS needs to feed information into the dialogue between stakeholders so that a shared vision of the catchment can be generated. Figure 1 shows how this will be achieved. Stakeholders will need to know the present status of the catchment, in terms of environmental, economic, and social performance, and will also need to know how this changes with various catchment management scenarios. It is planned to calculate summary *triple bottom-line indicators* of catchment scenarios developed within the deliberation process. These indicators will be calculated by the linking of biophysical and economic models, as shown in Figure 1.

Effective catchment planning requires engagement of stakeholders: these would include representatives of agriculture, forestry, aquaculture, local government, Maori, conservation, and recreation. IDEAS is designed to help stimulate this engagement by providing an interactive visualisation tool of scenarios generated by stakeholders. Visualisation of scenarios increases the sense of control over, involvement in, and responsibility for the environment. Provision of triple bottom-line indicators of scenarios will not be immediate as the modelling process is complex and will be done by specialists, off-line, but the indicators will be provided in response to scenarios generated by the stakeholders. As such, the stakeholders will be driving the process, and the feedback of indicators will create a *collaborative learning* environment.

Scenario generation tool

The purpose of the scenario generation tool is to provide digital maps from written descriptions of scenarios provided by the catchment stakeholders. These spatial maps of land use are required by the physical models to make predictions of mass flows for the scenarios. The tool will be essentially be a GIS (geographic information system) with scripts for implementing rules governing land use or land cover. Where scenarios are expressed in terms

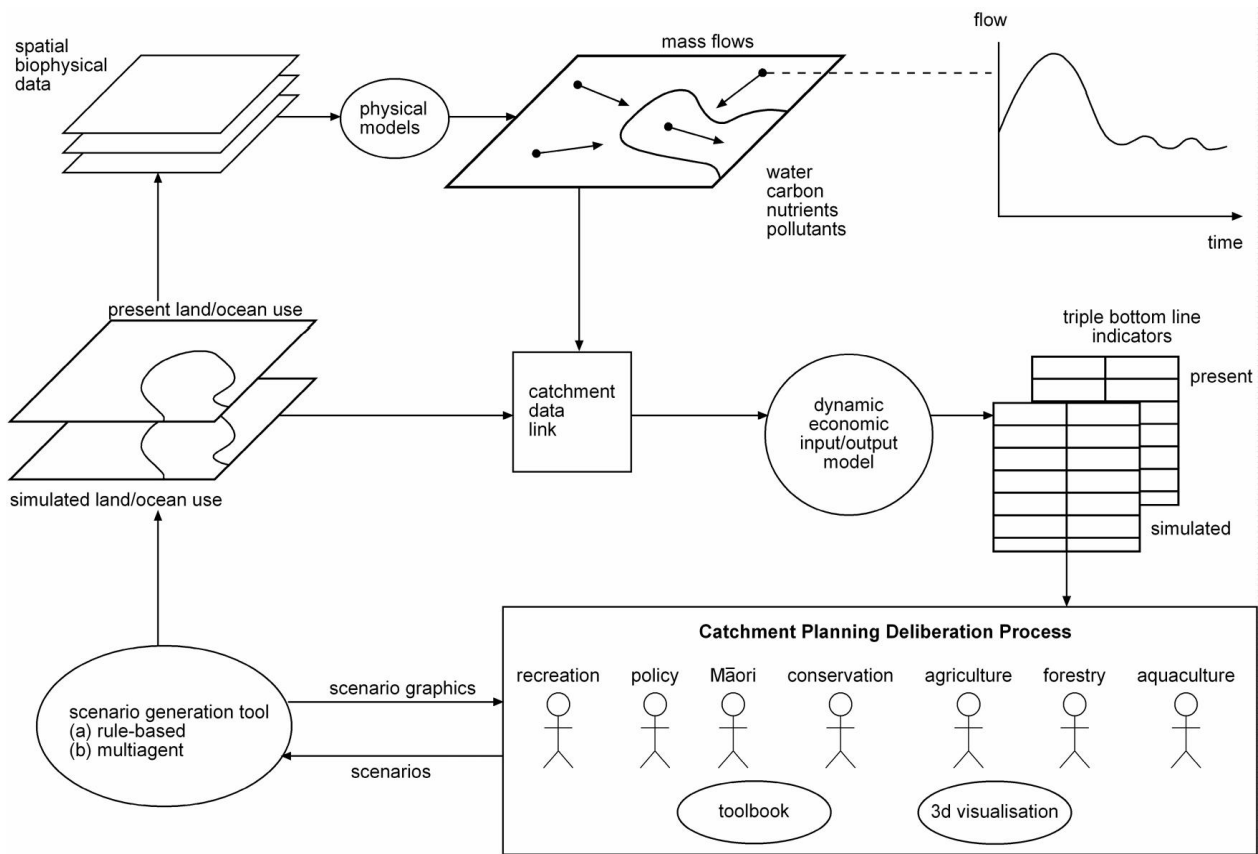


Figure 1. IDEAS framework

of policy implementation (such as incentives), then more sophisticated techniques such as multiagent modelling will be required. In either case, the output of the scenario generation tool will be a digital map of land use or land cover or ocean use, which can be examined by three dimensional visualisation (already provided by existing GIS software packages). The output will need to be consistent with the scenarios of industry demands needed by the environmental input-output modelling. It is planned to have the scenario generation tool and visualisation software operating interactively on a notebook at stakeholder meetings. The scenario generation tool will be operated by a specialist, but the three dimensional visualisation will be operated by the stakeholders.

Spatial data and catchment data link

The biophysical models need to be spatially explicit so that mass flows can be summarised per industry using a land use map(industry equates with land use for the primary sector). Spatial data underpinning the models will therefore be required. Table 1. lists these. Note that land use and land cover change with time and will need continuous updating. Land cover will be updated as required by remote sensing. The input of mass flows into the environmental input-output model requires the summary of mass flows on a land use basis. This process will be managed by a catchment data link which will prepare mass flow data in a form required by the input-output model. The next section gives an example of the catchment data link preparing suspended sediment yield data.

<i>Attribute</i>	<i>Database</i>	<i>Comments</i>
topography	EcoSat 15m DEM	15m and hydrologically consistent
soils	NZLRI	
erosion processes	Erosion Terrains	NZLRI derivative
climate	LENZ	
landuse	ENSUS	LCDB2 and AgriBase derivative
land cover	LCBD2 EcoSat woody layer	1 ha minimum mapping unit 15m pixel

Table 1. Spatial biophysical data underpinning physical models

We use a spatial model of suspended sediment yield to demonstrate the catchment data link. Figures 2, 3, and 4 show maps of different land use scenarios. And Figures 5, 6, and 7 show maps of specific sediment of those scenarios as predicted by the New Zealand Empirical Erosion Model. Table 2 gives an example of the catchment data link where average specific sediment yield for each land use is calculated.

<i>Land use</i>	<i>Motueka catchment</i>		
	<i>Average specific sediment yield (t/km²/yr)</i>	<i>Sediment yield (t/yr)</i>	<i>Area (km²)</i>
Exotic forest	110	62,000	568
Sheep/beef	210	65,000	310
Orchards	180	4,000	22
Crops	180	1,000	6
Dairy	220	1,000	38
Indigenous forest	70	58,000	830
Scrub	80	14,000	172
Tussock grassland	160	17,000	105
Bare ground	160	3,000	22

Table 2. Suspended sediment yields per land use for the Motueka catchment

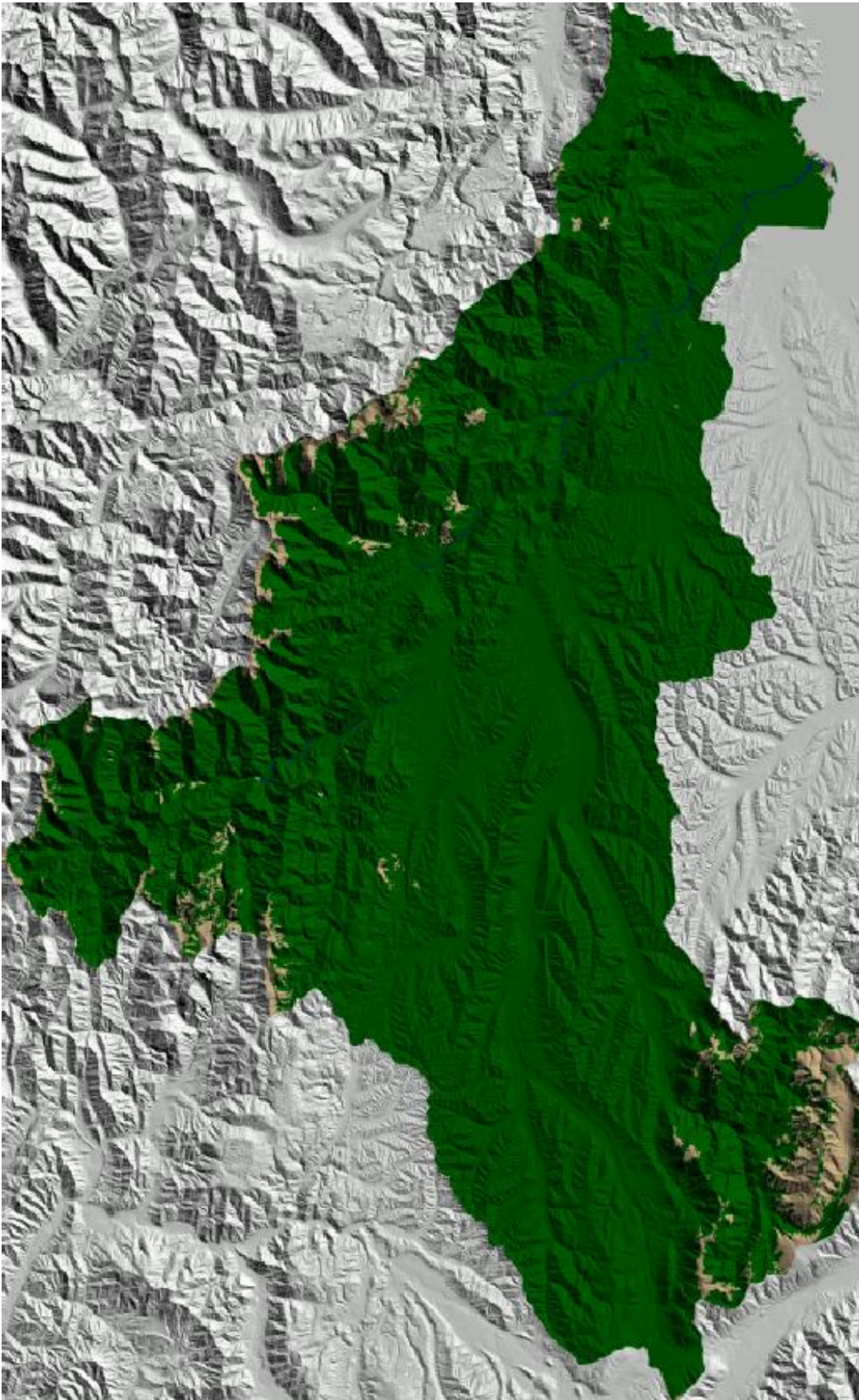


Figure 2. Historic land use of the Motueka catchment.
Dark green – indigenous forest. Light brown – tussock grassland.

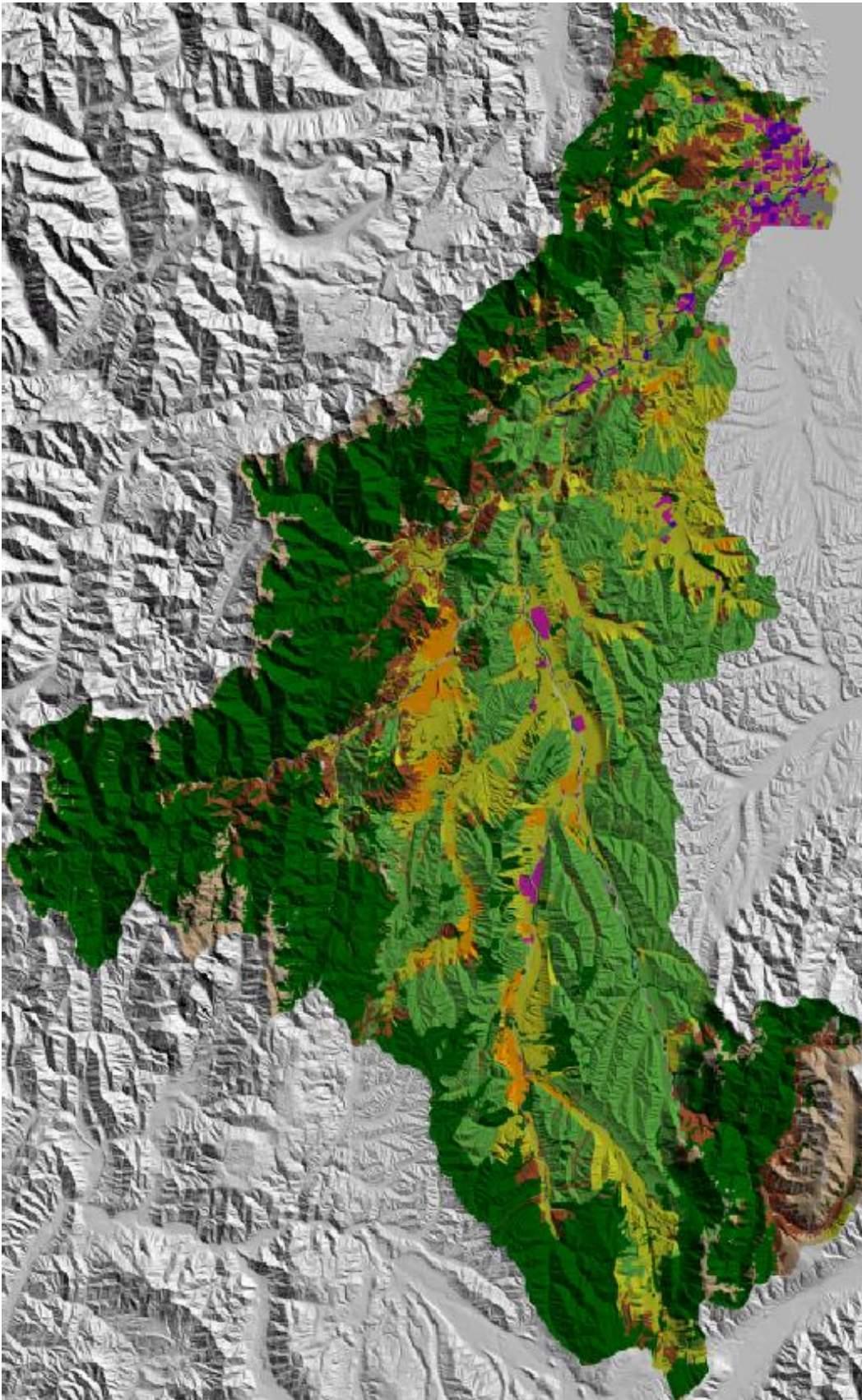


Figure 3. Present land use of the Motueka catchment.

Light green – exotic forest. Yellow – sheep/beef. Orange – dairy. Magenta – orchards. Purple – crops. Dark green – indigenous forest. Brown – scrub. Dark grey – urban. Light brown – tussock grassland.

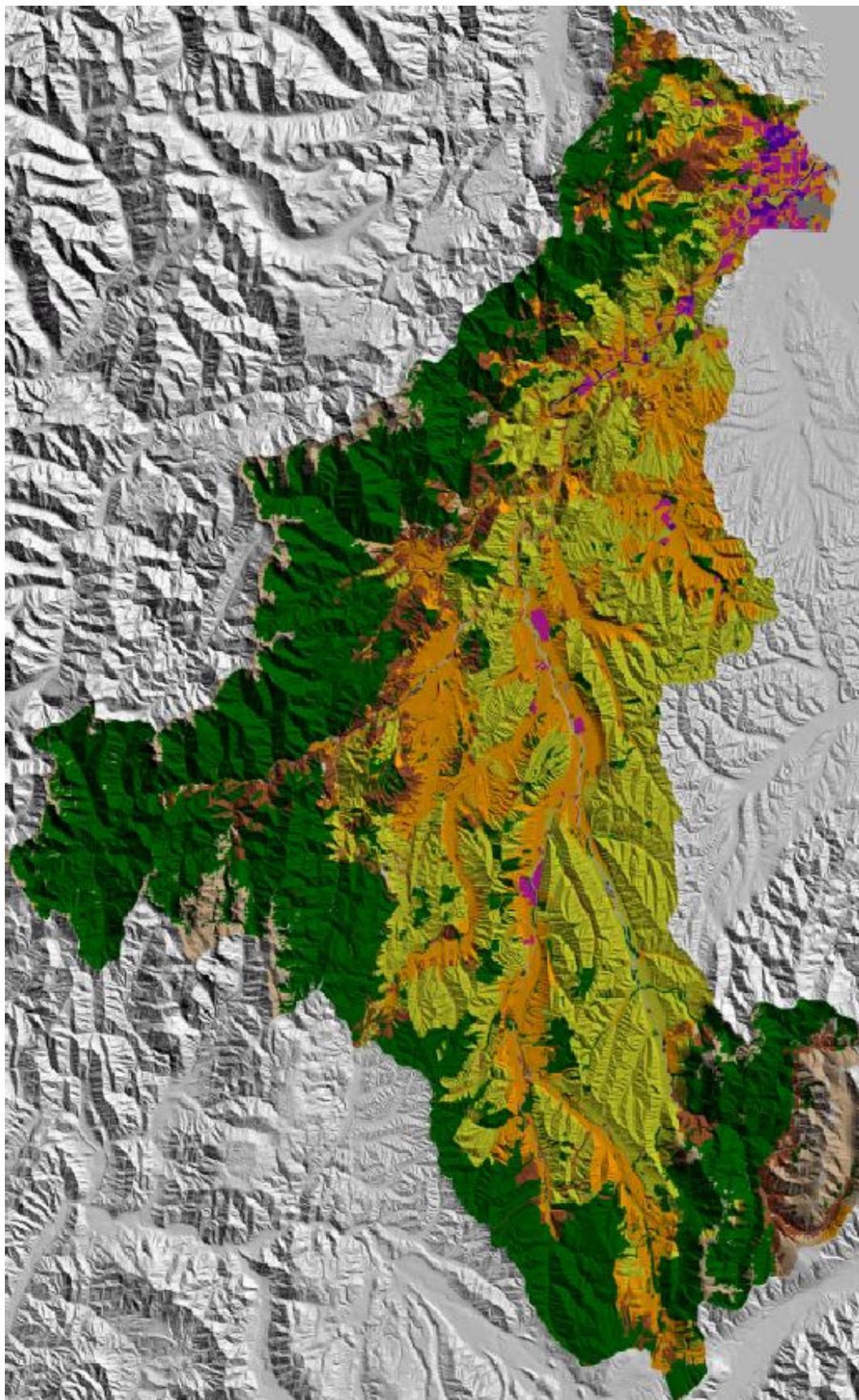


Figure 4. Intensive land use of the Motueka catchment.
 Light green – exotic forest. Yellow – sheep/beef. Orange – dairy. Magenta – orchards.
 Purple – crops. Dark green – indigenous forest. Brown – scrub. Dark grey – urban. Light brown – tussock grassland.

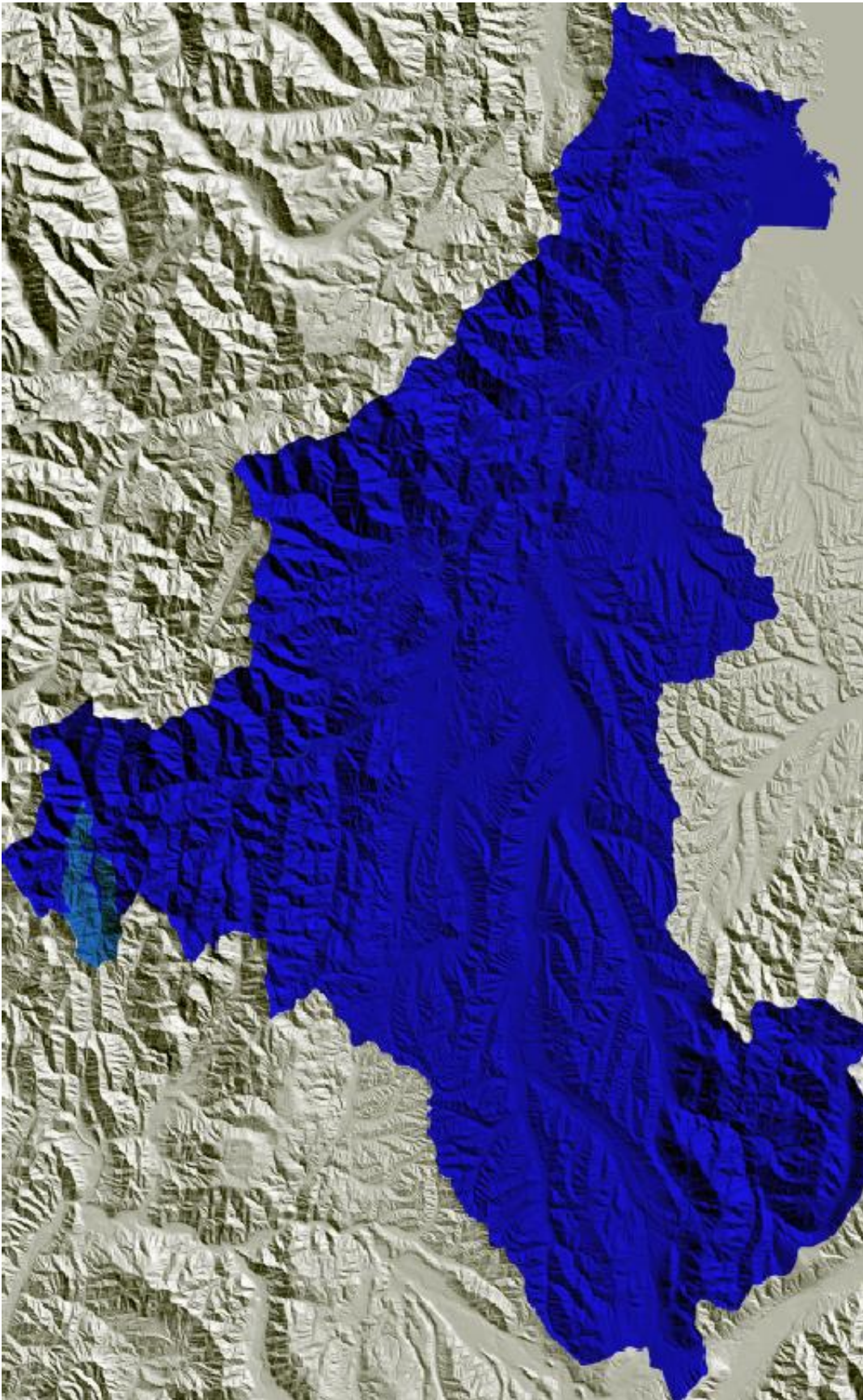


Figure 5. Map of specific sediment yield (t/km²/yr) for **historic** land use predicted from the New Zealand Empirical Erosion Model. Dark blue < 250 t/km²/yr. Light blue 250-500 t/km²/yr. Total sediment yield is 150,000 tonnes per year.

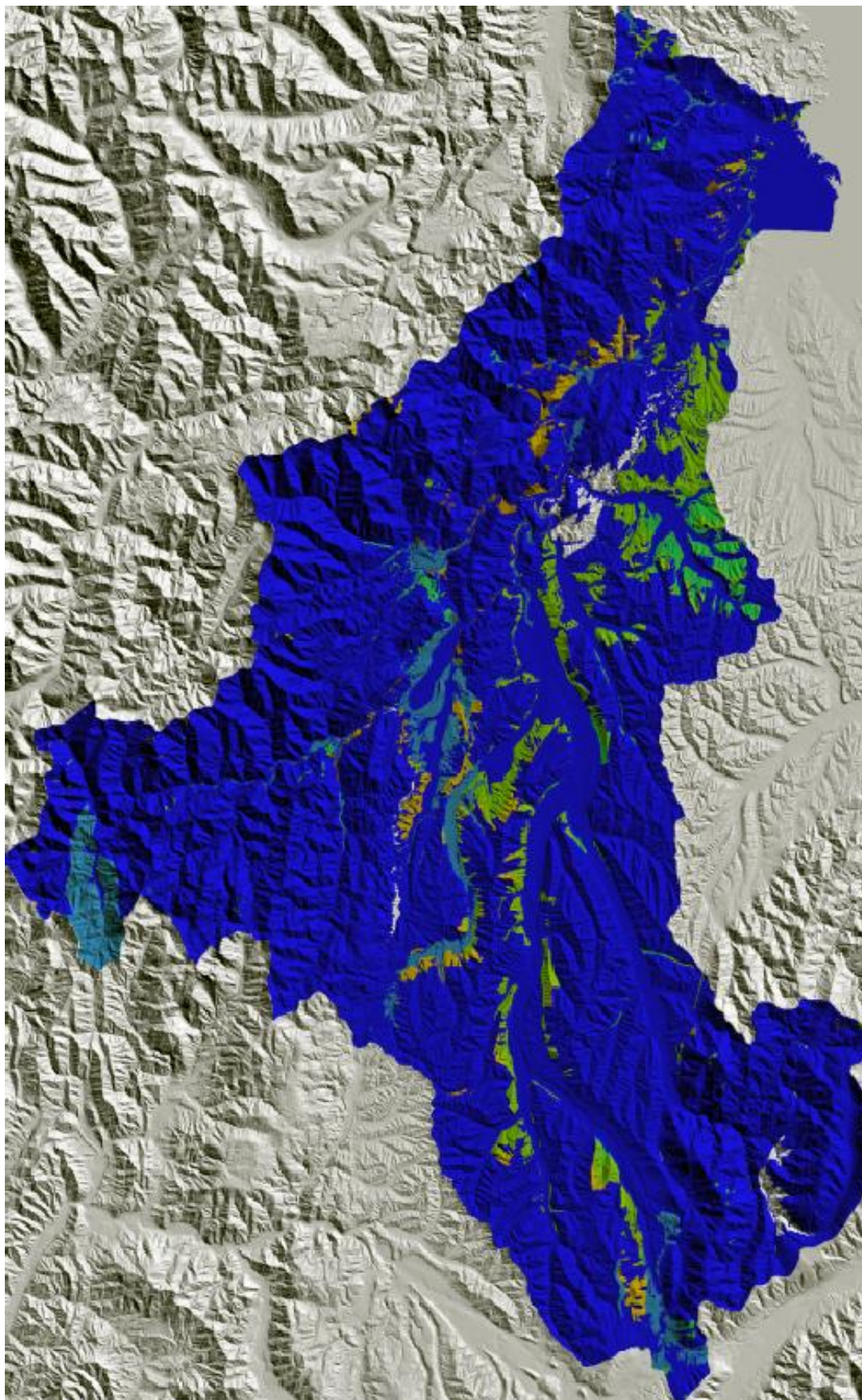


Figure 6. Map of specific sediment yield ($\text{t}/\text{km}^2/\text{yr}$) for **present** land use predicted from the New Zealand Empirical Erosion Model. Dark blue < 250 . Light blue 250-500. Aquamarine 500-750. Olive 750-1000. Light brown 1000-1250. Dark brown > 1250 . Total sediment yield is 320,000 tonnes per year.

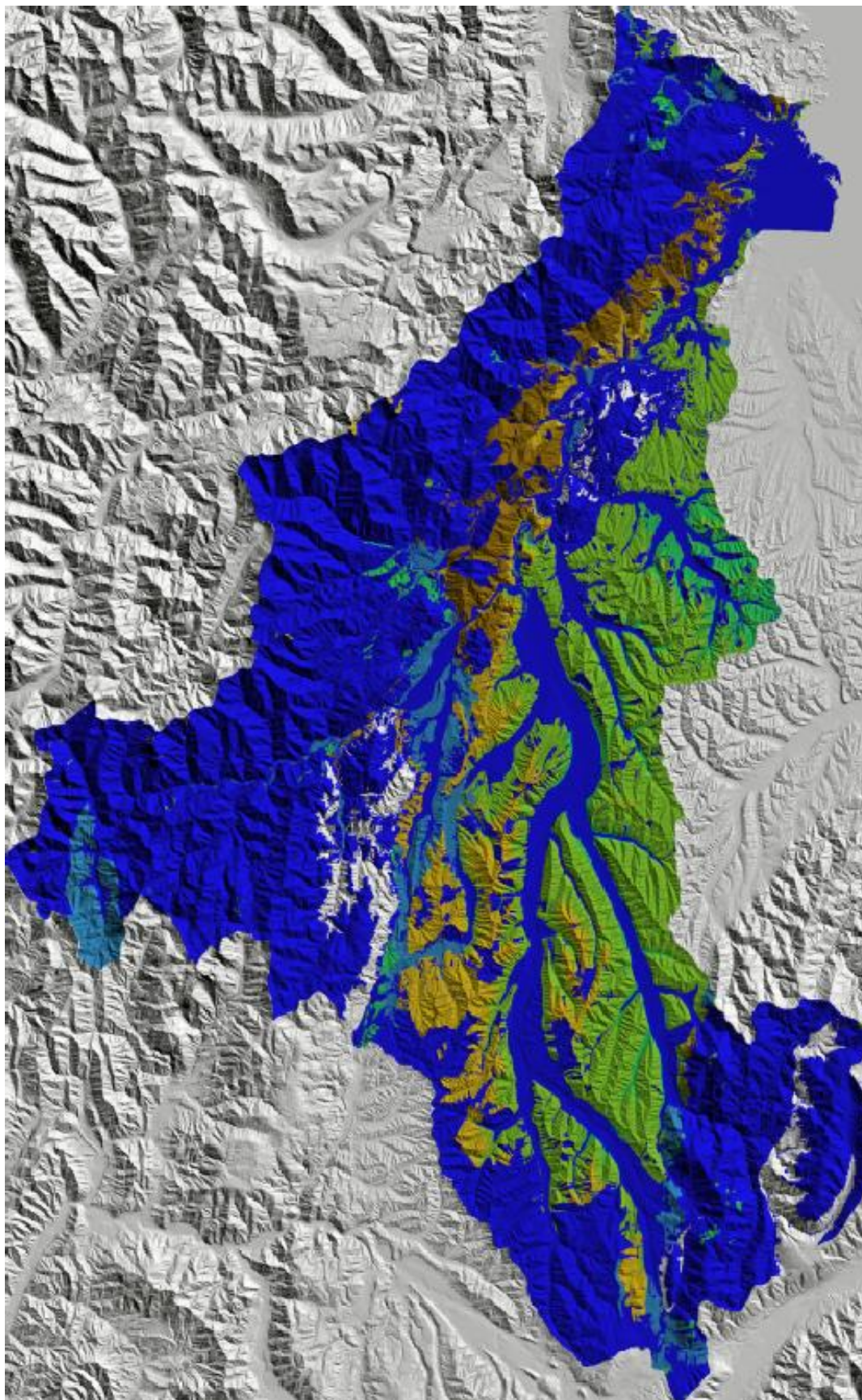


Figure 7. Map of specific sediment yield ($\text{t}/\text{km}^2/\text{yr}$) for **intensive** land use predicted from the New Zealand Empirical Erosion Model. Dark blue < 250 . Light blue 250-500. Aquamarine 500-750. Olive 750-1000. Light brown 1000-1250. Dark brown > 1250 . Total sediment yield is 750,000 tonnes per year.

Physical models

The biophysical models in IDEAS predict the flow of water, and associated sediment, carbon, nutrients, and pollutants, through the catchment and into the marine environment. Inputs to the models will be the spatial data described in the previous section (land use is time dependent). Outputs from the models will be time-dependent digital maps of mass flows (water, carbon, nutrients, and pollutants). No one model is able to handle all of the processes of interest in the catchment, so we plan to use several models of what we judge to be the important processes and to link them. Figure 8 shows the linkage of models of hillslope hydrology (SWAT), bedload transport (CAESAR), groundwater flow (FEFLOW), and ocean circulation (POM-3d).

The SWAT model (Soil and Water Assessment Tool; USDA, 2005) is used to assess the impacts of management decisions on water, sediment, and nutrient yields in basins. The smallest spatial elements are hydrological response units (HRUs). The HRUs are amalgamated into subbasins, which are routed into a main channel. The output of SWAT is a time sequence of water, sediment, and nutrient discharge at the basin outlet. This output is the input to the Princeton Ocean Model (POM-3d; Princeton University, 2005) which predicts water, sediment, and nutrient fluxes at each point in a regular grid. The water discharge from the subbasins in the SWAT model may be used as input to the CAESAR model (Coulthard *et al.*, 2002) to predict bedload transport through the main channel. Finally, percolation from the HRUs in SWAT may be used as input to the FEFLOW model of groundwater flow which predicts water discharge and head in aquifers divided into finite elements.

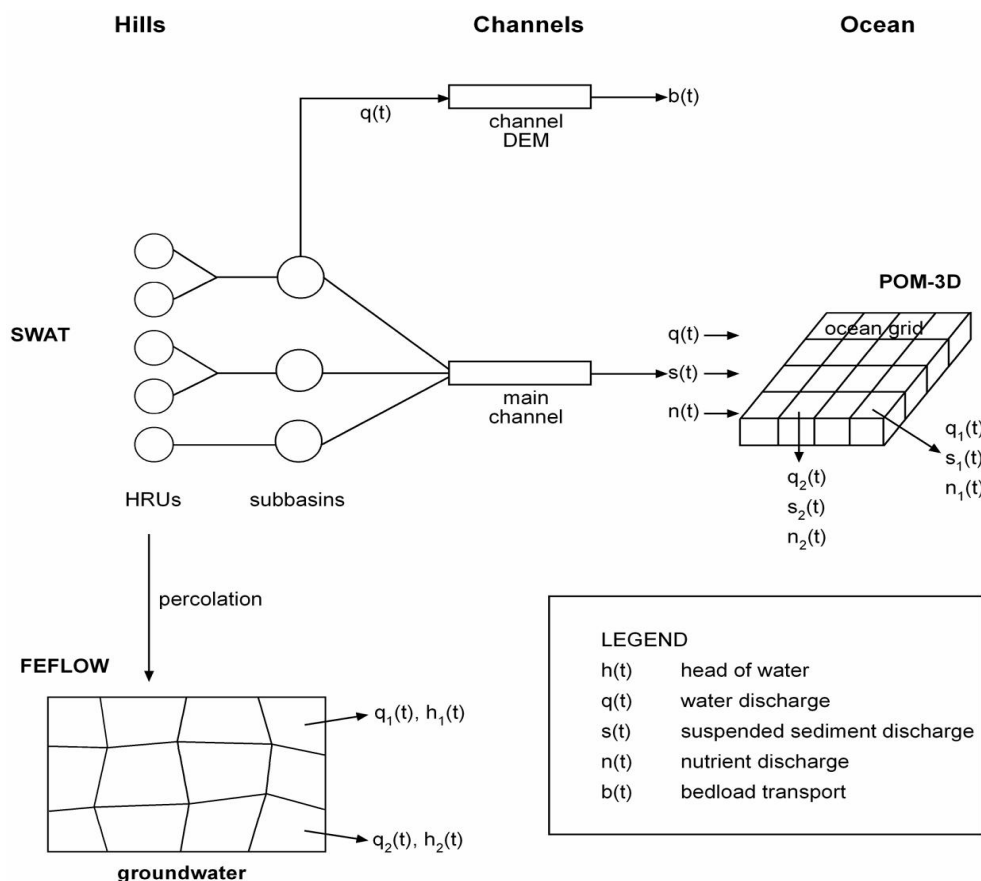


Figure 8. Linkage of biophysical models.

Environmental input-output modelling

The gross output of an industry comprises the net output (or final demand) and the output to other industries. This may be expressed mathematically as

$$X_i = \sum_j X_{ij} + Y_i \quad i = 1, \dots, n \quad (3)$$

where

X_i is the gross output of industry i ,
 X_{ij} is the sales of commodity i to industry j ,
 Y_i is the sales of commodity i to final demand,
and n is the number of industries.

It can be assumed that intermediate inputs are constant proportions of the output of the purchasing industry (Leontief, 1970). This is written as

$$X_{ij} = a_{ij} X_j \quad (4)$$

Substitution of X_{ij} in equation (3) with equation (4), permits the matrix equation to be written

$$\mathbf{X} = \mathbf{A}\mathbf{X} + \mathbf{Y} \quad (5)$$

where

\mathbf{X} is a $n \times 1$ vector of gross outputs,
 \mathbf{A} is a $n \times n$ matrix of intermediate input coefficients, a_{ij} ,
and \mathbf{Y} is an $n \times 1$ vector of final demands, Y_i .

Equation (5) may be rearranged to solve for \mathbf{X} .

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{Y} \quad (6)$$

Equation (6) gives the gross outputs per industry of an economy as a linear function of the final demands per industry, and may be used to generate *future economic scenarios* from predicted industry demands.

Ecosystem services may be included in the consideration of an economy by relating ecosystem services to gross outputs. This can be done by dividing the direct use of a particular ecosystem service per industry (in physical units) by the gross output of the industry, to form w_i say. The total of that ecosystem service provided to all industries, E , is then

$$E = \sum_i w_i X_i \quad (7)$$

For more than one type of ecosystem service, equation (7) may be generalised to matrix form

$$\mathbf{E} = \mathbf{W}\mathbf{X} \quad (8)$$

where

\mathbf{E} is a $m \times 1$ vector of services (physical units) for m different ecosystem services, and \mathbf{W} is a $n \times m$ matrix of ecosystem service coefficients, w_{ij} .

Equation (8) can then be used in *future economic scenarios* to predict required *ecosystem services* associated with predicted gross outputs.

Although the concept is simple, it is often difficult to estimate the ecosystem service coefficients. IDEAS will provide many of these coefficients directly through the linked biophysical models. The biophysical models provide digital maps of mass flows (water, carbon, nutrients, pollutants) that can be intersected with “present” land use maps to estimate direct ecosystem service per sector. Table 3 shows a list of ecosystem service coefficients useful for consideration of five environmental issues: (i) competition for water; (ii) water pollution; (iii) conservation of biodiversity; (iv) greenhouse gas emission; and (v) sediment. All the ecosystem service coefficients are for land-based sectors, so for convenience they are expressed in physical units per hectare, rather than per dollar.

<i>Ecosystem service</i>	<i>Coefficient</i>	<i>Units</i>	<i>Limits</i>
Water provision	Volume of water provided from sector per hectare per year	m ³ /ha/yr	Total water provision is the difference between total rainfall (in m ³ /ha/yr) and total water use
Water use	Volume of water used by sector per hectare per year	m ³ /ha/yr	Total water use should not exceed a threshold required by trout
Groundwater use	Volume of groundwater used by sector per hectare per year	m ³ /ha/yr	Total groundwater use should not exceed groundwater recharge
Nitrogen waste	Mass of nitrogen exported from sector to sea per hectare per year	tonnes/ha/yr	Total nitrogen exported to sea should be less than maximum threshold set by aquaculture sector
Phosphorus waste	Mass of phosphorous exported from sector to sea per hectare per year	tonnes/ha/yr	Total phosphorous exported to sea should be less than a threshold set by aquaculture
Biological pollution	Faecal bacteria counts exported from sector to sea per hectare per year	number/ha/yr	Total faecal counts should be less than a given threshold set by aquaculture
Sedimentation	Volume of fine sediment exported from sector to sea per hectare per year	tonnes/ha/yr	Total fine sediment delivered to sea should be less than a given threshold
Gravel supply	Volume of gravel exported from sector to sea per hectare per year	tonnes/ha/yr	Total coarse sediment delivered to sea should be greater than gravel extraction by a set amount.
Carbon sink	Net carbon sink for sector per hectare per year	tonnes/ha/yr	Net carbon sink for catchment should be zero
Biodiversity	Number of endemic animal and plant species per hectare	number/ha	Total number of endemic species in catchment should be greater than a threshold

Table 3. Ecosystem service coefficients useful for consideration of four environmental issues: (i) competition for water; (ii) water pollution; (iii) conservation of biodiversity; (iv) greenhouse gas emission; and (v) sediment.

Ecosystem service coefficients are dependent on both the *spatial pattern of land use and management practices*. Hence the biophysical models should really be run for each new land use scenario to be evaluated, as is indicated in Figure 1. However, this can cause delays and reduce the interactivity of the catchment deliberation process. To facilitate immediate evaluation of land use scenarios within the catchment deliberation process it can be assumed that the coefficients of spatial land use patterns similar to the “present” scenario are constant. For the dependence of ecosystem service coefficients on management practice, it will be necessary to prerun biophysical models to determine a lookup giving the dependence of the coefficients on the proportion of the sector adopting best management practice. For land use scenarios much different from the “present” scenario, the biophysical models will have to be run separately.

Triple bottom-line indicators

Triple bottom-line indicators are required to summarise catchment performance environmentally, economically, and socially, for the stakeholders participating in the deliberation process. It is therefore desirable to include indicators that are relevant to each of the stakeholders, both on a catchment and per industry basis. Table 4 shows a breakdown of possible stakeholders and indicators of particular interest. The biophysical, economic, and social indicators associated with scenarios would come directly from IDEAS as presently proposed.

<i>Industry/Sector</i>	<i>Biophysical indicator</i>	<i>Economic indicator</i>	<i>Social indicator</i>
Agriculture	Area of agriculture (ha) Water take (m ³ /yr)	Gross output (\$) Operating surplus (\$)	Job numbers (FTE)
Horticulture	Area of horticulture (ha) Water take (m ³ /yr)	Gross output (\$) Operating surplus (\$)	Job numbers (FTE)
Forestry	Area of forestry	Gross output (\$) Operating surplus (\$)	Job numbers (FTE)
Aquaculture	Suspended sediment yield (kg/s) Nutrient yield (kg/s) Faecal counts (number/s)	Gross output (\$) Operating surplus (\$)	Job numbers (FTE)
Conservation/ recreation	Area of conservation estate (ha) Number of endemic species Fish numbers	Administration cost (\$)	Visitor days Tramping days Hunter days Fisher days

Table 4. Proposed triple-bottom-line indicators of future scenarios

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