Guidance for Councils on choice and use of erosion and sediment models in regulation

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Melissa Robson-Williams, Chris Phillips

Manaaki Whenua – Landcare Research, a group of the Bioeconomy Science Institute

Matt Oliver

Marlborough District Council

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Prepared for: Envirolink

Reviewed by:

Andrew Neverman
Research Priority Area Leader – Erosion processes and management
BSI - Manaaki Whenua – Landcare Research Group

Approved for release by:

Suzie Greenhalgh
Principal researcher – Catalysing Change
BSI - Manaaki Whenua – Landcare Research Group

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Summary

Project and client

In response to a request for guidance for Councils on choosing and using erosion and sediment models in regulation, Manaaki Whenua – Landcare Research (MWLR)[1] in conjunction with Matt Oliver from Marlborough District Council (MDC) received an advice grant application from Envirolink to provide such guidance.

Objectives

The objectives of this study are listed below.

- Establish sound, underlying principles for choosing and using erosion and sediment models in regulation based on existing national guidance.
- Test the proposed principles and modify if necessary.
- Collect relevant data from Councils and model developers, scientists, and consultants to inform development of guidance based on the principles.
- Develop guidance for Councils on choosing and using sediment and erosion models in regulation.

Methods

- Based on existing national guidance, derive principles for fit-for-purpose model use.
- Conduct a survey of regional council and unitary authority staff to determine what models are being used and for what purpose.
- Conduct a survey of modellers, based on the responses from the Councils.
- Undertake AI-enhanced literature searches, as needed.
- Collate responses and analyse the results
- Develop guidance for Councils on the choice and use of erosion and sediment models in regulation.

Results (principles, survey insights, and guidance)

- Three principles were derived for evaluating fitness-for-purpose for use of erosion and sediment models in regulation based on the model development, model governance and model use:
  - Model development or adaptation is robust
  - Model governance is appropriate
  - Model application is appropriate

[1] On 01 July 2025 Landcare Research New Zealand Ltd became the New Zealand Institute for Bioeconomy Science Ltd; Manaaki Whenua – Landcare Research operates as an internal group within this Institute, which is less formally known as the Bioeconomy Science Institute (BSI).

- Based on the survey data collected, 15 sediment and erosion models were assessed against the principles, and all met the requirements of a scientifically sound basis for their development and were found to be relatively transparent. For the other dimensions of Principle 1, including computing infrastructure needed, assumptions, uncertainty analyses and validation, there was variation between models. There was a general absence of Māori involvement in model development, and governance arrangements for models considered in Principle 2 were mixed. There was often a mismatch between the Councils and modellers on what model was used and where.
- An eight-step guidance process was developed to support Councils through a sequence of questions to determine the suitability and fitness-for-purpose of relevant models and/or their outputs.

Conclusions

- All 15 sediment and erosion models that were assessed were found to have a scientifically sound basis and were relatively transparent. For the other elements considered in Principles 1 and 2, there was variation between models. There was often a mismatch between the Councils and modellers on what models were used where.
- The Guidance developed for Councils delivers the following:
    - It focusses attention on the critical need for a clear understanding of the question being asked, or the need for erosion-sediment information, before considering choosing or using models.
    - It outlines three key questions to help identify suitable models.
    - It steps through the assessment of robustness of the model development and appropriateness of model governance relative to its intended use.
- The Guidance can assist each Council to make its own decisions about erosion and sediment models, thus contributing to the PCE (2024) recommendation on guidance to support the use of models. Although a step forward, this guidance does not go as far as to set out the preferred suit of tools as recommended by the PCE (2024, recommendation 4).

Recommendations

- We recommend the development of a short companion document to this report that concentrates solely on the eight overarching steps and the detailed questions/considerations that underpin each one.
- We recommend a centralised repository of information to address issues of institutional memory and the modeller/model user disconnect.
- We recommend that the information presented in this report be used to develop the "selection of a preferred suite of models adaptable to local circumstances" as recommended by the PCE (2024).

1 Introduction

New Zealand has a natural environment and history of land management that predisposes the country to soil erosion (Basher 2013). Erosion processes are naturally very active because of a dominance of steep slopes, weak rocks and frequent high-intensity rainfall. Regional patterns of soil erosion are distinctive, reflecting both natural environmental variation and land management practices. Because New Zealand's landscapes change rapidly over short distances, erosion can be highly variable within a catchment or a region. Erosion and sedimentation are thus natural processes, driven largely by climate and geology, which have been accelerated by human activities.

Erosion is a key national environmental issue, with land use affecting soil loss and sediment polluting waterways (Ministry for the Environment & Stats NZ 2018), and landslides - a common erosion process - are also a key natural hazard. As such, erosion data collection and modelling have been an important domain for science in New Zealand. Eyles (1983) provided a summary of the occurrence of erosion in New Zealand using data collected during the surveys that resulted in the New Zealand Land Resource Inventory (NZLRI). Since then, various approaches and models have been used to build on this. Recent advances in geospatial science have added several erosion-focussed models to the extensive list that exists in the general literature, many of which have been or are currently used by regulatory agencies in New Zealand.

Modelling and monitoring (i.e. field data and measurements) are interdependent and models can provide information on processes and characteristics that may be hard or impossible to measure (PCE 2024 a,b). Regional Councils and Territorial Authorities (Councils) across the country use erosion models for a range of purposes including freshwater and natural hazard management. This range of applications, the multiple erosion models that exist, and the complexity and variability in erosion and transport processes, makes it hard for Councils to evaluate models adequately. Use of inappropriate models and the information derived from them can be costly and undermine the usefulness of such tools, especially if applied in regulation. Councils thus require guidance on model choice and use.

National guidance on environmental modelling was recently released by the Ministry for the Environment (2023) and the Parliamentary Commissioner for the Environment (2024). Building on these reports, this report aims to support a more informed approach by Councils through guidance around choosing and using erosion and sediment models in Council processes.

1.1 Project and client

In response to a request for guidance for Councils on choosing and using erosion and sediment models in regulation, Manaaki Whenua – Landcare Research (MWLR)[2] in conjunction with Matt Oliver from Marlborough District Council (MDC) received an advice grant application from Envirolink to provide such guidance.

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2 Background

Erosion is a key national issue from both an environmental and a hazard perspective. Appendix 1 gives a useful and important recap on erosion processes and sediment yield.

2.1 Previous reviews on erosion and sediment models

In 2011 Elliott and Basher (2011) reviewed catchment-scale approaches to modelling sediment flux in New Zealand. Key insights from this review remain pertinent today.

- There are a range of erosion and sediment transport processes occurring in New Zealand.
- Erosion and sediment transport processes are complex and diverse within a catchment.
- Many models developed overseas are often not relevant for New Zealand conditions as they do not represent the range of processes that occur here.
- There is widespread use of sediment flux models in research and practical applications in New Zealand
- Simple empirical models for mean annual flux give limited insight to processes and so only provide limited guidance for mitigation and intervention methods. This was reinforced in Neverman et al. (2023) who highlighted such models may be inappropriate for anticipating the impact of climate change on erosion and sediment yields, which requires modelling of individual erosion processes and their primary hydroclimatic drivers.
- Detailed process models are difficult to run and express in terms of parameters. They often require data that is not commonly available, and still have difficulty in accommodating the range of relevant processes.

Elliott and Basher (2011) concluded that the models available at that time were not yet mature in terms of being able to answer practical management questions across the country. Finally, they suggested that none of the models they reviewed included long-term morphodynamics (i.e. the dynamic adjustment of landforms and stream morphology in response to climate, geological, tectonic, and anthropogenic factors, as mediated by sediment dynamics). Since that review, some models have matured to the extent that they are now routinely used to answer practical management questions. The challenge of including long-term morphodynamics in models remains.

More recently the PCE undertook a model stocktake and found 13 models designed to assess sediment in rivers and streams (PCE 2024). They reported that Councils used seven different models specifically intended to estimate sediment loads in rivers and streams and to explore options to reduce sediment loss. Six additional models were used for other environmental domains, but also have sediment components for rivers and streams. Given the complexity of erosion and sediment processes, it is reasonable to assume that using more than one sediment model could be beneficial, however the range of models suggests an unnecessarily large overlap in their application (see Table 2.1, Table 2.2 in PCE 2024 a).

The PCE (2024 a,b) also concluded that the outputs from these sediment models diverge significantly and so would decisions based on them. For example, different models used to estimate sediment yield in and around the Manawatū River provided significant differences when compared to observations. Similarly, large differences were also reported in local studies in Southland, Waikato, Auckland and Northland.

2.2 National Guidance on environmental modelling and use

Two key reports (MfE 2023; PCE 2024) were recently produced on environmental model development and use in New Zealand and acknowledge the importance of modelling as a source of information to support policy and regulation development.

In June 2023, the Ministry for the Environment (MfE) published a report 'Developing, adapting and applying environmental models in a regulatory context in New Zealand' (MfE 2023). Key points from the report are summarised below.

- Environmental models are just as important to regulatory management as data from sampling, monitoring, and observation programmes.
- Environmental modelling allows environmental managers and regulators to identify system drivers (causes) and forecast future conditions (outcomes) under a range of different management scenarios, and at a range of spatial and temporal scales.
- A model's design and use should reflect the context for which it is developed, and the model should be 'fit' for its intended purpose.
- To be 'fit-for-purpose' the model must address the needs of the end user, be aligned with the management or decision-making context, be scientifically credible and operate within the practical constraints of the context.
- Every environmental model contains simplifications and assumptions, and one cannot expect a model's predictions to correspond exactly to observed outcomes.
- Models should be developed, adapted for use, and applied carefully. There should be a transparent understanding of their scientific foundations, the judgements made by the model builders, the uncertainties inherent in their predictions – and the implications of all these factors for resource management and decision making.
- When applying models in a regulatory context, it is more appropriate to use models to inform actions and decisions at the 'harder' end of the regulatory spectrum (e.g. setting regulatory limits, compliance, etc.) when the models are well established, have a long-standing history of use, are underpinned by comprehensive data, and are validated. For the 'softer' end of the spectrum, less mature models or those with greater uncertainty may also be used.

Building on the MfE report, the PCE conducted a review of freshwater models to support the regulation and management of water in New Zealand (2024). Key points from the report are summarised below.

- Model development is siloed and fragmented. While most models tend to have a good scientific basis (model structure, algorithms, peer review and validation) many have shortcomings with respect to transparency, uncertainty and computational infrastructure. Data shortcomings affect models and there is a lack of model evaluation.
- Models are not systematically evaluated even though criteria for evaluation exist, which makes it hard to judge which models are best for a particular need or if they are fit for purpose and current guidance on model use falls short to support implementation.
- The inherent uncertainty in modelling outputs needs to be well understood by model users so they can be confident in the application of results and are able to communicate these internally and externally.

- There are challenges in the comparability and interoperability of models, including the potential to reuse them when needed, or assess their effectiveness at a later stage.
- There is variable use of models in a regulatory context, often models are not used to their full potential and resourcing is thin in terms of model developers and in-house staff with the technical skills to use models and/or their outputs.
- There is a lack of commitment to models developed by tangata whenua.

The PCE report (2024) goes on to make five recommendations, two of which are relevant here, on developing further guidance on the use of models (recommendation 1), and the selection or development of a preferred suite of models adaptable to local circumstances (recommendation 4).

While both MfE (2023) and PCE (2024) reports place critical importance on technical robustness, the MfE report has an additional focus on the socialisation of the modelling process. This means that some of the fitness-for-purpose elements or questions set out in MfE 2023, and incorporated into this report, may be addressed in the resource management processes that the models are intended to inform.

3 Objectives

The objectives of this study are listed below.

- Establish sound, underlying principles for choosing and using erosion and sediment models in regulation based on existing national guidance.
- Test the proposed principles and modify if necessary.
- Collect relevant data from Councils and model developers, scientists, and consultants to inform development of guidance based on the principles.
- Develop guidance for Councils on choosing and using sediment and erosion models in regulation.

4 Methods

We reviewed the current relevant guidance (MfE 2023; PCE 2024) and synthesised draft key principles for choosing and using erosion models. These draft principles were tested by one of the authors of 'Developing, adapting and applying environmental models in a regulatory context in New Zealand' (MfE 2023), to check that the principles represented their guidance. The draft principles were then tested with members of the Land Monitoring Forum and Land Management Group Special Interest Groups and clarified where necessary. The principles were then finalised.

We sent a simple spreadsheet with a list of questions (see Appendix 2) to Councils to determine what models were being used and for what purpose.

Based on the feedback from Councils and the models/tools that they were using we sought information about 16 models. We contacted New Zealand-based model developers, scientists, and consultants, who were surveyed to understand the technical and governance details of their models, based on the guidance principles (Appendix 3).[3] We received information on 15 models. A limitation to this approach is that not every district council was surveyed and some district councils may have used models which their regional council were not aware of.

We collated the responses from both Councils and modellers and analysed the results.

In developing our Guidance, we considered that concurrence with Principles 1 and 2 (Section 5) could generally be assessed based on information supplied by the modellers. However, in assessing whether models met certain criteria for particular principles, some judgement calls were necessary. These were undertaken by the second author with extensive sediment and erosion expertise. Additionally, these assessments were sent back to respondents and adjusted based on their feedback (noting that not all responded). Based on the agreed principles and the information about the models, we prepared guidance. The guidance was tested frequently with Marlborough District Council during development.

We used Google's search tool and generative AI Gemini to enhance literature searches, obtain additional information on models/tools, or to clarify definition of terms. AI was not used in data analysis or in writing this report.

5 Principles for evaluation of 'fit-for-purpose' use of models

Based on the existing guidance (i.e. MfE 2023; PCE 2024) the following principles were derived for evaluating fit-for-purpose use of erosion and sediment models. Models more broadly refers to mathematical models, GIS layers and tools.

Model is fit for its intended purpose when these three principles criteria are met.

1 Model development or adaptation is robust

2 Model governance is appropriate

3 Model application is appropriate.

Principle 1: Model development or adaptation is robust when the following criteria are met or accounted for:

- A sound conceptual model has been developed, described, tested and confirmed.
- It is built on the foundation of te Tiriti.
- It has included relevant perspectives in its development or adaptation (e.g. end users, other technical experts and knowledge holders, regulatory decision-makers, tangata whenua) and the process for doing that described.
- It draws on best possible and diverse sources of data.
- The development has been according to good practice i.e.:

[3] No response was received on Rainfall Induced Landslide Model, partial response on "Donovan" RUSLE model.

  - there is a problem definition and the matter or matters the model is intended to address are specified
  - objectives are specified and the context which the model is intended to operate is defined
  - the geobiophysical context which the model is intended to operate is defined
  - the spatial resolution which the model is intended to operate is defined.
- A suitable model framework is selected and model parameters and key relationships between model components are described:
  - the model is built, and model performance is tested and calibrated and then validated to corroborate its predictions
  - the model is deployed and its performance evaluated.
- Uncertainty analyses to investigate lack of knowledge about aspects of model, and sensitivity analyses to investigate how model outputs change with model inputs, have been undertaken and described:
  - uncertainty analysis has been conducted e.g. model framework uncertainty,[4] input uncertainty,[5] and niche uncertainty[6]
  - sensitivity analysis has been conducted e.g. to ascertain what is the influence of each model input on model outputs and which model input is making the model change most
  - results and implications of results on appropriate model use or limitations communicated.
- There is a model versioning method.
- The model can be updated with new data.
- There has been a robust peer review conducted covering the:
  - application of sound scientific principles in the model development
  - appropriateness of model choice (based on quality and quantity of data)
  - whether all important drivers and processes are represented in the model
  - appropriateness of input data
  - appropriateness of boundary condition specifications
  - documentation of inputs and assumptions, calculations, and extrapolations
  - applicability and appropriateness of selected parameter values
  - appropriateness of data standards used
  - accuracy and robustness of model code
  - calibration and validation processes

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[4] Uncertainty that results from incomplete knowledge about factors that control the behaviour of the system being modelled, limitations in spatial or temporal resolution, and simplifications of the system.

[5] Uncertainty that results from data-gathering or measurement errors (including bounds of uncertainty in laboratory results due to the accuracy/sensitivity of equipment), gaps in data, inconsistencies between measured values and those used by the model (for example, in their level of aggregation/averaging), and parameter value uncertainty.

[6] Uncertainty that results from the use of a model outside the system for which it was originally developed, and/or from developing a larger model from several existing models with different spatial or temporal scales.

- adequacy of the uncertainty and sensitivity analysis
  - certainty of model predictions and reliability of conclusions drawn from them.
- Measures have been taken to build public trust and confidence in the model e.g. by providing documentation that clearly describes the development or adaptation process, or by using open source, or open platform models.
- Measures have been taken to make model documentation easy to access for users e.g. open access journal paper, freely available publication or directly from modeller.
- Assumptions and limitations are clearly and openly explained.

Principle 2: Model governance is appropriate when the following criteria are met or accounted for:

- There is a governance structure or process in place for model development and use.
- There is a process for deciding appropriateness of model applications.
- There are stable financial arrangements for any improvements of updates to model.
- There is a continued outcomes-oriented focus i.e. produces relevant information that enables decision-makers to make informed decisions with a reasonable understanding of confidence risk and uncertainty and helps to illuminate the effectiveness of actions to improve the situation.
- Single-point dependencies (e.g. only 1 or 2 modellers able to use the model) are managed or avoided.

Principle 3: Model application is appropriate when the following criteria are met or accounted for:

- Modelling provides the best available information.
- The model addresses the needs of the user (including the spatial and temporal resolution).
- Tangata whenua (i.e. local, indigenous people, and their descendants) have been engaged with regarding model approach and or model application.
- The modelling approach including model complexity is appropriate for the intended usage.
- The intended usage in terms of stage of planning cycle, (e.g. development of planning instruments, consenting, compliance, enforcement, assessment of plan effectiveness) fits with model capability.
- The intended usage on a regulatory spectrum (i.e. softer end or harder end) aligns with model capability.
- When applying an environmental model in a regulatory context, resource managers and decision makers should keep in mind it is generally more appropriate to use models to inform actions and decisions at the 'harder' end of the regulatory where models:
  - are well established (mature) and have a longstanding history of effective and reliable use in equivalent contexts
  - are underpinned by a comprehensive set of data
  - are corroborated by the outputs of other models and evidence
  - have been validated by investigations that have demonstrated a strong and reliable correlation between model predictions and sampling results.

- It is generally more appropriate to use environmental models to inform actions and decisions at the 'softer' end of the regulatory spectrum where models:
  - are new (immature) and are being used for the first time or are being used in a significantly different context than the one for which they were initially designed
  - are attempting to simulate a highly complex system with many unknowns
  - suffer from a paucity of data, or if the model outputs are likely to change as more data becomes available (for example, as understanding of the system increases)
  - have not been sufficiently corroborated by investigations, or where they have demonstrated weak relationships between model predictions and sampling results.
  - More well-established models may also be used at the 'softer' end of the regulatory spectrum.
- The model users have a clear understanding of the model's abilities, limitations and uncertainties.
- The model is aligned with the decision-making context and skills of those in councils who will use it/use its outputs.
- Quality Assurance processes (for data collection/entry) and model acceptance (model performance), and Quality Control processes (e.g. alerts for missing data) are specified.
- Interoperability between linked models is managed (e.g. by sharing a common architecture or aligning model and data assumptions of linked models and evaluating individual components and linked models).
- The likelihood of modelling updates/new model versions) is accounted for (both in terms of science e.g. updated results and policy/planning/consents e.g. instruments that have used the model results).
- There is a process of ongoing model evaluation by users including monitoring against model predictions.

Note that assessment of each of these criteria for every modelling exercise is likely to be unnecessary, e.g. if a model has been developed elsewhere or previously and relevant uncertainty analyses have already been undertaken, it is not expected that these should be performed again.

Similarly, we also note that the degree to which each of the above elements is dealt with will vary in response to the context and intended use of the model. The evaluation of the fitness for purpose of a model should be especially comprehensive and formal where models are likely to have a significant influence on regulatory decision making at the harder end of the regulatory spectrum.

6 Erosion and sediment models assessed

Responding Councils indicated 16 ‘models’ focused on sediment and/or erosion are used in both regulatory and non-regulatory contexts to assist with land and water management, Table 1. These models have been used in the preparation of this guidance. See Appendix 4 for further details on the models.

Table 1. Erosion and sediment ‘models’ for estimating sediment in rivers and catchments and their use by Councils as reported by Councils.

Model/tool/layer	Used by
(Revised) Universal Soil Loss Equation (USLE/RUSLE)	GWRC, HRC
“Donovan” RUSLE model	BOPRC
New Zealand Empirical Erosion Model (NZEEM)	GWRC, WRC, HRC, AC, GDC
Highly Erodible Land (HEL) layer	MfE, HRC, StatsNZ, WRC
MPI erosion susceptibility layer	All councils as a national standard
Waikato-Auckland-Northland Sediment Yield model (WANSY1, WANSY2)	NRC, WRC, AC
New Zealand Sediment Yield Estimator (NZSYE)	NRC, AC
SedNetNZ	BOPRC, ES, GWRC, HBRC, HRC, NRC, ORC, TRC, WRC, AC
Catchment Land Use for Environmental Sustainability (CLUES)	ES is the only regional council using CLUES for sediment modelling. (BOPRC, ECAN, GWRC, HRC, NRC, ORC, TRC and WRC, AC use it for other environmental domains but not for sediment modelling)
Soil and Water Assessment Tool (SWAT)	GWRC, HBRC, MDC, ORC and WRC use it for other environmental domains but not for sediment modelling
Freshwater Management Tool (FWMT)	AC, NRC
Simplified Contaminant Allocation and Modelling Platform (SCAMP)	NRC, HRC, TRC, ES, WRC
Melton Ratio	MDC, TDC
Landslide Susceptibility model with connectivity	GDC, HBRC, MDC
Rainfall Induced Landslide Model	GDC, MDC
Radiometric derived erosion vulnerability model	ES, NRC, NCC, MDC

Abbreviations for councils: AC = Auckland Council , BOPRC = Bay of Plenty Regional Council , ECAN = Environment Canterbury, ES = Environment Southland, GDC = Gisborne District Council, GWRC = Greater Wellington Regional Council, HBRC = Hawke’s Bay Regional Council, HRC = Horizons Regional Council, MDC = Marlborough District Council , NCC = Nelson City Council (does not use models), NRC = Northland Regional Council , ORC = Otago Regional Council, TDC = Tasman District Council, TRC = Taranaki Regional Council, WCRC = West Coast Regional Council , WRC = Waikato Regional Council.

7 Guidance for Councils for assessing fit-for-purpose model use

In developing our Guidance, we considered that concurrence with Principles 1 and 2 (Section 5) could be assessed relatively objectively based on information supplied by modellers. For the third principle relating to use by Councils we took the guiding principles outlined in Section 5 and structured them into questions to support Councils to step through a process to determine the suitability and fitness-for-purpose models and/or their outputs (the 'Guidance'). The Guidance includes results based on the responses of modellers and Councils to the questions we posed (summary tables and figures) as well as questions for the user to respond to. The end-to-end process is outlined in Figure 1.

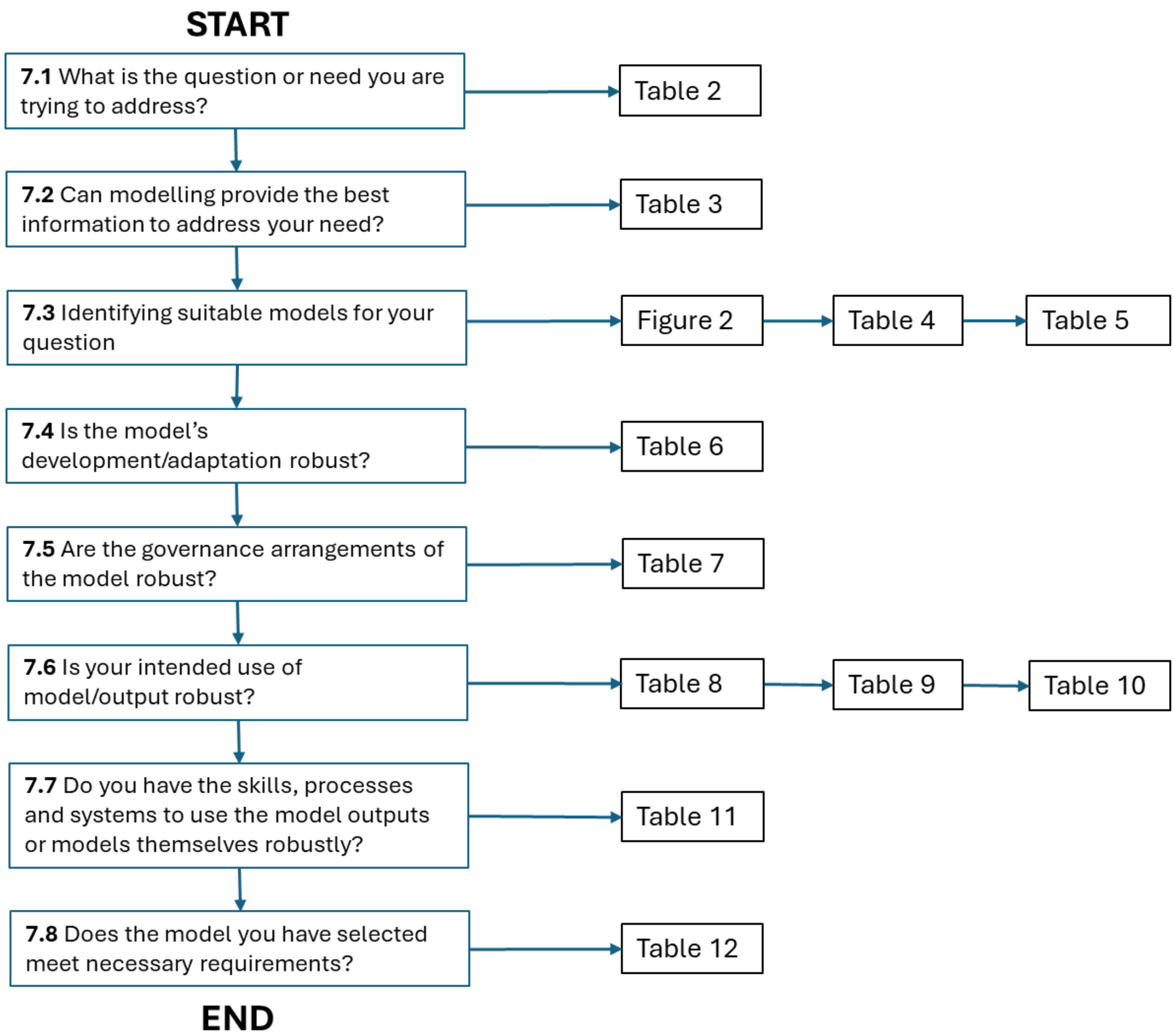

Figure 1. Quick reference guidance summary.

7.1 What is the question or need you are trying to address?

Before engaging in modelling, the problem being addressed should be clearly defined. Ask 'why is erosion and sediment information needed?'. Furthermore, the desired end state should be at least partly understood. Appendix 1 includes an important summary of key erosion and sediment processes and terms to assist with answering the questions. Table 2 indicates the purpose for which models and their outputs were sought by the Councils we surveyed. Most Councils had a primary focus on sediment as it related to water quality with a few who had an additional interest in understanding natural hazards, particularly rainfall-initiated shallow landslides.

Table 2. Assessment of council responses of purpose for which erosion and sediment models are used.

Primary purpose or problem	Councils who require this
To understand erosion, sediment, and water quality	NRC, AC, BOPRC, GDC, NCC, ECAN, HRC, TRC, MDC, GWRC
To understand natural hazards	GDC, MDC
To identify where sediment is coming from	BOPRC, HBRC, NCC, ECAN, HRC, TRC, MDC, GWRC
To prioritise catchments	GDC, MDC, TRC
To determine benefits of land management	ORC, HBRC, HRC, TRC
To support investment in sediment reduction	ORC, HBRC, HRC, TRC, GWRC
All of the above	NRC, AC, BOPRC

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7.2 Can modelling provide the best information to address your need?

Modelling is an important part of the knowledge acquisition process and is well suited to certain uses. Ask 'can modelling provide the best information to address your need?' Table 3 outlines resource management reasons for using models (MfE 2023).

Table 3. Resource management reasons for using models.

Model use is appropriate for any one or more of the following applications
Setting limit on resource use
Having regard to the foreseeable impacts of climate change
Setting special provisions for attribute(s) affected by nutrients
Assessing trends
Maintaining freshwater accounting systems
Assessing whether processes are occurring naturally
Allocating contaminant discharge capacity
Safeguarding the coastal environment and sustaining its ecosystems
Quantifying catchment contaminant loads and any changes in loads

7.3 Identifying suitable models to address your question

7.3.i Are you principally interested in freshwater quality or hazards?

Once the initial question on 'why erosion and sediment information is needed for policy and regulation' is answered, the next question is 'will the information be used for freshwater quality management and assessment (including land management) or for natural hazard assessment and management?' Some models may provide information that can be used for both purposes, though usually hazard information requires different models. The broad end-use of the models assessed is shown in Figure 2. Note, some multi-contaminant models available in NZ also cover sediment. .

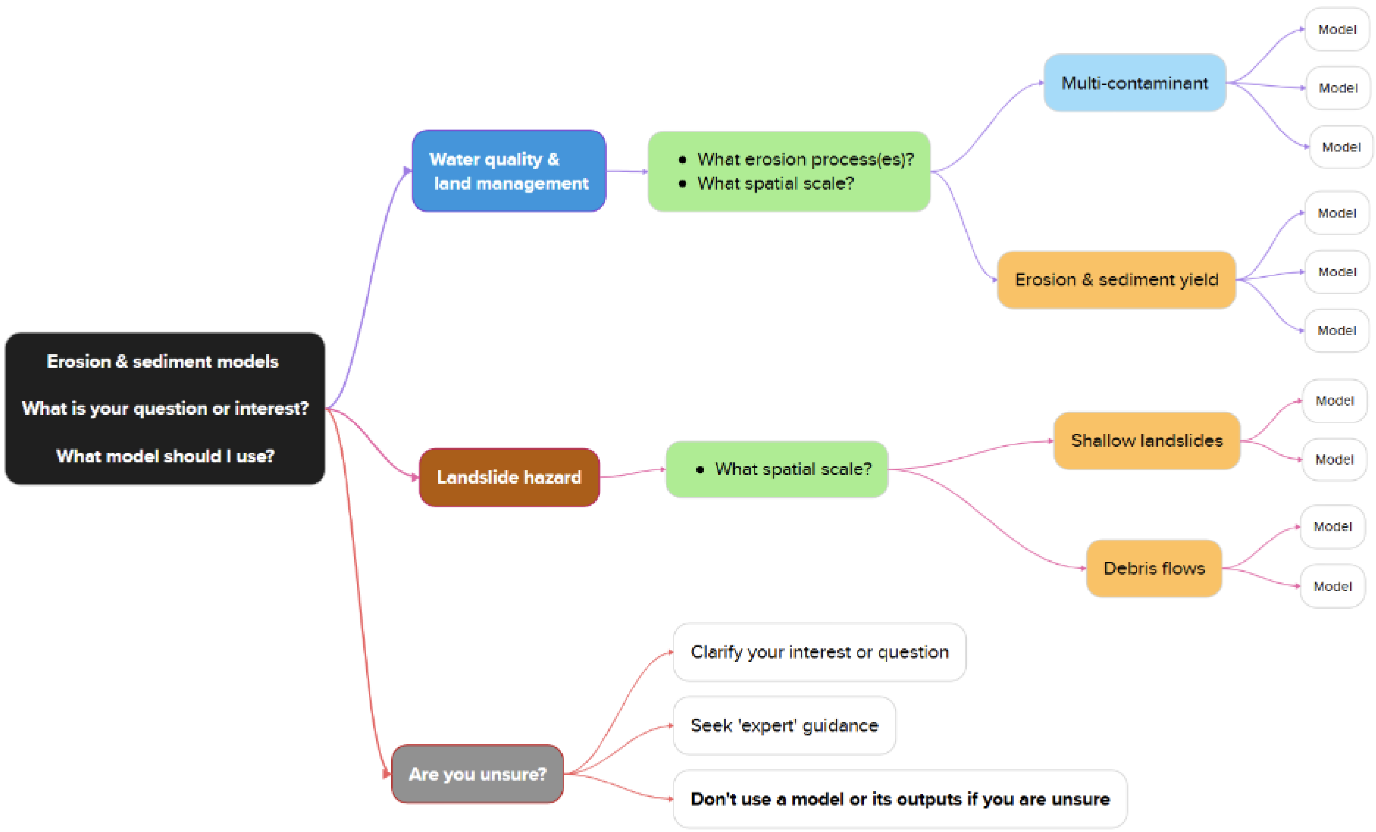

Figure 2. Flow path for assessing models to provide information on erosion and sediment as they relate to water quality, land management and landslide hazard assessment.

7.3.ii What erosion processes are most relevant to your question?

Understanding the key erosion processes that are relevant to your questions can help identify appropriate models. Also, in some end use applications, it may be necessary to obtain information on a specific erosion process. Ask 'what erosion processes are most relevant to the question?'.

We note that some models only provide sediment yields representing the combined contributions from all or a few erosion processes, i.e. some models lump total sediment loads together while others model discrete processes. This means that it can be difficult to derive information specifically about an individual erosion process. Many of the models covered in this report only deal with one or two erosion processes such as surface erosion and bank erosion, i.e. those processes affected by runoff. An example of models and their linkages to different erosion processes is shown in Table 4.

Table 4. Erosion process representation in assessed models.

	Erosion process representation						
Model	**Surface erosion**	**Shallow landslide**	**Earthflow**	**Gully**	**Riverbank**	**Floodplain deposition**	**Total suspended load**
(Revised) Universal Soil Loss Equation (USLE/RUSLE)	✓						
"Donovan" RUSLE model	✓						
New Zealand Empirical Erosion Model (NZEEM)							✓
Highly Erodible Land (HEL) layer		✓	✓	✓			
MPI erosion susceptibility layer	✓	✓	✓	✓	✓		
Waikato-Auckland-Northland Sediment Yield model (WANSY1, WANSY2)							✓
New Zealand Sediment Yield Estimator (NZSYE)							✓
SedNetNZ	✓	✓	✓	✓	✓	✓	✓
Catchment Land Use for Environmental Sustainability (CLUES)							✓
Soil and Water Assessment Tool (SWAT)	✓				✓		✓
Freshwater Management Tool (FWMT)					✓		✓
Simplified Contaminant Allocation and Modelling Platform (SCAMP)							✓
Melton Ratio	Used exclusively to determine sub-catchments susceptible to debris flows						
Landslide Susceptibility model with connectivity		✓					
Rainfall Induced Landslide Model	No response						
Radiometric derived erosion vulnerability model	Doesn't model specific erosion processes						

7.3.iii What spatial and temporal resolution do you require to address your question?

Understanding the temporal and spatial resolution required to answer your questions can help identify appropriate models. Ask 'what spatial and temporal resolution is required for the question?'

Model respondents provided information on the spatial scales they recommended their models or outputs were most suitable for. However, there is no requirement or constraint on the users to follow those recommendations. Often models use a finer resolution for computation but their outputs may not be intended to be analysed or interpreted at that scale. As a consequence, there is a risk that some use this information at inappropriate scales. For example, a model developed for use at regional or national level should not be used at farm scale and vice versa. Anecdotally, we are aware of examples where this happens within Councils and it is something that users need to be aware of, particularly if information is going to be used to support regulation.

The survey asked modellers what temporal scale their model was designed to operate on. Responses, although incomplete, ranged from daily or sub-daily to annual figures. Lack of input data, be it spatial or temporal can be a limiting factor on the usefulness of a particular model for the application in mind.

Table 5. Spatial scale of interest for assessed sediment and erosion models.

	Spatial scale of interest					
Model	**All scales**	**Farm**	**Sub-catchment**	**Catchment**	**Regional**	**National**
(Revised) Universal Soil Loss Equation (USLE/RUSLE)	✓					
"Donovan" RUSLE model	✓					
New Zealand Empirical Erosion Model (NZEEM)			✓	✓	✓	✓
Highly Erodible Land (HEL) layer				✓	✓	✓
MPI erosion susceptibility layer				✓	✓	✓
Waikato-Auckland-Northland Sediment Yield model (WANSY1, WANSY2)			✓	✓	✓	✓
New Zealand Sediment Yield Estimator (NZSYE)			✓	✓	✓	✓
SedNetNZ			✓	✓	✓	✓
Catchment Land Use for Environmental Sustainability (CLUES)			✓	✓	✓	
Soil and Water Assessment Tool (SWAT)				✓	✓	

	Spatial scale of interest					
Model	**All scales**	**Farm**	**Sub-catchment**	**Catchment**	**Regional**	**National**
Freshwater Management Tool (FWMT)		✓	✓	✓	✓	
Simplified Contaminant Allocation and Modelling Platform (SCAMP)			✓	✓		
Melton Ratio				✓	✓	
Landslide Susceptibility model with connectivity			✓	✓	✓	
Rainfall Induced Landslide Model	No response					
Radiometric derived erosion vulnerability model		✓	✓	✓	✓	

7.4 Is the model's development/adaptation robust?

Understanding the scientific robustness of potential models is an important step in identifying appropriate models. We note that where models are intended to be used at the harder end of the regulatory spectrum, the requirements of the extent and formality of this assessment is likely to increase.

Principle 1 (Section 5) states that model development and/ or a model is robust when: the model has a sound scientific base; is transparent in terms of how it was developed and operates; addresses and provides information on the assumptions and limitations of the model and its use; has been peer reviewed; undergone sensitivity and uncertainty analysis; and been validated against an independent set of observations. Table 6 outlines our assessment of the modeller response to the survey questions about model robustness and an assessment of the computational requirements.

Table 6. Our assessment of model robustness based on modeller response to Principle 1 questions.

Model/tool/ layer (abbreviated names only)	Robust scientific basis and transparency (Yes, some, No)	Computing infrastructure needs (Low, Medium, High)	Assumptions & limitations (Low, Medium, High)	Peer review (Yes, No, Maybe/ unknown)	Uncertainty analysis (Yes, No, Maybe/ unknown)	Validation (Yes, No, Maybe/ unknown)
(USLE/RUSLE)	Yes	Low	Low	Yes	Yes	Yes
"Donovan" RUSLE	Yes	Medium	Medium	Yes	Yes	Maybe/ unknown
(NZEEM)	Yes	Low	Medium	Yes	Yes	Yes
(HEL) layer	Yes	Low	Medium	Yes	Yes	Yes
MPI erosion susceptibility layer	Yes	Medium	Medium	Yes	No	Maybe/ unknown
WANSY1, WANSY2)	Yes	Low	Medium	No	No	Yes
(NZSYE)	Yes	Low	Medium	No	No	Yes
SedNetNZ	Yes	Medium	Medium	Yes	No	Yes
(CLUES)	Yes	Medium	Medium	Yes	Not for sediment	No
(SWAT)	Yes	Medium	Medium	Yes	Yes	Yes
(FWMT)	Yes	Medium	Medium	Yes	Yes	Yes
(SCAMP)	Yes	Medium	Medium	No	Yes	Maybe/ unknown
Melton Ratio	Yes	Medium	Medium	Yes	No	Yes
Landslide Susceptibility	Yes	High	Medium	Yes	Yes	Yes
Rainfall Induced Landslide Model	No response					
Radiometric erosion vulnerability model	Yes	Medium	Medium	Some	Yes	Yes

7.5 Are the governance arrangements of the model appropriate?

Understanding the appropriateness of the governance arrangements of potential models is important in assessing a range of risks associated with model use including e.g. single person dependency. We note that where models are intended to be used at the harder end of the regulatory spectrum, the requirements of the extent and formality of this assessment is likely to increase.

Principle 2 (Section 5) states that the model governance arrangements are appropriate when: there is a governance structure in place; a process for decision-making, stable financial arrangements, sufficient staff and an outcome focus. Many respondents indicated they were unsure about their governance arrangements. Table 7 outlines our synthesised assessment of the modeller response to the survey questions about model governance. Some level of governance exists for half the models with the other half having no formal governance arrangements.

Table 7. Our assessment of appropriate governance arrangements based on modeller response to Principle 2 questions.

Model/tool/layer	Appropriate governance arrangements
(Revised) Universal Soil Loss Equation (USLE/RUSLE)	No
"Donovan" RUSLE model	No
New Zealand Empirical Erosion Model (NZEEM)	No
Highly Erodible Land (HEL) layer	Yes
MPI erosion susceptibility layer	Yes
Waikato-Auckland-Northland Sediment Yield model (WANSY1, WANSY2)	No
New Zealand Sediment Yield Estimator (NZSYE)	No
SedNetNZ	Some
Catchment Land Use for Environmental Sustainability (CLUES)	Yes
Soil and Water Assessment Tool (SWAT)	Some
Freshwater Management Tool (FWMT)	No response given in survey
Simplified Contaminant Allocation and Modelling Platform (SCAMP)	No
Melton Ratio used to produce regional debris flow susceptibility layer	No
Landslide Susceptibility model with connectivity	No
Rainfall Induced Landslide Model	No response
Radiometric derived erosion vulnerability model	Some

7.6 Is the intended use of model/output appropriate?

7.6.i Have tangata whenua been engaged on model approach or application?

In all cases, tangata whenua were not consulted in the development of the models or tools surveyed in this report. However, in model choice and application of either a model or its outputs, what is critical for robustness is how well tangata whenua are embedded in, and comfortable with, the policy and planning processes run by Councils.

7.6 ii What stage of the planning cycle is the model suited for?

Some models are more appropriately used at different stages of the planning cycle. Respondents indicated that many of their models or outputs could be used at all stages of the planning cycle, though some indicated that they were better suited to the start. As plan development is generally iterative, with information flowing into the policy and planning process over time, there was little to differentiate models for specific parts of the planning cycle. Table 8 shows modellers' suggestions for how their model and its outputs could be used within the planning cycle.

Table 8. Modeller assessment of appropriate planning stages for models and modelling outputs.

Model/tool/layer	Stage of planning cycle (start, mid, end, all)
(Revised) Universal Soil Loss Equation (USLE/RUSLE)	All
"Donovan" RUSLE model	All
New Zealand Empirical Erosion Model (NZEEM)	Start
Highly Erodible Land (HEL) layer	Start, mid
MPI erosion susceptibility layer	Start
Waikato-Auckland-Northland Sediment Yield model (WANSY1, WANSY2)	All
New Zealand Sediment Yield Estimator (NZSYE)	End
SedNetNZ	All
Catchment Land Use for Environmental Sustainability (CLUES)	Start, mid
Soil and Water Assessment Tool (SWAT)	All
Freshwater Management Tool (FWMT)	All
Simplified Contaminant Allocation and Modelling Platform (SCAMP)	All
Melton Ratio	All (but start better)
Landslide Susceptibility model with connectivity	All
Rainfall Induced Landslide Model	No response
Radiometric derived erosion vulnerability model	All

7.6.iii Does the intended usage on the regulatory spectrum fit with the model capability?

For any model or its output(s), the intended usage needs to fit with model capability. For a model or its outputs to be used to support regulation, it needs to satisfy several criteria (in Principle 3) otherwise it, or the conclusions drawn from its use, risk being challenged. Similar to Section 7.5, we note that where models are intended to be used at the harder end of the regulatory spectrum, the requirements of the extent and formality of this assessment are likely to increase.

Table 9 outlines our assessment for each of the models in terms of their capability to meet such criteria. References to data are New Zealand data for New Zealand situations.

Table 9. Assessment of models against key criteria for use on regulatory spectrum.

Model, tool or layer (abbreviated names only)	Are well established (mature) and have a longstanding history of effective and reliable use in equivalent contexts	Are underpinned by a comprehensive set of data	Are corroborated by the outputs of other models and evidence	Have been validated by investigations that have demonstrated a strong and reliable correlation between model predictions and sampling results.	Are new (immature) and are being used for the first time or are being used in a significantly different context than the one for which they were initially designed	Are attempting to simulate a highly complex system with many unknowns	Suffer from a paucity of data, or the model outputs are likely to change as more data becomes available (for example, as understanding of the system increases)	Have not been sufficiently corroborated by investigations, or they have demonstrated weak relationships between model predictions and sampling results
				Criteria (yes, some, sometimes, no, unknown)				
(USLE/RUSLE)	Yes	Yes	Yes	Yes	No	Sometimes	No	No
"Donovan" RUSLE	Unknown	Some	Some	Unknown	Unknown	Yes	Yes	No
(NZEEM)	Yes	Yes	Some	Yes	No	Sometimes	No	No
(HEL) layer	Yes	Yes	Yes	Yes	No	Sometimes	No	No
MPI erosion susceptibility layer	Yes	Yes	Yes	Yes	No	Sometimes	No	No
WANSY1, WANSY2)	Some	Yes	Yes	Some	No	Sometimes	Unknown	No
(NZSYE)	Yes	Yes	Yes	Yes	No	Sometimes	No	No
SedNetNZ	Yes	Yes	Yes	Yes	No	Sometimes	No	No
(CLUES)	Yes	Yes	Yes	Yes	No	Sometimes	No	No
(SWAT)	Yes	Some	Yes	Yes	No	Sometimes	No	No
(FWMT)	Yes	Yes	Unknown	Yes	Yes	Sometimes	No	No
(SCAMP)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Melton Ratio	Yes	Some	Some	Unknown	No	No	No	Yes
Landslide Susceptibility	Yes	Yes	Some	Yes	Yes	No	No	No
Rainfall Induced Landslide Model	No response							
Radiometric erosion vulnerability model	No	Some	Some	Unknown	Yes	Yes	Unknown	Yes

7.6.iv Is model complexity appropriate for intended usage and is not more complex than needed?

Deciding adequate complexity is a matter of judgement. MfE (2023, p. 25) state:

> When choosing between alternative model types, it is important to recognise that model complexity can significantly affect the certainty of model predictions. Models tend to become more uncertain as they become increasingly simple (that is, if they focus too narrowly on specific attributes or relationships within a system) or as they become increasingly complex (that is, if they aim to closely represent extremely complex inter-relationships between attributes or system components.)

So, ask 'what level of complexity do your modelling needs require?'

- Is the geographic area large and or diverse? (larger and diverse areas increase complexity)
- Are the processes to be modelled complex and varying spatially or temporally?
- Do you require detail on this variability for your use?

If your modelling needs are more complex, you are likely to require more than a simple model.

Once complexity requirements have been considered, data sufficiency must be considered:

> Are there sufficient relevant data available, or sufficient understanding of the processes occurring, to justify a more complex model?

If you are unsure of this, ask the modellers to confirm whether there is adequate data available, or sufficient understanding of the processes occurring for the location/region in question to run their model.

7.6.v Are the model's abilities, limitations and uncertainties transparent and understood?

It is important that what the model can do, its limitations and uncertainties are understood by the users, in this case the Councils, to ensure appropriate application. Table 10 provides a template for considering these questions. In our survey, the modellers assessed all their model[7] documentation (e.g. in client reports, journal papers) as including clear and open description of the assumptions and limitations and were available to users.

Table 10. Questions related to the understanding of abilities, limitations and uncertainties by model users (to be completed by user).

Question	Yes	Maybe	No
Are the model's abilities (e.g. what the model models, the scale, erosion processes, outputs) understood by Council users?			
Are the model's limitations and uncertainties understood by Council users?			

[7] Except the Donovan model.

7.7 Are the skills, processes and systems in place to use the model outputs or models themselves robustly?

It is important that some level of skill/competency in the use of models or their outputs exists within Council to ensure there is alignment between the needs for what the model can provide and what it is to be used for. Table 11 provides a template for considering questions that need to be considered before using a model or its outputs.

Table 11. Questions related to the use of models in-house (to be completed by user).

Question	Yes	Maybe	No
Is the likelihood of updates accounted for (both in terms of science and policy/planning/consents)?			
Is the model and its outputs aligned with decision-making context and skills in your council?			
Can the model be maintained in house? Are adaptations reviewed with respect to original and any deviations from starting point documented			
Is continued external input required?			
If you are using multiple linked models, is Interoperability between linked models managed?			
Are Quality Assurance processes (for data collection/entry) and model acceptance (model performance), and Quality Control processes (e.g. alerts for missing data) specified?			
Is there a process of ongoing model evaluation by users including monitoring against model predictions?			

7.8 Does the model you have selected meet necessary requirements?

Table 12 provides a final list of questions to ask about any sediment and erosion model being considered.

Table 12. Questions to determine if model and its usage is fit for purpose (to be completed by Council user).

Question	Yes	Maybe	No
Are you clear on the question(s) or need(s) you are trying to address?			
Does the model focus on your domain of interest and relevant erosion processes?			
Does the model provide the spatial resolution needed?			
Was model development or adaptation robust?			
Are model governance arrangements robust?			
Is your intended use of model outputs robust?			
Do you have the skills, processes and systems in place to use the model outputs now and in the future?			

If the model fulfils *all* the requirements in Table 12, it is 'fit-for-purpose'. If the model cannot fulfil all the requirements, it might still be useful to partially address your needs but should not be relied upon exclusively. If the model cannot fulfil all the requirements, the earlier parts of the Guidance can still be useful to provide a steer on 'what to do next'. This could include seeking funding for further data collection or support for further work or seeking external assistance.

It is important that the decisions and justifications used to determine fitness-for-purpose choice and use of erosion and sediment models are documented to provide a sound basis for future decisions and potential use of the information derived from models or their outputs, for example in hearings.

8 Key additional insights from surveys

8.1 Key additional insights from survey of Councils

The term 'Model' was interpreted widely ranging from 'true' models to GIS layers and maps, on-line tools, and information/outputs supplied by consultants.

Some Councils use more than one model, and some models are used by more than one council. There is no one model/tool/layer that is universally used by all Councils other than several national mapping layers that are used at the regional level, e.g. the Erosion Susceptibility Classification (ESC) as part of the National Environmental Standards for Commercial Forestry (NES-CF).

Most Councils reported using models/model outputs supplied by others. One of the larger and better-resourced Councils (Auckland Council) developed and applied models in-house.

There were multiple examples of limited knowledge of what models may have been, or are being, used within a Council. This is possibly as a result of lack of either organisational memory or internal communication.

Councils were asked what their primary purpose was for seeking a model or its outputs. Most Councils indicated that sediment/water quality was the main driver for their reason for seeking information largely in response to implementing national policy on freshwater management. Some councils also had additional needs related to natural hazard assessment particularly for rainfall-initiated shallow landsliding.

8.2 Key additional insights from survey of modellers

The guidance incorporates relevant technical information from modellers. However, there are some additional insights arising from the survey information that are relevant.

The modellers' responses and assessments indicated that all models/tools surveyed had clear development pathways and had moderate assumptions and limitations. Few had not been peer reviewed. Where peer review took place, it ranged from internal organisation review to situations where the model had been discussed, modified and presented in peer-reviewed publications. Models/tools/outputs appeared to be conceptually and scientifically sound and generally consistent with current science.

The complexity of the model and the computing/user requirements also varied significantly. In many cases a report with associated GIS layers was the ‘product’ delivered to Councils, often with little further end-user training. In some cases, follow-up ‘training’ sessions or interactions were provided either by the modeller face-to-face or via on-line help.

In terms of transparency, most respondents indicated that their model/tool/output had clear objectives, descriptions and explanations, many of which were backed up by peer-reviewed publications and reports. However, many outputs were targeted to a specific council and ‘problem’ and instructions on use or application were for that ‘client’ and not for general application. In most cases, models and tools were not open source or freely accessible. Some exceptions include SWAT and RUSLE. However, some components (sub-models or ‘engines’) of more complex models, were open source and freely available, though the complete package was not.

Sensitivity and uncertainty analysis and validation was variable across models and tools surveyed. Respondents often indicated that some analysis was done, but this was often undertaken as a part of the development pathway of the model/tool. Such analyses were generally not communicated to end-users. Similarly, model validation tended to be either a ‘selling point’ or provided a level of confidence to the modeller before its delivery to the end user.

Model scale and the scale for its application appeared to be one area where there was significant variation. This potentially leads to inappropriate use of a model output which has been designed for one scale but applied at another often because the end-user is unaware of the limitations of the model/output at this different scale, e.g. a national-scale model output is not appropriate for use at a paddock or sub-catchment scale and vice versa. A further limitation can be the scale of the commonly used input base data sets available in New Zealand. Frequently, a new model will use a data set such as Qmap, NZLRI layers, S-Map etc. These data are all produced at national or regional scales and are often underpinned by legacy data. When combined with more recent data sources such as fine-scale LiDAR digital elevation models, the resulting output can give the appearance of a highly accurate and precise result. Given that modern GIS methods can allow a user to ‘zoom in’ any desired magnification (note not using the word scale here), this can lead to misleading assessments at scales finer than the coarsest base data used to create the new model outputs.

Governance arrangements were also mixed with more than half respondents indicating no formal governance. A couple had processes in place to deal with version control and updating and mechanisms to provide feedback.

There was a general absence of involvement of Māori in the development of the models or outputs. Given that many models (or the basis of them) were developed outside of New Zealand, it is perhaps not surprising. However, there is opportunity for more involvement of Māori in the broader resource management process that a model is being used in.

Similarly, there was little indication of any process in place for deciding whether the model or its outputs were appropriate for the intended application, i.e. feedback/evaluation from the user to the modeller or vice versa. This could potentially lead to some less experienced end-users or modellers misapplying or overstating the outputs.

9 Conclusions

Erosion is a key national issue from an environmental and natural hazard perspective. There are a variety of erosion and sediment models in use in New Zealand. These models are challenging to calibrate and validate due to relatively scarce data and due to the diversity and complexity of New Zealand's erosion and sediment processes.

There are a range of erosion and sediment models and their outputs currently used by Councils. There is no one model to 'rule them all', i.e. no one model that meets all needs expressed by Councils. The strengths, weaknesses and suitability of different erosion and sediment models have not typically been evaluated systematically.

Building on current national guidance, three principles were derived for evaluating fit-for-purpose use of erosion and sediment models based on the model development, model governance and model use. Applying these principles and information about currently used erosion and sediment models, an eight-step guidance process was developed to guide Councils through a process for choosing and using erosion and sediment models based on their fitness-for-purpose.

The Guidance highlights that a clear understanding of the question or the need for erosion-sediment information is crucial before considering using models and/or their outputs particularly to support regulation, and addressing whether modelling can provide the required information. The guidance goes on to outline key questions to identify suitable models focussing on domain of interest, erosion processes and spatial and temporal resolution. Once potentially suitable models have been identified the guidance steps through the robustness of the model development or adaptation, the robustness of the governance arrangements and the robustness of the model's intended use.

For the 15 sediment and erosion models that were assessed (out of 16 used by Councils), all models met the requirements for having a scientifically sound basis for their development and were relatively transparent. For the other elements considered in Principle 1, such as computing infrastructure needed, assumptions, uncertainty analyses and validation, there was variation between models. There was a general absence of involvement of Māori in model development, and governance arrangements for models considered in Principle 2 were mixed.

There was often a mismatch between the Councils and modellers on what model was used and where.

The Guidance can assist each Council to make its own decisions about erosion and sediment models, thus contributing to the PCE (2024) recommendation on guidance to support the use of models. Although a step forward, this guidance does not go so far as to provide the preferred suite of tools as recommended by the PCE (2024, recommendation 4).

10 Recommendations

We recommend the development of a short companion document to this report that concentrates solely on the eight overarching steps and the detailed questions/considerations that lie beneath each one.

We report instances where council staff had poor knowledge of what models had been or were being used within their Councils, and disagreement between what modellers thought were being used and actual practice. While implementation of this guidance may go some way to addressing this, we recommend a centralised repository of information to address issues of institutional memory and the modeller/model user disconnect.

The PCE (2024) recommended "the selection of a preferred suite of models adaptable to local circumstances". Although this guidance will assist each Council to make its own decisions, it does not provide the preferred suite of tools (and this was not part of the project brief). However, we consider that the work presented in this report provides a solid basis for developing a preferred suite of models. The information already captured would allow for the development of a matrix-type approach to identifying preferred models across a range of uses and scales. Given the complexities of multiple physical processes and scales it might be useful to think in terms of a three-dimensional matrix incorporating models, uses, and scale of application. Such an exercise is not without its challenges, not least of which would be resourcing. However, we recommend this be undertaken as the benefits of national consistency are clear.

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Declaration of the use of generative AI/AI-assisted technologies

This research work included the use of Google's search tool and generative AI Gemini to enhance literature searches, obtain additional information on models/tools, or to clarify definition of terms. AI was not used in data analysis or in writing this report.

After using this tool/service, the content was reviewed and edited as needed by the authors.

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Appendix 1 Erosion processes and sediment yield – introduction and recap

Erosion is the first step in the sediment cycle, i.e. without erosion there would be no sediment to be transported or deposited.

Rainfall-induced rapid, shallow landslides are the most common type of mass movement erosion in New Zealand and are the dominant source of sediment in soft-rock hill country, but other mass movements (e.g. earthflows and slumps), gully, surface (sheet, rill, wind) and streambank erosion are locally significant (Basher 2013). From a policy/catchment management or hazard management perspective, some erosion processes are more relevant than others, as is the temporal scale over which they might operate. Additionally, there are considerable differences both between and within regions in terms of which erosion process(es) dominate the sediment budget.

Before seeking to apply or use erosion, sediment or natural hazard models it is important to understand the different erosion processes that are likely to occur in the region of concern and their magnitude and frequency. An overview of the main erosion processes in New Zealand is given by Basher (2013), some of which is repeated below.

Surface erosion

Surface erosion includes splash, sheet and rill erosion and is often associated with 'runoff', i.e. dirty water during or following rain. Splash erosion represents the first stage in the erosion process as a result of raindrop impact. Sheet erosion, which is the uniform removal of topsoil by moving surface water, is widely distributed and typically occurs on bare ground, such as cultivated slopes, forestry cutovers, unsealed roads and tracks, stock tracks, and earthworks associated with urban development, farming, forestry or other land uses. It also occurs on erosion features such as on landslide scars and tails and gullies (Figure A1.1.) It is often considered a precursor to more severe rill and gully erosion. When sheet erosion becomes concentrated it forms rills (rill erosion), which in extreme cases enlarge to form gullies. In addition to the presence of bare ground, factors that influence surface erosion include slope angle and length, aspect, soil texture, compaction, and rainfall, especially rainfall intensity and duration. Many erosion models focus on these processes.

Figure A1.1. Examples of surface erosion including rills. (Left) in loess on the Port Hills, Christchurch, and (Right) under market gardening at Pukekohe. Sheet erosion occurs in the inter-rill areas.

Mass movement erosion including landslides

Because of the dominance of hilly and mountainous terrain in New Zealand, the most widespread type of erosion is mass movement (landslides, earthflows, slumps), especially rainfall-triggered shallow landslides (Figure A1.2.)

'Landslide' is an umbrella term, and a wide variety of landslide types occur in New Zealand ranging from small, shallow, rapid failures, to large, deep, creeping rock failures. The most common types are shallow, rapid slides and flows involving soil and regolith,[8] which occur during rainstorms (Glade 1998; Crozier 2005). They are typically characterised by small scars and long, narrow debris tails, where much of the landslide debris is redeposited downslope. This type of landslide can be triggered by smaller rainfall events after prolonged wet periods that result in high antecedent soil moisture conditions, or by individual storm cells with high intensity.

Varying classifications of landslides are associated with the specific mechanics of slope failure and the properties and characteristics of failure types (Hungr et al. 2014). The term 'landslide' encompasses five modes of slope movement: falls, topples, slides, spreads and flows. These are further subdivided by the type of the geological material (bedrock, debris, or earth). Landslides may also form a complex failure encompassing more than one type of movement (e.g. debris slide and debris flow; See Figure A1.2., Right panel).

Slumps, earthflows, and large-scale failures in regolith and bedrock are typically deeper failures and are also common in the New Zealand landscape but tend to have a restricted distribution. However, they may be locally important.

Landslides are usually initiated by rainfall and/or wet ground conditions, but seismic activity can also trigger landslides. For a landslide to occur a threshold must be exceeded which is why rainfall thresholds are the tools most used to forecast the possible occurrence of a landslide in a given area (Guzetti et al. 2008). A threshold represents the lower bound of known hydrological conditions (e.g. rainfall, infiltration, soil moisture) that resulted in landslides (Reichenbach et al. 1998). This is relevant for landslide hazard and risk assessment and for landslide forecasting. In New Zealand there have been several attempts to define rainfall thresholds using different methods (Rosser et al. 2021; Smith et al. 2023). Establishing a simple threshold for when landslides will happen is complex, but daily rainfalls greater than 120–150 mm are likely to cause landslides – although this is likely to be regionally variable.

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8 Regolith is the layer between the soil and the bedrock. It is generally unconsolidated rock or weathered rock and lies like a blanket over unfragmented bedrock.

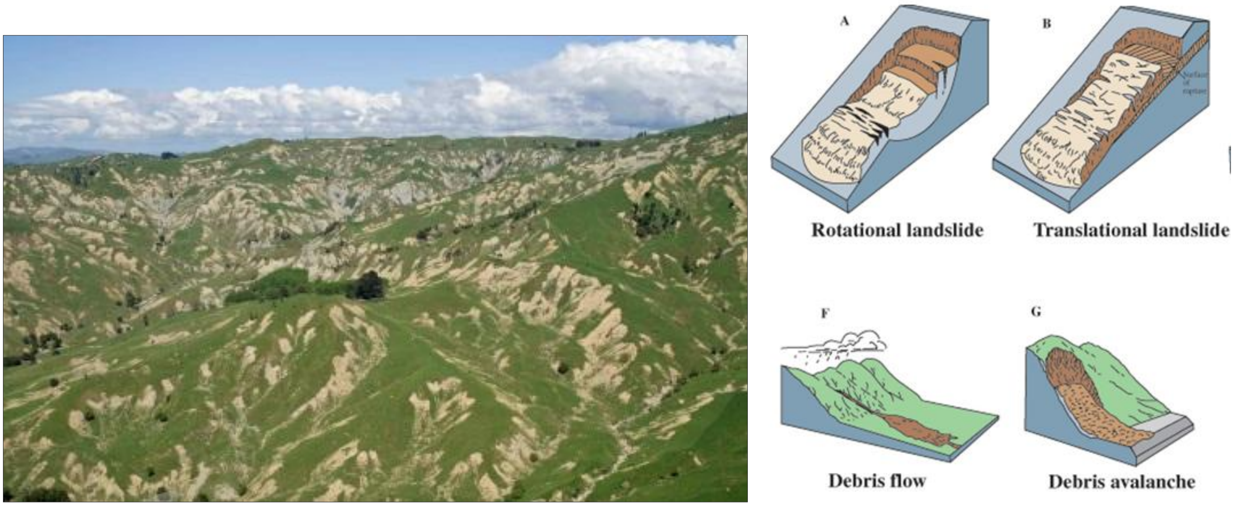

Figure A1.2. Examples of landslides. (Left) rainfall-induced shallow landslides in the Hawke's Bay region (Photo: Peter Scott). (Right) examples of different types of mass movements (Varnes 1978). (A) rotational landslide, (B) translational landslide, (F) debris flow, and (G) debris avalanche.

Earthflow erosion

Earthflows are slow mass movements characterised by internal deformation that move soil and regolith along basal and lateral shear planes. Earthflows range from shallow (<1–2 m) to deep-seated (>10 m, and typically 3–5 m). Deep-seated earthflows typically occur on slopes between 10° and 20° and can cover large areas of a hillslope (See Figure A1.3), while shallow earthflows are more common on slopes >20° and are smaller in area. Earthflow erosion occurs mostly in the North Island and is most extensive on crushed mudstone and argillite in the Gisborne–East Coast area, Manawatū, Wairarapa, and southern Hawke's Bay.

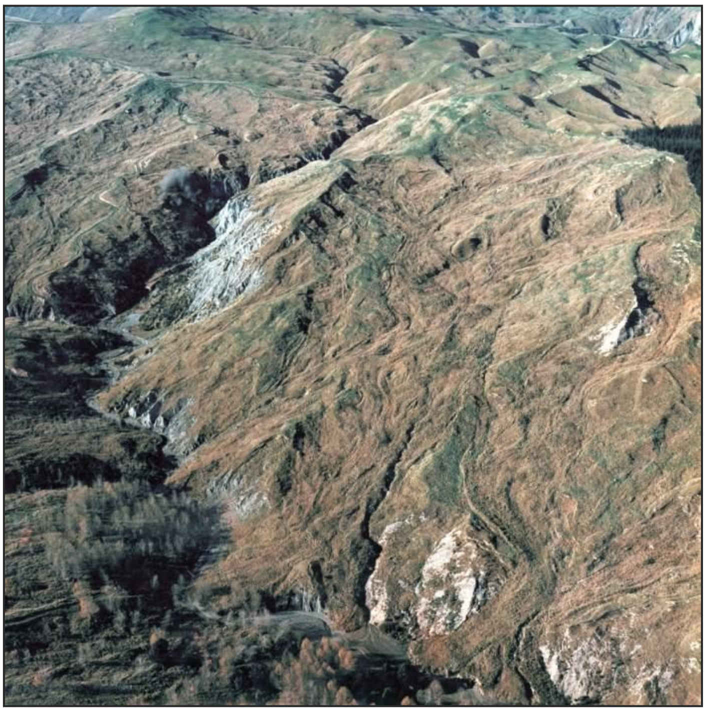

Figure A1.3. An example of earthflow erosion, Mangatu Forest near Gisborne. (Photo: Jonathan Barran).

Gully erosion

Gully erosion has two main forms in New Zealand: linear features cut by channelised run-off, and large, complex, mass-movement–fluvial-erosion features that are typically amphitheatre-shaped (Marden et al. 2012). See Figure A1.4. It is most common in the soft-rock hill country of the East Coast of the North Island, on crushed argillite and mudstone, and in the North and South Island mountainlands. It also occurs in Northland and the central Volcanic Plateau (Eyles 1983).

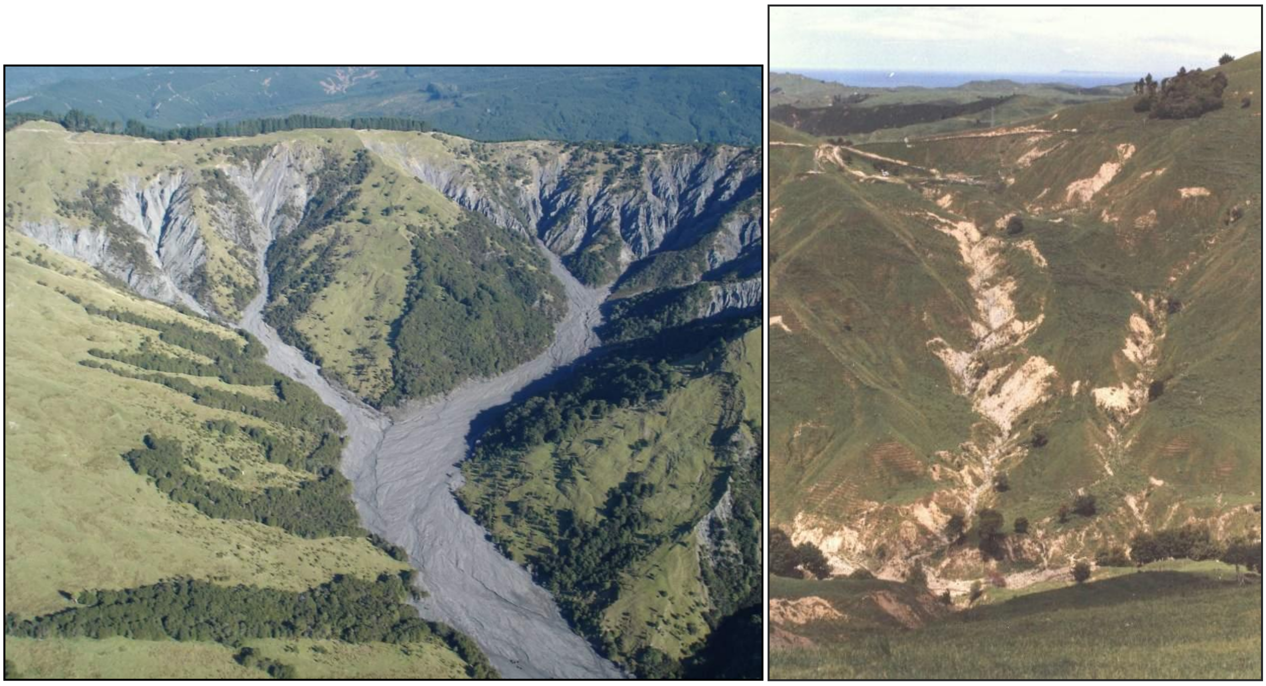

Figure A1.4. Examples of gully erosion from the Gisborne region. (Left) large amphitheatre-shaped gully (Photo: Mike Marden). (Right) linear gully (Photo: unknown).

Streambank erosion

Streambank erosion, and particularly its contribution to sediment budgets, is one of the least understood erosion processes in New Zealand. A wide variety of fluvial and mass movement processes contribute to bank erosion (Watson & Basher 2006) and result in a wide range of styles of bank erosion, ranging from small banks to cliffs. It is commonly seen along rivers and streams throughout New Zealand (Figure A.1.5.) It is increasingly viewed as being a more significant contributor to a catchment's sediment budget than originally thought.

Figure A1.5. Examples of streambank erosion. (Left) mass failure in fine alluvium caused by stream undercutting (Photo: Chris Phillips). (Right) streambank and cliff erosion (Photo: Chris Phillips).

Sediment budget

A sediment budget calculates the balance between the amount of sediment entering a system (like a river, catchment, estuary, or coastline) and the amount leaving. It essentially shows whether the system is experiencing net erosion or deposition over time by comparing sediment inputs and outputs within a defined area. A budget thus consists of sediment sources (areas of erosion) and sinks (areas of deposition) – acting like an accounting system for sediment within the catchment/system boundary.

Sediment budgets can be designed to quantify the magnitude of a process or response rate, its location and its timing, or to explore the influences contributing to a morphological change. They can be used to compare the likely outcomes of different land-management options or climatic changes or to evaluate the significance and implications of climatic, tectonic or land-use changes that have already occurred. Sediment budgets provide a framework for organizing both qualitative information about process interactions and quantitative information about process rates (Reid & Dunne 2016).

Commonly used sediment budgets take the form of qualitative flowcharts that describe relationships between sediment sources and transport processes. Long-term monitoring often provides more precise measurements of budget components. There are many reasons for using sediment budgets, including describing past and present systems, forecasting future conditions, evaluating erosion, and evaluating sediment storage and sediment yield. Sediment budgets now play a key role in basic and applied geomorphological studies over a range of scales and levels of complexity. A catchment sediment budget integrates the sediment system within that catchment. However, there is often significant uncertainty in the measurements or estimates of the components of a quantitative sediment budget, particularly over short time scales. Qualitative and semi-quantitative budgets may be useful for providing general guidance on catchment behaviour.

Many erosion models use sediment budgets to determine which catchments are providing the most sediment which then helps with prioritising management aimed at reducing it. A watershed or catchment sediment budget is one that identifies the magnitude of sediment sources and sinks in a watershed relative to watershed output (Reid & Trustrum 2002).

A sediment budget needs to represent *all* erosion and depositional processes, and it is determined for a time period of interest, e.g. annually or historically (over a long period of time) (Figure A1.6.) Estimates made of different processes use different methods for measurement and have different assumptions.

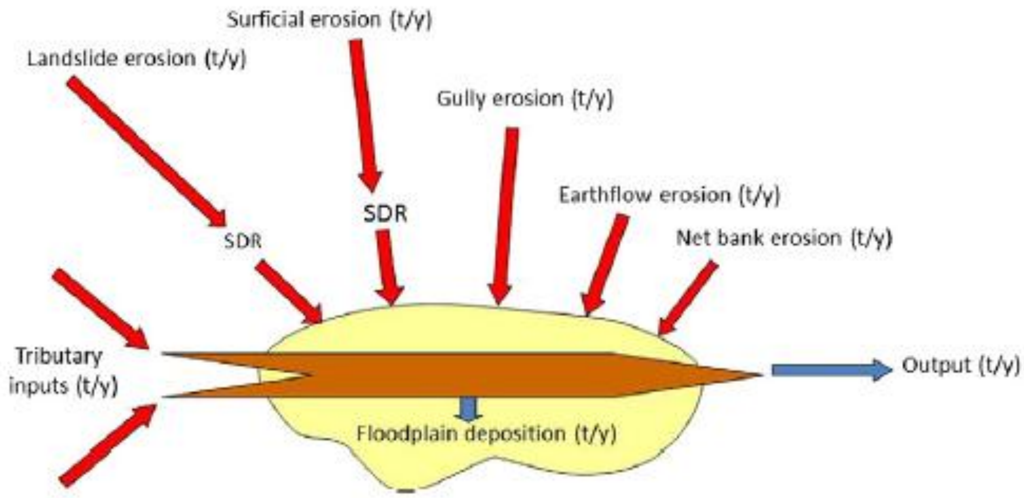

Figure A1.6. Conceptual example of a sediment budget showing different processes. (t – tonnes, y – year, SDR – sediment delivery ratio. Based on Figure 1 from Betts et al. (2017).

Sediment yield

'Sediment yield' is the rate of sediment output from a catchment. Because sediment yields vary with catchment size, comparisons between catchments are usually based on yields per unit catchment area, also referred to as specific sediment yield, e.g. in tonnes (t) per square kilometre (i.e. as t km^{-2}) and are often annualised (i.e. expressed as t km^{-2} y^{-1}).

The concept of 'sediment delivery ratio' (SDR) can be applied to a catchment or a specific erosion process. The SDR is defined as the proportion of sediment eroded that is exported from its source or from the catchment, because not all eroded soil becomes part of the sediment yield as some of it remains close to where it was generated (i.e. on the slope). A typical SDR for shallow rainfall-initiated landslides on New Zealand hill country is 0.5.

Appendix 2 – Survey questions for Councils

The following questions were circulated to Council staff:

If your Council has used (or is thinking of using) a model for erosion or sediment work, can you please let us know:

- The name of the model.
- The researcher/entity that developed it.
- The problem you were trying to solve.
- Are there any models you are interested in using that you want us to include?

Appendix 3 – Survey questions for model developers, scientists and consultants

Model Background

- What is the model's name?
- What is the model's intended purpose and use?
- What are the model's outputs? E.g. GIS layers, summary data, maps, summary information such as traffic lights, etc
- What geographic location(s) /biogeographic setting has the model been developed to be used in? Can it be used elsewhere? Please detail this briefly.
- Are there geographical limitations to the model's application? Can these be overcome with additional data?
- What scales does the model operate at- farm scale, sub-catchment, catchment, FMU, Regional or National?
- Is the model intended to fit within a specific stage of a planning cycle?
- What do you consider to be the base data required to run the model?
- What do you consider to be the necessary knowledge to use the model and its outputs?
- Are Quality Assurance and Quality Control processes in place and documented (for data collection/entry) and model acceptance (model performance), and processes (e.g. alerts for missing data) specified?
- Does the model need to talk with other models? Is Interoperability between linked models managed (e.g.by sharing a common architecture or aligning model and data assumptions of linked model and evaluating individual components and linked model)?
- How likely are model updates? Frequency?
- Is there capacity for continuous improvement in model application? Please detail this briefly.
- How is feedback from user model evaluation and comparison between modelled and actual results incorporated into the model structure?

Principle 1: Model development/adaptation is robust

Scientific basis- Description of the scientific concept(s) on which this model is based

- Is the scientific concept sound and consistent with current science? Please give brief details
- Is the algorithm(s) appropriate?
- Was it built on a te tiriti foundation?
- Has mātauranga Māori been included in the model?
- Have other concepts, i.e. alternative approaches, or other models, been explored?
- Is the model structure scientifically sound:
    - Does it compute the variables needed, or proxies thereof?
    - Are there any model dependencies?
    - Is every sub-component using the same data source?

- Has it included relevant perspectives in its development or adaption (e.g. end users, other technical experts and knowledge holders, regulatory decision-makers, mana whenua)? Has the process for doing that been documented?

Transparency

- Is there is a problem definition that the model is trying to tackle and are the matter or matters the model is intended to address are specified? Please give details.
- Are the Objectives specified and the context within which the model is intended to operate defined? Please give details.
- Is the model open source?
- Is the model open access?
- Is model use for research free?
- Is commercial model use free?
- Is the model currently maintained?
- Is there a good description and explanation of the model? For example, does the model have clear user instructions and a detailed description of how it operates? Please provide links or attachments if relevant
- Have the model results been made publicly accessible?
- Can the model results be linked back to the source model equations?
- Have the model and the model results been communicated appropriately with all stakeholders in the development process?

Computational infrastructure and maintenance

- Is the computational infrastructure such that a model can be applied flexibly? For example, does the model require high performance computing systems to run? If so, what is the availability of that high performance computing system?
- How much expertise is required to run the model? (Rated from simple (1) to complicated (3).)
- Is the model software, including its versioning methods, up to date?
- Can the model be easily run again with new data – i.e. how updateable is the model?
- How interoperable is the model – i.e. can the model be joined with other models, and is there evidence of that being done in the past?
- Are there any processes in place for quality control? For example, is there a regular assessment of data quality? Are alerts generated when data are missing, or results are out of bounds? Are there other issues with comparison or correlation with observed or other known data?

Assumptions and limitations

- What are the assumptions in the model that affect model performance?
- What are model limitations (such as statements where it cannot be applied)?
- Are these assumptions and limitations explained clearly and openly?

Peer review

- Has the model itself undergone a review by at least two reviewers who are experts in that field of modelling?

- Has the model description and application been published in a peer reviewed journal?

Sensitivity and uncertainty analysis

- Have uncertainty analyses been conducted? E.g. on model framework uncertainty, input uncertainty, niche uncertainty. (See notes below for definition)
- What is the technical capability of the model to generate an estimate of uncertainty and/or an estimate of probabilities?
- Has a sensitivity analysis been conducted? E.g. to ascertain what is the influence of each model input on model outputs and which model input is making the model change most?
- Are uncertainty and sensitivity analysis communicated when deploying the model (e.g. in client report)?

Validation

- Are model results validated against an independent set of observations (i.e. not the observations that the model was developed with/calibrated against)?
- When deploying the model are the size of dataset available for use of the model and for validation of the model adequate?
- What are the results of studies where the model has been compared or benchmarked to other models? This could include descriptions of model incongruence, if any.

Temporal and spatial scale and resolution

- Is there a description of the spatial and temporal resolution of the model? It should include a description of whether a model is technically limited to steady-state results, or capable of generating dynamic outputs.

Principle 2: Model governance is appropriate

- Is there a governance structure or process in place for model development and use keeping it outcome-oriented?
- Is there a process for deciding appropriateness of model applications?
- Are there stable financial arrangements for any improvements or updates to model?
- Is single point dependency managed or avoided?

Notes

- Model framework uncertainty - Uncertainty that results from incomplete knowledge about factors that control the behaviour of the system being modelled, limitations in spatial or temporal resolution, and simplifications of the system.
- Input uncertainty - Uncertainty that results from data-gathering or measurement errors (including bounds of uncertainty in laboratory results due to the accuracy/sensitivity of equipment), gaps in data, inconsistencies between measured values and those used by the model (for example, in their level of aggregation/averaging), and parameter value uncertainty.
- Niche uncertainty - Uncertainty that results from the use of a model outside the system for which it was originally developed, and/or from developing a larger model from several existing models with different spatial or temporal scales.

Appendix 4 – Models/tools/layers assessed

Additional details of some models listed below can be found in the PCE (2024) report, some details of which are repeated below.

Model/tool/layer	What it does	Used by
USLE/RUSLE	The Revised Universal Soil Loss Equation (RUSLE) and its predecessor, the Universal Soil Loss Equation (USLE), predict mean annual soil loss from surface erosion based on a set of equations derived from empirical measurements of soil losses from agricultural plots.	GWRC, HRC
"Donovan" RUSLE model	National-scale assessment of soil loss from surface erosion	BOPRC
NZEEM	The New Zealand Empirical Erosion Model (NZEEM) is one of the erosion models for evaluating regional land-use scenarios. The model can be used to predict mean annual sediment discharge in response to landcover/land-use scenarios in a GIS	GWRC, WRC, HRC, AC, GDC
HEL layer - Highly Erodible Land	Identifies land at risk of severe mass-movement soil erosion (landslide, earthflow, or gully erosion) if it lacks protective woody vegetation	MfE, HRC, StatsNZ, WRC
MPI/ NESCF erosion susceptibility layer (not a model)	The Erosion Susceptibility Classification (ESC) is used to identify the erosion risk of land as a basis for determining where a plantation forestry activity: • is permitted, subject to certain conditions being met, or • requires resource consent because it's on higher-risk land.	All councils as a national standard
WANSY1, WANSY2 (superseded by NZSYE)	Waikato-Auckland-Northland Sediment Yield model, is a regional empirical model used to estimate sediment loads, particularly in rural catchments. Forerunner to NZSYE.	NRC, WRC, AC
New Zealand Sediment Yield Estimator (NZSYE)	The New Zealand Sediment Yield Estimator (NZSYE) is a statistical model that has been calibrated nationally against measured sediment loads determined for water quality sites across New Zealand. It's a GIS-based tool.	NRC, AC
SedNetNZ	This sediment erosion model predicts the generation and transport of sediment through river networks based on a simple representation of soil, hillslope and channel processes, providing estimates of sediment yield and load generated by erosion processes (landslides, gullies, earthflows, surface, and bank erosion) and sediment deposition in lakes and on floodplains.	BOPRC, ES, GWRC, HBRC, HRC, NRC, ORC, TRC, WRC, AC
Catchment LandUse for Environmental Sustainability (CLUES)	The Catchment Land Use and Environmental Sustainability (CLUES) model is a self-labelled 'super model' that combines multiple catchment-scale models (Overseer, SPASMO, SPARROW) in a simplified form to evaluate current loads and perform rapid scenario testing for nutrients, Escherichia coli (E. coli) and sediment.	ES is the only regional council using ES is the only regional council using CLUES for sediment modelling. (BOPRC, ECAN, GWRC, HRC, NRC, ORC, TRC and WRC, AC use it for other environmental domains but not for sediment modelling)

Model/tool/layer	What it does	Used by
Soil and Water Assessment Tool (SWAT)	The Soil & Water Assessment Tool (SWAT) covers a range of simulations in quantity and quality of surface water and groundwater at a range of scales (e.g. small watershed to river basin scale). It predicts the environmental impact of land use, land management practices and climate change, and assesses soil erosion (runoff-generated processes such as surface erosion and bank erosion) prevention and control, non-point source pollution control and regional management in watersheds.	GWRC, HBRC, MDC, ORC and WRC use it for other environmental domains but not for sediment modelling
Freshwater Management Tool (FWMT) embeds LSPC (Loading Simulation Program in C++)	Uses US EPA watershed modelling system Loading Simulation Program in C++ (LSPC) which simulates hydrology, sediment and general water quality on land, and contains a simplified stream transport model.	AC, NRC
Simplified Contaminant Allocation and Modelling Platform (SCAMP)	The Simplified Contaminant Allocation Model Platform (SCAMP) is a spreadsheet-based method to assess effects of land use and contaminant (diffuse and point) discharge on water quality. It assesses loads at various points and is simplified in that councils can simulate scenarios in a reasonably short time. It was previously known as the Contaminant Allocation & Simulation Model (CASM)	NRC, HRC, TRC, ES, WRC
Melton Ratio used to produce regional debris flow susceptibility layer	The Melton ratio is a dimensionless number used in geomorphology to assess the susceptibility of a watershed to debris flows and debris floods. It is calculated by dividing the basin relief (the difference between the maximum and minimum elevations) by the square root of the basin area. Higher Melton ratios generally indicate steeper, more erosive terrain, which is more prone to debris flows. Used to show debris flow and debris flood susceptibility, but not hazard.	MDC, TDC
Landslide Susceptibility incorporates connectivity	Morphometric landslide-to-stream connectivity layers derived from statistical rainfall-initiated shallow landslide model. Classes (high/moderate/low) for both the susceptibility and connectivity layers are defined based on the percentage of mapped landslides or stream-connected landslides within each class.	GDC, HBRC, MDC
Rainfall Induced Landslide Model	Incorporated into future landslide early warning systems	GDC, MDC
Radiometric derived erosion vulnerability model	A set of statistical methods and spatial data to infer factors controlling landscape susceptibility to loss of contaminants. Utilises physiographics combined with other GIS based tools to produce different output layers.	ES, NRC, NCC, MDC

Abbreviations for councils: AC = Auckland Council , BOPRC = Bay of Plenty Regional Council , ECAN = Environment Canterbury, ES = Environment Southland, GDC = Gisborne District Council, GWRC = Greater Wellington Regional Council , HBRC = Hawke's Bay Regional Council, HRC = Horizons Regional Council, MDC = Marlborough District Council , NCC = Nelson City Council (does not use models), NRC = Northland Regional Council, ORC = Otago Regional Council, TDC = Tasman District Council, TRC = Taranaki Regional Council, WCRC = West Coast Regional Council , WRC = Waikato Regional Council