National river digital networks and the River Environment Classification:

future pathways for stewardship, maintenance, and upgrading of products and services for national benefit

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Executive summary

Digital Networks (DN) comprise representations of surface flow pathways (segments), areas contributing to each surface flow pathway (watersheds), and connections between surface flow pathways (routing). DNs are an important input for a variety of freshwater research, management, and policy development purposes. Applications of DNs largely fall into two broad categories.

A. Biophysical modelling purposes such as hydrological or water quality modelling that simulate fate and flux of substances within watersheds and between segments. Depending on the particular application and the data available for model parameterisation, biophysical modelling can benefit from detailed spatial representation of surface flow pathways both inside and outside of river channels. Detailed representation of surface flow pathways is particularly beneficial for flood modelling.

B. River management and policy development purposes such as landscape-scale river classification that require information on river channels and their interconnections but do not require information on surface flow pathways outside of river channels. Landscape-scale representation of river channels and their catchments is particularly beneficial for regional- and national-scale conservation planning.

It is recognised that biophysical modelling often feeds into river management purposes.

A DN is typically generated by applying automated mathematical methods to a Digital Elevation Model (DEM) which is itself generated by post-processing point observations of topography. Accuracy of positioning and level of spatial detail of surface flow pathways represented within a DN is influenced by: the resolution and accuracy of the raw topography data; the horizontal resolution and mathematical methods used to produce the DEM from the raw topography data; the mathematical methods and user choices for parameterisations used to derive the DN from the DEM; and manual manipulations to segment alignment and routing following automatic generation of the DN.

Several versions (and sub-versions) of a national DN have been developed and released by NIWA over the past two decades. Differences between national DN versions have occurred due to a combination of differing user needs, and changes in available technical methods and input data. For example, DEMs derived from Light Detection and Ranging (LiDAR) which represent fine-scale topographic patterns were used as input to the most recent DN version. However, LiDAR-derived DEMs are not available across all NZ, resulting in potential inconsistencies in DN generation. Despite not providing a perfect representation of the ground surface LiDAR-derived DEMs can provide advantages for generating detailed surface flow pathways, but identifying which pathways represent river channels is challenging.

All DN versions developed in NZ have been used for both river management and biophysical modelling purposes. The most recent national DN version was developed with an emphasis on hydrological routing for biophysical modelling purposes, partly because it was created in conjunction with the New Zealand Water Model (NZWaM), which is used for water quantity and quality modelling. The first national DN version was developed with an emphasis on river classification for river management and policy development purposes because it was created in conjunction with the River Environment Classification (REC) to aid river management.

The REC is a deductively defined hierarchical classification system that classifies river segments based on climate, topography, geology, and land cover factors that control spatial patterns in river hydrology, geomorphology, and ecosystems. Maps of REC classes have been used for many river management and policy development purposes, including: delineation of Freshwater Management Units (FMUs); models of various ecological-chemical-physical states; and spatially varying targets of the National Objectives Framework (NOF) within the National Policy Statement for Freshwater Management (NPS-FM). A DN is needed to assign segments to classes and then display maps of classes.

This report describes how input data, technical algorithms, and methodological decisions influence DN and REC outputs. Maintenance and upgrading of national DNs and mapping of REC classes are currently supported with NIWA-SSIF funding on an annual basis. The ad hoc funding by which the DN and REC are currently supported does not systematically consider user needs across purposes and agencies. Ad hoc funding arrangements make synchronising development of DNs with collection of LiDAR data difficult. The current approach for updating the DN and REC generation is therefore not meeting the needs of all potential users.

This report then outlines a future vision for stewardship, maintenance, and upgrading of DNs and REC to support policy development, river management, and biophysical modelling from a national perspective. A framework is proposed to operationalise ongoing development and support of national DNs, river classifications, and their dependent products. The proposed framework includes the following components.

- Project steering to provide oversight on overall aims, intermediate objectives, and timing delivery.
- Project management to prioritise tasks, distribute resources to complete tasks, and report on delivery.
- Technical work to advance tasks and deliver outputs and services.
- Trial users to test outputs and services.
- Communication pathways to receive user feedback, and to ensure users are aware of outputs and services.

The proposed framework could also facilitate and co-ordinate future technical tasks that would probably fall into two categories:

- Operational tasks where methods are known but not implemented.
  - Workflow to produce DN using DEM as input.
  - Tool for users to submit recommended changes to DN alignment or routing.
  - Procedure to ingest, assess, verify, and apply recommended changes.
  - Procedure to calculate REC classes on any DN and using any input environmental data.
  - Tool for users to apply routing (e.g., downstream accumulation to calculate conditions in the area upstream of each segment).

- Research tasks where methods are currently unknown or untested.
  - Procedure to identify river channels from remotely sensed images.
  - Procedure to classify flow pathways as being inside or outside of river channels.

If enacted, the proposed framework will:

- produce DNs that are consistent with each other and fit for purposes ranging from local-scale flood modelling to national-scale river classification by producing parent DNs comprising highly detailed surface flow pathways and child DNs comprising only surface flow pathways that are classified as river channels;
- encourage consistency in use of DNs across applications by ensuring that segment alignment and identifiers are comparable between parent and child DNs;
- react to improvements in data availability and methodological advancements by developing an automated procedure to produce DNs and DN-derived outputs following updates to inputs;
- produce DNs in a replicable and transparent way by applying best practices for version control;
- reduce unnecessary duplication of effort and confusion at the national level by allowing various agencies to provide input about their needs for DNs and river classifications; and
- react to user needs by ingesting and prioritising requests for amendments to segment alignment or network routing.

Achieving these objectives and maintaining fit-for-purpose DN tools will require: a custodian organisation, input from various organisations, adequate funding, access to computing facilities, and a commitment to periodically update biophysical input data. There are several challenges to operationalisation of the proposed framework, but none are insurmountable. Input from DN users across agencies can be supported through formation of a dedicated steering group or via existing groups (e.g., Environmental Monitoring and Reporting group, Surface Water Integrated Management groups). Intellectual property issues can be resolved during project initiation. On-going funding must be obtained from central government or elsewhere but pathways for funding are currently unclear.

1 Introduction

1.1 Brief and deliverables requested by MfE

The Ministry for the Environment (MfE) have requested NIWA to prepare a prioritised list of improvements needed to enhance the utility of digital river networks and river classifications for policy development, environmental management, and national environmental reporting purposes. The components of digital river networks and river classifications of interest to MfE are as follows.

1. Input data used to make river networks and classifications.
2. Digital river networks, especially those with national coverage.
3. River classifications that are mapped onto river networks, especially those used for regulatory purposes.
4. Products that are derived from any combination of components 1 to 3 (e.g., predictions of river flows or water quality conditions across river networks), especially those used for environmental reporting purposes.

These components are not independent. Component 2 is dependent on Component 1. Component 3 is dependent on components 1 and 2. Component 4 is dependent on components 1 and 2, and sometimes 3. Improvements to components 1, 2, or 3 have the potential to improve all dependent components.

MfE have requested that NIWA propose a framework for the ongoing stewardship and upgrading of the DNs and river classifications, particularly the REC, from a national perspective. A description of processes that could be applied within the proposed framework to formally link components of interest is required by MfE. The proposed framework should include the possibility for undertaking strategic planning, and identifying and prioritising options for technical work, carried out in collaboration between the MfE, regional council staff, NIWA, and others.

1.2 Aim and objectives

The overall aim of this report is to outline a framework that produces the following outcomes.

1. A consistent, responsive national strategy that provides national direction for developing digital networks and river classifications that meet most requirements, and allows incorporation of regional/local knowledge.
2. Receive, collate, and prioritise suggestions from a variety of potential users about purposes that a national DN can support, and whether a single national DN can fit all purposes or DN variants are needed to fulfil for specific purposes.
3. Reduce unnecessary duplication of effort and confusion at the national level because DNs are being independently created or a national DN is being independently adapted at the catchment or regional levels.
4. Support ongoing maintenance and upgrading of a national DN in light of differing user needs, improvements in data availability, and methodological advancements.

5. Encourage consistency between agencies with respect to use of DNs for national environmental reporting, freshwater management, and freshwater policy development.

1.3 Structure of this report

The next two main sections of this report provide background information that is relevant when considering a framework for maintaining and upgrading DNs and the REC. Descriptions of current uses and user needs of the DNs and the REC are provided in each section.

Section 4.1 outlines the status quo for the national DN and the REC. Agencies that should be involved in maintenance and upgrading of the national DN and the REC are then recommended. A future vision for stewardship, maintenance, and upgrading of the national DN and REC to support policy development, river management, and biophysical modelling is outlined. A framework is proposed to operationalise ongoing development and support of the national DN, REC, and derived products.

Some definitions of technical terms and acronyms used in this report are provided in Table 6-1.

1.4 Collation of user feedback and needs

This report was informed by the result of a questionnaire and a workshop about the national DN and REC conducted as part of this project. The questionnaire and workshop were used to canvass views of staff from regional councils, the Department of Conservation, and MfE. See separate appendix describing responses to the questionnaire.

2 Digital Network (DN)

2.1 What is a DN?

A DN is a spatial framework contained within a Geographic Information System (GIS) that represents the spatial configuration of surface flow pathways. A DN typically comprises segments, watersheds, and routing information (Figure 2-1). Segments represent surface flow pathways. Each segment represents the length of a flow pathway between either a confluence (where two segments meet) or a headwater (the upstream end of a segment where a surface flow pathway begins e.g., s1 in Figure 2-1). Watersheds represent surface areas draining to each segment. Routing information represents connections between segments. Routing information can be used to find which segments are upstream or downstream of any segment of interest. Routing within a DN is used to determine properties of segments along flow pathways (e.g., catchment area, distance to coast, proportion of upstream area covered by heavy pasture). Routing within a DN is also used when modelling fluxes and fates of materials within and between both watersheds and segments (e.g., catchment modelling of water quantity, water quality, fish passage, sediment transport etc).

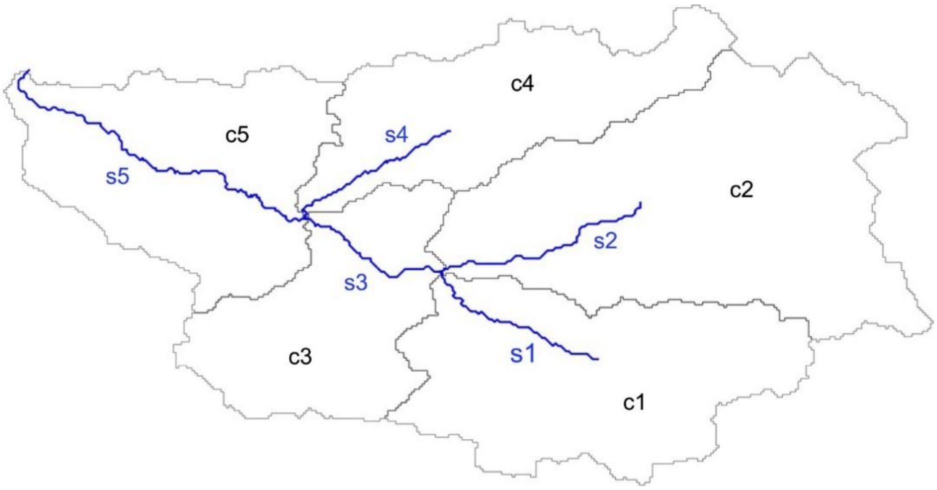

Figure 2-1: Illustration of a vectorized DN. Blue lines are surface flow pathways. Dark grey polygons are watersheds of segment. Light grey polygon is the entire catchment. Downstream routing in this figure is from right to left. Segment s5 is a terminal segment. Segments s1, s2, and s4 are headwater segments. Source; Mizukami et al., (2016).

An important stipulation is required for DN routing to be functional; each segment must route downstream either to only one other segment, or to no segments (e.g., because the segment flows into the sea). The stipulation means that all routing within a standard DN is deterministic because downstream routing from each segment can only take one route. Because material can only take one route downstream, the stipulation is very useful for modelling of water quantity, water quality, fish passage, sediment transport, etc. The stipulation means that a standard DN can contain confluences (where the downstream ends of two segments meet to flow downstream into a single other segment). The stipulation can be used to realistically represent routing for the vast majority of natural situations where there is one route downstream from each location in a catchment to the sea. However, the stipulation also means that DNs have some limitations. The following phenomena cannot be explicitly represented within a standard DN because transport within each segment can only be in one direction and bifurcations (where flow from an upstream segment is received by two downstream segments) cannot be represented.

- Multiple channels within a braided river.
- Bifurcations such as when a river flows around an island or into a delta or estuary.
- Flow pathways that can flow in one direction at some times and the other direction at other times.
- Canals flowing between rivers.
- Ditches or raceways that flow away from a river segment.
- Ditches or raceways that flow in a ring.
- Diversions that take flow from one segment and discharge flow into another segment.
- Transient changes to routing cannot be represented such as might occur naturally amongst wetland channels, or artificially when a sluice gate or dam weir is operated.

Many of the above listed phenomena can be represented by augmenting the routing of a standard DN with bespoke amendments when applying a particular modelling application. Incorporating these non-standard routing phenomena into applications that derive from a DN (e.g., simulations of river flow of water quality state) requires bespoke inputs (e.g., input time-series data or a mathematical method for representing under what conditions different routing behaviour occurs).

DN segments, watersheds, and routing are typically stored in an ARC-GIS (ESRI) or similar geodatabase, and associated Postgres database. DN segments, watersheds, and routing can also be converted to many other formats (e.g., R spatial data frame objects). These data files typically also include information about the coordinate system and DN version being used. DN routing information can be stored in different formats. Some formats produce smaller file sizes but are not conducive to quick routing calculations, whereas other formats produce larger file sizes but allow quicker routing calculations.

2.2 What input data are used to produce a DN?

The main source of input data to a DN is a Digital Elevation Model (DEM). A DEM is typically a regular grid representing spatial patterns of land elevation. DEMs can be derived using various raw input data (elevation and horizontal position). DEM input elevation data can have varying resolutions and accuracies. For example, manual topography surveys typically produce point observations with coarse spatial resolution and narrow coverage but high positional accuracy. In contrast, Light Detection and Ranging (LiDAR) typically produces many point measurements with very fine spatial resolution and broad coverage but some inaccuracies associated with each point observation. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure distances to the earth surface from a sensor. LiDAR data can vary in its characteristics (e.g., point density) depending on environmental conditions, sensor used, height of the sensor, overlaps of swaths, and speed of the sensor during collection. LiDAR data are currently not available for all NZ (Figure 2-2). See LINZ elevation data webpage for more details.

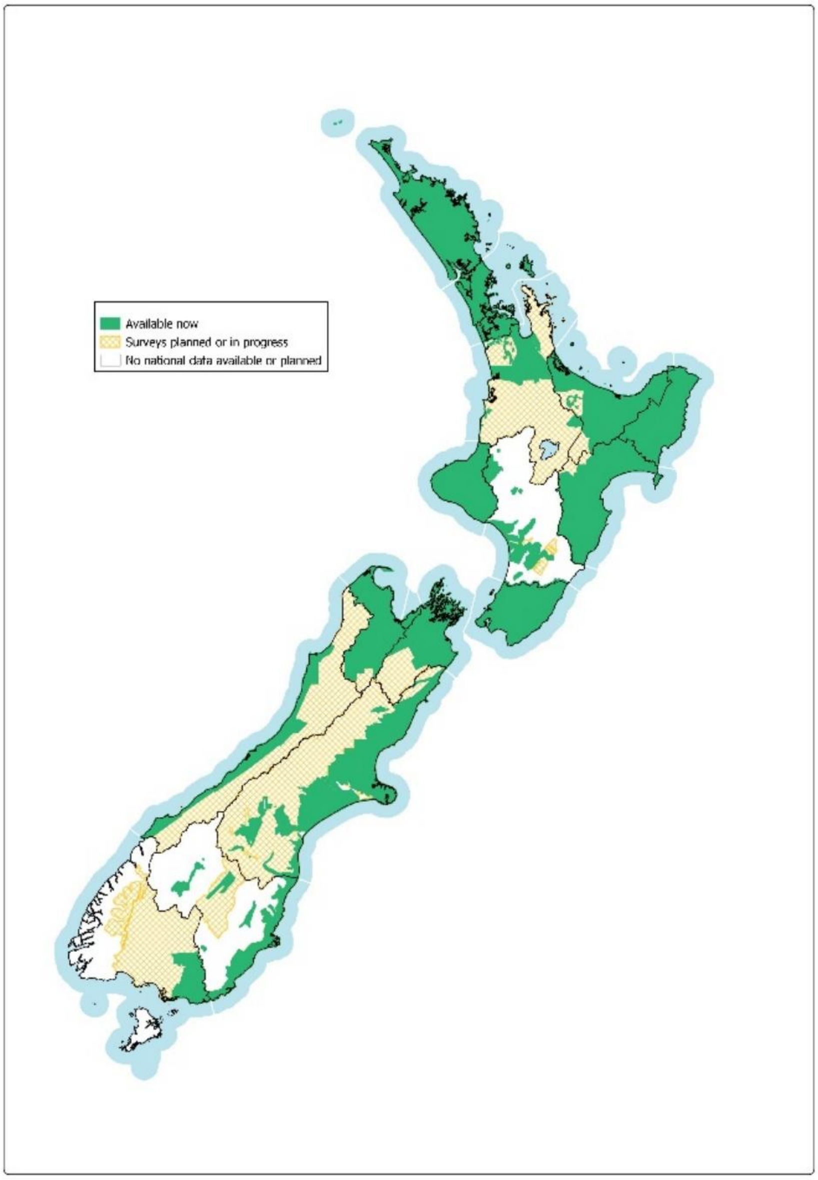

Figure 2-2: Coverage of LiDAR across NZ. LINZ elevation data webpage.

DEMs are generated using various techniques that interpolate raw elevation data onto grids of varying horizontal resolutions. The ability of a DEM to represent true topography depends on the coverage, resolution, and accuracy of the raw input data, the interpolation scheme applied, and the chosen output horizontal resolution for the DEM.

Digitised river lines are sometimes used to amend DEMs before DNs are produced. Information from aerial photos, local surveys, or site visits can be used to check and amend segment alignment and routing of a DN.

2.3 How is a DN typically created?

The steps typically involved in development of a DN are listed in Table 2-1. Automated analyses are often used to create a DN from a DEM. Essentially, mathematical algorithms are applied to assign a surface flow direction for each cell of the DEM. Spatial patterns of surface flow direction are used to delineate surface flow pathways that are then used to create segments and determine network routing. Automated processes are typically used to define a DN from a DEM. Many options for DN creation are available, and some user inputs are required. Mathematical methods must be selected or devised to fill sinks (depressions) within the DEM, determine local surface flow directions, and determine the upstream starting point of each segment. The outcomes of these mathematical methods are often dependent on interactions between the DEM, the mathematical methods applied, and some form of user defined or automated parameterisation. An example of a parameter input is a threshold for the minimum upstream area of a watershed that could be applied to determine the upstream starting point of segments.

Table 2-1: Steps for generating a DN.

Number	Name	Description
1	Collect raw topography data	Collection of raw ground topography (e.g., LiDAR) data via low-level remote sensing (e.g., aeroplane or drone); this step includes making decisions regarding selection of sensor used, height of the sensor, overlaps of swaths, and speed to travel of the sensor during collection, etc.
2	Create DEM	Post-processing of raw LiDAR data into a DEM on a regular grid, including designation of a co-ordinate system, method of data cleaning (e.g., outlier detection), method of interpolation.
3	Fill sinks	Application of an algorithm for filling “sinks” which are topographic depressions.
4	Burn river lines	Burn river lines into a DEM to artificially reduce the height of the DEM along known river paths to ensure that surface flow pathways follow the river. This step requires a digital representation of river lines as input. The input river lines could come from a variety of sources (e.g., LINZ's 1:50,000 or 1:250,000 maps, Open Street Map, manually digitised or automatically generated from remotely sensed images). This step may not be necessary if a very accurate and high horizontal resolution DEM is available.
5	Get surface flow directions	Automated assignment of surface flow direction across cells of the DEM.
6	Delineate flow pathways	The spatial pattern of surface flow direction is used to delineate surface flow pathways that are then used to create segments and to determine network routing. A mathematical method and some form of parameterisation is required to determine the upstream starting point of each segment (e.g., a threshold for the minimum upstream area of a watershed can be applied).
7	Refine network	Additional sources of information can be used to refine a DN. Manual changes to segment alignment (i.e., the position of segments) can be applied if true local alignment or routing is known and the DN is found to be a poor representation of the truth.
8	Check network functionality	Apply tests of a functioning network. Do all segments flow to a single downstream segment? Are the terminal segments all near to the coastline? Are any segments upstream of more than one terminal segment indicating that an error in routing has occurred?

Number	Name	Description
9	Release or apply network	Apply a naming and description of this version of the DN using version control procedures, and release the network to either specific users for a specific application, or to a set of users for whatever applications they deem suitable.
10	Revise	Receive feedback and apply improvement to segment and/or watershed alignment and routing.

Surface flow pathways can be identified with a high level of detail when appropriate mathematical methods and LiDAR-derived DEMs are used to derive a DN. DNs derived from LiDAR-based DEMs have the potential to represent more detailed channel alignment and a higher density of surface flow pathways compared to non-LiDAR-derived DNs. There can also be disadvantages to creating a DN from LiDAR because uncertainties in DEM topography can be introduced due to the presence of vegetation, boulders, buildings etc. Furthermore, representation of very high density of surface flow pathways may be useful for some purposes (e.g., flood routing) but not useful for other purposes for which DNs are used (e.g., analysing the representativeness of a monitoring site compared to all river reaches within an FMU). See following sub-section for more details.

Step 4 in Table 2-1 entails burning river lines into a DEM to artificially reduce the height of the DEM along known river paths to ensure that surface flow pathways follow the river. Several sources of information are available to be used for burning river lines. However, Figure 2-3 and Figure 2-4 indicate that available maps are not fit for the purposes of burning river lines. For example, Figure 2-3 and Figure 2-4 both contain blue lines than run in loops, and also blue lines that are isolated from all other blue lines. Figure 2-4 shows the same areas as Figure 2-3 but Figure 2-4 represents more blue lines that Figure 2-3.

Figure 2-3: Open Street Map showing blue lines with representations of rivers, ditches, and raceways. Image taken from OpenStreetMap.

Figure 2-4: NZ Topo Map showing blue lines with representations of rivers, ditches, and raceways. Image taken from NZ Topo Map.

Manual adjustments are often applied to automatically generated DNs before they are finalised. Manual changes to segment alignment can be applied if true local alignment is known and DN segment alignment is found to be a poor representation of the true flow pathway alignment. For example, manual changes to alignment may be required in very flat locations, around lakes, in urban environments, near the coastline, etc, if the true alignment is known. Manual changes to routing can also be applied. For example, manual changes to routing may be required in very flat locations where routing direction may be incorrectly assigned as a result how the automated DN process interacts with the DEM.

Mathematical functionality of a DN can be checked before finalisation. A standard set of tests can be applied to check for logical routing. For example, all segments must route downstream to only one terminal segment. Terminal segments should only exist near to the sea or at locations where flow pathways are known to flow underground or into a lake with no flow pathway outlet.

2.4 Why is version control important for a DN?

Before a DN is applied to a problem or released for general use it is typically given a version number and accompanied by a description using best practices for version control. It is possible that a DN needs to be amended after it is initially released because improvements to routing or alignment are required. Amendments to a DN are typically traced using a version sub-number and a description of the amendment using best practices for version control.

Variability of input DEM data and the plethora of decisions applied during development of both DEMs and DNs create variability between DNs. Version control of DNs is important for users to know which DN they are using and how it has been produced. Furthermore, several applications may need to be derived using comparable DNs. However, some participants in our workshop were not aware of the DN versioning system or which DN version(s) were being used inside their organisations.

2.5 What types of data, products, and analysis are dependent on a DN?

Many models, products and derived datasets have been, or could be, created using a DN at the catchment, region, or national level. Some examples include the following.

- Biophysical modelling that aims to simulate fate and flux of substances within watersheds and between segments.
  - Hydrological models (e.g., TopNet, SWAT) used for flood prediction and water resource assessments.
  - Water quality (e.g., CLUES) and sediment catchment models used to assess impacts of landcover change (e.g., dairy conversion, afforestation) or river mitigations schemes (e.g., riparian planting).
- River management and policy development purposes applied at the landscape-scale that require information on river channels and their interconnections.
  - Translations of various forms of biophysical modelling for regional planning and/or policy development.
  - Estimates of naturalised conditions for water quality and sediment used for setting target attribute states in rivers.

- Estimates of cumulative water resource impacts (e.g., streamflow depletion resulting from consented water use or actual water abstraction).
- Water accounting as required by the NPS-FM.
- Species distribution models used for conservation planning.
- Site selection and analysis of monitoring site representativeness.
- Estimates of length of fence required exclude livestock from river channels under proposed regulations.
- Basic information on river reaches such as catchment area, stream order, segment average upstream rainfall, etc. (e.g., FWENZ database).
- River classifications used for regional planning and the NOF within the NPS-FM.
- Impacts of climate change and climate change adaptations in relation to each of the above points.

2.6 Is there a DN with national coverage, and have there been updates through time?

The report of Shankar et al. (2022) describes the history and development of several versions and sub-versions of a DN with national coverage. Essentially, several revisions of the digital river network have been developed over the past 25 years. The original DN (Version 1.0) was developed on behalf of the Ministry for the Environment (MFE). DN version 1.0 was first released in 2004. Updated DNs were then released by NIWA in 2008 (version 2.3), 2012 (version 2.4), and 2015 (version 2.5) as improved DEM data became available and minor improvements to segment alignment and routing were applied. With increasing, but not ubiquitous, availability of 1 m resolution LiDAR data across NZ, the most recent DN (version 3.0) has been derived from a hybrid of both an 8 m and 15 m resolution DEM (derived from LiDAR data and a national 15 m DEM developed by the University of Otago respectively).

DN version 1 comprised approximately 560,000 segments. Version 2 comprised approximately 570,000 segments. DN version 3.0 comprises many more (approximately four times more) segments compared to previous versions (e.g., Figure 2-5).

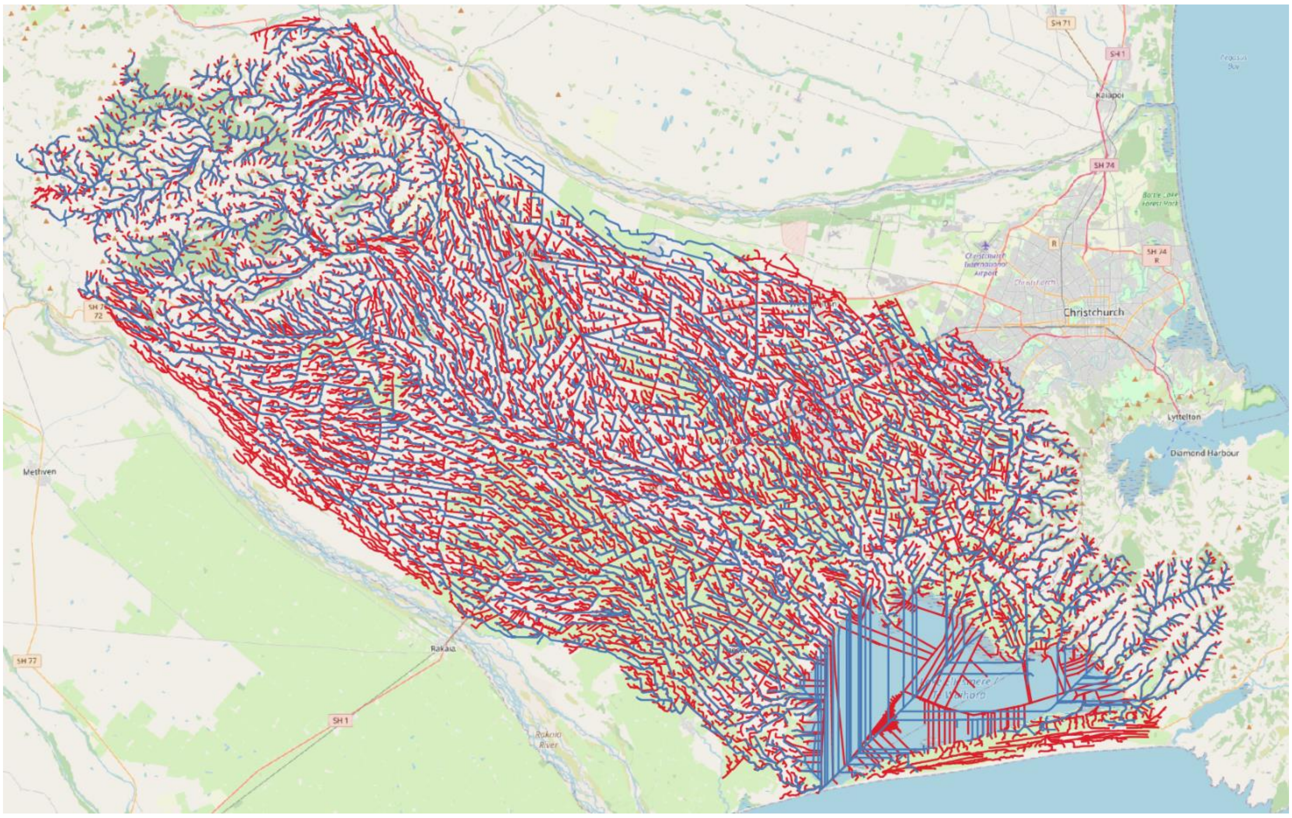

Figure 2-5: DN maps showing two versions of river lines for rivers draining to the of Te Waihora-Lake Ellesmere. Version 2 (blue; 3,690 segments) and Version 3 (red; 12,700 segments). Note there are more difference between version in flat areas compared to steeper areas. The red line is only visible where it is not obscured by the blue line.

2.7 How does the national DN relate to NZWaM?

New Zealand Water Model (NZWaM) is a modelling framework designed to provide the inputs, methods, and tools needed for hydrological modelling across NZ. NZWaM is a modular system that was developed to meet a wide range of information requirements for modelling and hydrological prediction. Model configuration options are available for definition of a range of surface and groundwater processes, river and lake networks, and catchment scales. Essentially, NZWaM functions to collate, organise, and re-format input data and validation data needed for running hydrological models to predict surface water flows in any catchment across NZ. NZWaM is designed to be a national framework to support flow estimation in ungauged catchments for which there are few or no flow data available for model calibration. NZWaM uses national-scale climate, soil, landcover and geological data in order to provide flow estimates in ungauged catchments. The advantage of having a relatively high-resolution, national-scale, modelling framework is that it can be adopted by any regional or district council for water management within their boundary.

Functionality developed as part of NZWaM can be used to run hydrological models for various purposes and at various scales. Purposes for running hydrological models include for water resource assessments, estimates of naturalised flows, and estimates of flood flows. Scales over which hydrological models are run vary from individual catchments to whole regions to nationwide. For technical reasons NZWaM must be able to function using different versions of the DN, including sub-versions of Version 2 and Version 3, as well as DN versions that have been coarsened so that they represent less spatial detail than the DN from which they were derived. For example, DNs can be coarsened (from the Strahler 1 level to the Strahler 3 level of detail) in order to allow faster run times for detailed hydrological models. The default surface hydrological model for NZWaM is TopNet, but alternative models could be used. NZWaM is both dependent on the DN and also responsible for recent production of the DN.

Surface water and groundwater are inextricably linked. Groundwater flow pathways do not necessarily follow surface water pathways as they are represented by a DN. Adaptation of watershed polygons and routing methods represented within a DN for coupled groundwater-surface water modelling is in scope of NZWaM. Coupled groundwater-surface water modelling under the umbrella of NZWaM involves development of methods to represent groundwater routing between watersheds. Groundwater routing methods can break the routing stipulation for a DN which dictates deterministic surface water pathways can only take one route downstream.

2.8 What has the national DN been used for?

National DN version 3 has been developed mainly for hydrological modelling purposes, including flood modelling, partly because it has been housed under the umbrella of NZWaM. The legitimate need for detailed representation of overland flow pathways for accurate hydrological and water quality modelling, together with the availability of LiDAR data, partly explains the increase in number of segments in Version 3 compared to previous versions.

As part of our questionnaire, we asked respondents to indicate whether the national DN was used for each of 11 different purposes. We did not specify a DN version for this question. Responses collated across respondents indicated that their organisations used the national DN for all 11 purposes that we asked about. The majority of respondents also indicated that the national DN is either very important or somewhat important for all 11 purposes that we asked about. Overall, respondents indicated that the national DN is important for their organisation.

Respondents to our questionnaire and discussion in our workshop indicated that processes that rely on the national DN as input include the following.

- Obtaining upstream characteristics (catchment area, dominant upstream landcover type, dominant upstream geology) of monitoring sites.
- Selection of monitoring sites and analysis of monitoring site representativeness compared to river reaches within the FMU they are representing.
- Delineating Freshwater Management Zones.
- Consenting processes for groundwater and surface water abstractions.
- Estimating naturalised river flows.
- Water accounting.
- Identifying membership of sites to classes used in the NOF.
- Pairing impacted river sites with reference river sites.
- Modelling of baseline conditions for river water quality of metrics of ecosystem health.
- Hydrological and water quality simulation modelling.

The responses indicate that various versions of the national DN are being used for a wide variety of purposes. Some of the purposes that the national DN is being used for (or could potentially be used for) require a DN that represents river reaches rather than all potential surface flow pathways. There are therefore varying degrees of alignment between the main purpose for which national DN version 3 is being developed (bio-physical simulation modelling) and the various purposes for which various versions of the national DN is being used.

2.9 Have some regions adapted the national DN or developed their own DN?

A slim majority (18 of 33) of respondents to our questionnaire indicated that the national DN was the default DN used by their organisation. This indicates that, although many organisations are using the national DN, others organisation are either developing their own DNs, adapting the national DN, or not using a DN. To the best of our knowledge, several regions have either adapted the national DN or developed their own DNs. Examples include the following.

- Environment Canterbury (ECan) have created or adapted at least three different maps of rivers for various processes internal to ECan to support environmental and ecological assessments. These maps are currently not associated with watersheds or routing information.
- Northland Regional Council has created a hydrologically corrected and connected DN based on recently acquired LiDAR to meet their internal needs. However, this network is currently not associated with watersheds information.
- Environment Southland and Hawke's Bay Regional Council are actively using DN version 2.5 for national and regional reporting purposes, and DN version 3 for hydrological modelling purposes.
- Tasman District Council has created a hydrologically corrected and connected DN based on recently acquired LiDAR data to meet their internal needs and has derived associated watershed information.
- Auckland Council has created a hydrologically corrected and connected DN based on recently acquired LiDAR data, including representation of the stormwater network to meet their internal needs, and has derived associated watershed information.

There are advantages to local adaptation or creation of DNs because bespoke adaptations can be applied to suit particular purposes. For example, addition of artificial drainage channels for improved hydrological routing, or exclusion of surface flow pathways that are not considered to be river channels for river management purposes. However, there are also disadvantages to multiple DNs being created by multiple agencies for multiple purposes.

- Matching of monitoring sites to network segments can become confusing without clear identification of which network and which version is being referred to.
- Consistent naming conventions and version control practices are not applied.
- Between-region variability in network representation develops.
- Disconnects between the national DN and regional-bespoke DNs develop.

The strong majority of respondents to our questionnaire indicated that it is important that regionally developed DNs were consistent with the national DN (24 and 10 of 36 responded "very important" and "somewhat important" respectively). The following situations may arise if consistency between regionally developed DNs and national DNs is not maintained.

- There is inefficient and wasted use of money, human resources, and computational resources because a local DN is being generated when an equivalent national DN is available or could be adapted to provide the same functionality.
- Confusion for the public or decision-makers about where they expect to find rivers because they have inspected DNs from different sources.
- Errors and inefficiencies in national environmental reporting are more likely to arise when inconsistent DNs are being used across institutions. Monitoring sites need to be mapped onto the national DN when national-scale analyses are conducted for national environmental reporting (e.g., for water quality state and trends). Ideally, positions of monitoring sites on the national DN would be provided by the institution conducting the monitoring, but this is unlikely to be the case if the local institution is not using a national DN.
- Inconsistent DN (resolution, formatting, naming conventions) is a barrier to harmonisation and co-development of river management products (e.g., water accounting methods, procedures, or software).
- National-scale model outputs (e.g., estimates of naturalised river flows or target attribute states for water quality) will not easily feed into local scale river management decisions and actions.

2.10 What are the main user priorities for DNs?

Participants in our questionnaire and workshop indicated that some of the main user priorities for DNs should include the following (in no particular order).

- Consistency between regional and national DNs to aid national environmental reporting and facilitate between-region comparability regional planning processes.
- Consistency of segment identifiers to aid in national-scale analysis (e.g., estimation of water quality baseline state, or naturalised river flow conditions).
- Realistic positioning/alignment of river segments compared to "rivers in the real world" to aid with positioning of monitoring sites on the DN and using DNs to delineate FMUs.
- An interface to help users suggest improvements to segment alignment and routing within the national DN.
- The availability of regular improvements to allow users to use the latest available version.
- Version control so that users know about changes made to DNs and potential differences between DNs.

- The ability to add or update attributes by using the DN to apply downstream accumulation spatial data (e.g., to calculate percentage upstream area of a particular landcover type).
- Representation of artificial surface flow pathways such as raceways, canals, or diversions to more accurate biophysical modelling, and to allow mapping of environmental values in these locations.

2.11 Why might the national DN need to change or be adapted into the future?

All respondents to our questionnaire indicated that they would like to see regular updates to the DN. The majority of respondents (22 of 37) indicated that they would like to see new versions available every 3 to 4 years. The majority of respondents (25 from 37) indicated that they did foresee difficulties with incorporating different version of the DN into their work. A clear understanding of how updated DNs can be incorporated into end-user processes is therefore required to be incorporated into DN updates in order to maximise user uptake.

The following points would be beneficial with respect to future national DN maintenance and upgrading.

- The ability for the national DN to be efficiently and transparently re-generated to make best use of new data sources such as new DEM data (see Figure 2-2 for anticipated LiDAR coverage), areal photography, or other forms of remote sensing.
- The ability for the national DN to be "pruned" to create child versions whose level of detail is fit for a specified purpose (or matches the level of detail represented by a coarser DN or map of river lines) whilst maintaining consistency and precision in segment alignment with the parent DN.
- The ability for users to suggest changes to segment alignment and routing based on field experience or independent and verified evidence. Other users would then be able to benefit from accepted changes.
- The ability to optionally augment routing within DNs with representations of artificial surface flow pathways such as raceways, canals, diversions, or stormwater networks whilst maintaining consistency with the parent DN and not compromising routing functionality.

3 River Environment Classification (REC)

3.1 What is the REC?

The River Environment Classification (REC) is a deductively defined hierarchical classification of New Zealand's rivers (Snelder and Biggs, 2002). The REC classifies river segments based on climate, topography, geology, and land cover factors that control spatial patterns in river ecosystems. The REC assumes that ecological patterns are dependent on a range of landscape-scale characteristics and processes. The REC arranges several controlling factors of river conditions in a hierarchy with each level defining the cause of ecological variation at a characteristic scale ranging from broader to more local scales (Figure 3-1). The REC assumes that ecological characteristics of rivers are responses to interacting fluvial (hydrological, hydraulic), geomorphological (meso-habitat configuration such as pool-riffle bathymetry), chemical (water quality), and ecological (competition, growth, trophic exchange) processes. The REC assigns individual river segments to a class independently and objectively according to criteria that result in a geographically independent framework in which classes may show wide geographic dispersion rather than the geographically dependent schemes such as an ecoregion approach.

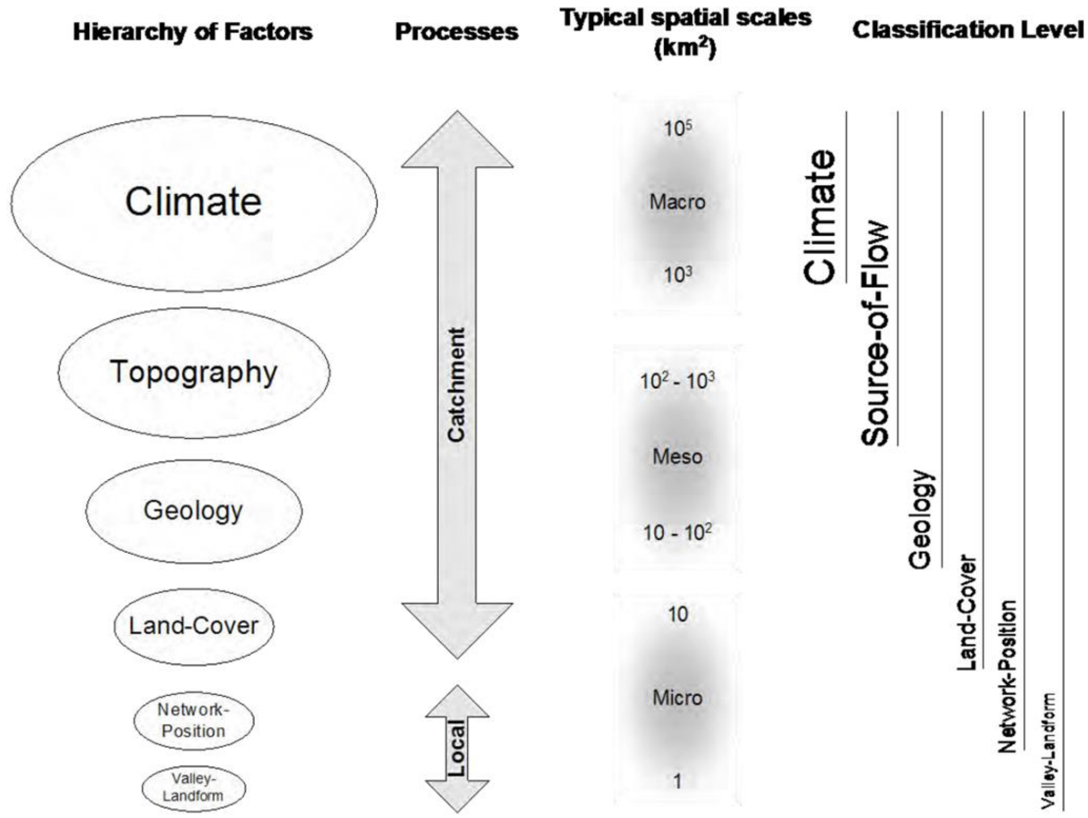

Figure 3-1: Diagram of the REC levels based on the controlling factors, differentiated at three general scales and the patterns of physical characteristics discriminated at each classification level. Taken from Snelder and Biggs (2002).

3.2 What input data are used to produce the REC?

The input data used to calculate REC classes circa 2000-2002 are shown in Table 3-1.

Table 3-1: Input data to the original REC. To the best of current knowledge.

Label	Description	Source
Rainfall	A spatial representation (e.g., grid) of mean annual precipitation (mm/year).	As documented in LENZ technical guide Leathwick et al. (2002).
Potential evapo-transpiration	A spatial representation (e.g., grid) of mean annual PET (mm/year). Likely using Priestly-Taylor method for PET calculation method, rather than Penman calculation method.	As documented in LENZ technical guide Leathwick et al. (2002).

Label	Description	Source
Temperature	A spatial representation (e.g., grid) of mean daily air temperature (°C).	As documented in LENZ technical guide Leathwick et al. (2002).
Elevation	A spatial representation (e.g., grid) of elevation to determine proportions of rainfall falling in mountainous, hill or lowland areas.	As documented in LENZ technical guide Leathwick et al. (2002).
Snow and ice cover	A spatial representation (e.g., polygons) of permanent coverage by snow and ice.	LRI “ice” class.
Lakes	A spatial representation (e.g., polygons) of lakes.	LRI “lak” class.
Geology	Simplified geology categories derived from LRI rock type.	Land resource inventory (LRI) geology rock type.
Landcover	Simplified landcover categories derived from LCDB version 1.	Land Cover Data Base (LCDB) version 1.

The REC classes are calculated using a set of thresholds and rules that describe the membership of segments to classes (see Table 3-2). A DN is needed to intersect watersheds with spatial input data (Table 3-2), assign classes to segments, and map the resulting distribution of classes.

Table 3-2: Summary of categories, mapping characteristics, and category membership criteria for assigning segments of a DN to classes of the REC.

Classification Level	Classes	Notation	Mapping Characteristics	Category Assignment Criteria
1. Climate	Warm Extremely Wet Warm Wet Warm Dry Cool Extremely Wet Cool Wet Cool Dry	WX WW WD CX CW CD	Mean annual precipitation, mean annual potential evapotranspiration, and mean annual temperature.	Warm: Mean annual temperature ≥ 12°C. Cool: Mean annual temperature < 12°C. Extremely Wet: Mean annual effective precipitation ≥ 1,500 mm. Wet: 500 > mean annual effective precipitation < 1,500 mm. Dry: Mean annual effective precipitation < 500 mm.
2. Source of Flow	Mountain Hill Low Elevation Lake	M H L Lk	Catchment rainfall volume in elevation categories, lake influence index	M: > 50 percent annual rainfall volume above 1,000 m ASL. H: 50 percent rainfall volume between 400 and 100 m ASL. L: 50 percent rainfall below 400 m ASL. Lk: Lake influence index > 0.033.
3. Geology	Alluvium Hard Sedimentary Soft Sedimentary Volcanic Basic Volcanic Acidic Plutonic	Al HS SS Vb Va Pl	Proportions of each geological category in section catchment	Class = The spatially dominant geology category unless combined soft sedimentary geological categories exceed 25 percent of catchment area, in which case class = SS..
4. Land Cover	Bare Indigenous Forest Pasture Tussock Scrub Exotic Forest Wetland Urban	B IF P T S EF W B	Proportions of each land cover category in section catchment	Class = The spatially dominant land cover category unless P exceeds 25 percent of catchment area, in which case class = P, or unless U exceed 15 percent of catchment area, in which case class = U.
5. Network Position	Low Order Middle Order High Order	LO MO HO	Stream order of network section	Stream order 1 and 2. Stream order 3 and 4. Stream order ≥ 5.
6. Valley Landform	High Gradient Medium Gradient Low Gradient	HG MG LG	Valley slope of section based on Euclidian length	Valley slope > 0.04. 0.02 ≥ Valley slope ≤ 0.04. Valley slope < 0.02.

3.3 How was the REC created?

The REC classes were calculated onto DN version 1.0 circa 2000-2002 using methods described in a NIWA report to MfE that was first released in 2004 and subsequently updated in 2010 (Snelder et al., 2010). To the best of our knowledge, REC classes were calculated at that time using scripts (Delphi) and some manual steps applied in ArcGIS software.

A recent (2022-2023) NIWA project has created a process (R script) to automatically and transparently calculate REC classes onto any functioning river network using input data equivalent to that shown in Table 3-1 and rules equivalent to those shown in Table 3-2. The process is depicted in Figure 3-2 and results shown in Figure 3-3. Work in the project indicated that input data and various technical decisions within the procedure combine to influence the output map of classes. For example, assignment of DN segments to climate classes was influenced by the following.

- Network routing represented by the DN.
- Watershed shape represented by the DN.
- Selected rainfall dataset.

- Selected PET dataset.
- Selected temperature dataset.
- Selected DEM dataset.
- Method for interpolating or joining environmental datasets onto watersheds.
- Methods for applying rules defining classes.
- Thresholds defining classes (i.e., numerical values in column 5 of Table 3-1).

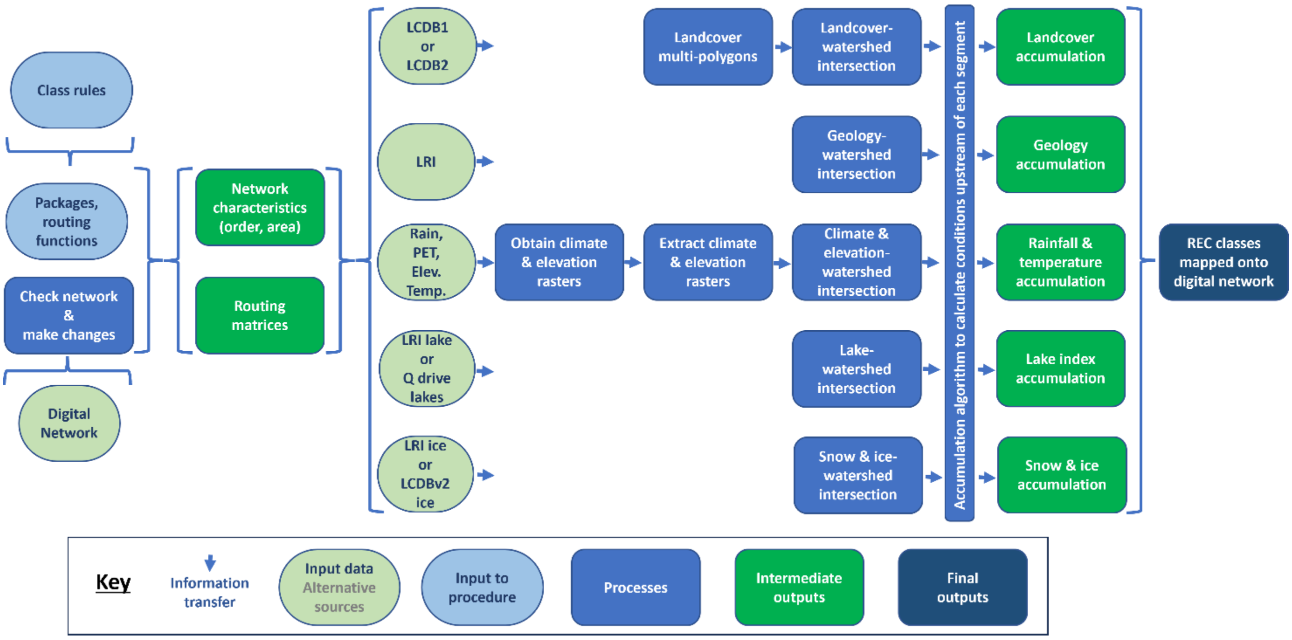

Figure 3-2: Depiction of a recently developed process for calculating REC classes onto a river network. Grey text indicates alternative source of input data.

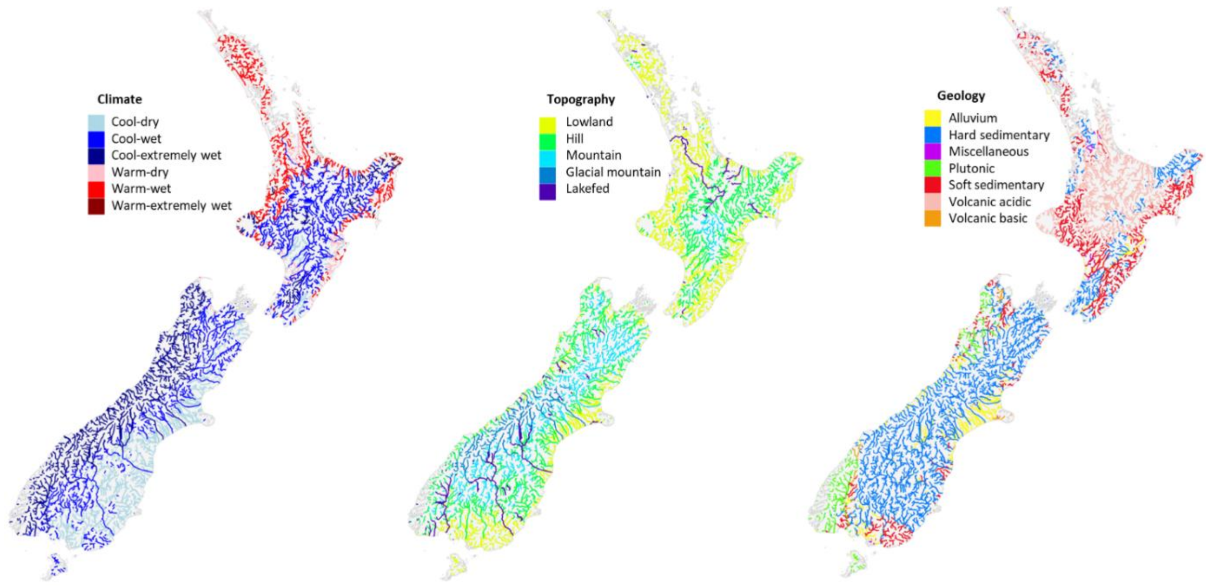

Figure 3-3: Map of classes for first three levels of the REC mapped onto larger rivers segment contained within national DN version 1.

3.4 What is the REC used for, and why is it important?

The REC classes have been used for delineation of FMUs. REC classes have also been used as predictors or covariates when modelling various ecological, physical, or hydrological states for river management and policy development purposes. Examples include sediment modelling (Stoffels et al., 2021), hydrological modelling (Snelder and Booker, 2013), periphyton modelling (Snelder et al., 2014), and water quality modelling (McDowell et al., 2013). Most importantly from a regulatory perspective, amalgamated REC classes have been used to apply targets for sediment in the National Objectives Framework (NOF) within the National Policy Statement for Freshwater Management (NPS-FM). Inclusion of REC in the NOF means that regional councils are obliged to assign an REC class to each site where deposited and suspended sediment is being monitored.

3.5 Is there a REC map with national coverage and have there been updates through time?

REC classes that were mapped onto national DN version 1 around 2000-2002 have been publicly available from MfE and NIWA for many years (since around 2004). Those maps of REC classes were calculated using input data available at the time of development. Maps of REC classes have not been regenerated using newer versions of the national DN, although REC classes have been mapped onto DN version 2.4 from DN version 1.0 using nearest neighbour and stream order. The presently available maps of REC classes were therefore produced using data that are at least 25 years old (see Leathwick et al., 2002 for details) and were calculated using a national DN that does not include potential improvements to segment alignment and routing contained within national DN versions 2 or 3.

3.6 What are the main user priorities for the original REC classification system REC?

The majority of respondents (30 from 37) indicated that an update of the REC would positively impact their work and planning processes. Participants in our questionnaire and workshop indicated that the main user priorities for the REC was availability of maps of REC classes using the original classification system and data but mapped onto various DNs that are being used in their organisations, or the ability for a user to map REC classes using the original classification system and data onto any DN.

3.7 Why might the REC or similar classification systems need to change into the future?

Participants in our workshop discussed adaptations, improvements, and alternatives to the original REC. The criteria, objectives, and purposes used to develop the original REC may need to be re-evaluated and/or changed in the future to include the following.

- Input data used to produce original REC classes have been updated (e.g., air temperature, rainfall, geology, landcover, lakes, urban areas) since the original REC system was applied. It should be noted that changes to threshold values may need to accompany changes to input data if systematic differences are found between new input data and the original input data.
- Input data available to devise a river classification has expanded since the original REC system was applied. New data brings the potential to create river classification with a different scope to the original REC system.
- The NPS-FM requires that regional councils have regard to the foreseeable impacts of climate change when setting limits. The NPS-FM also requires predictions of foreseeable effects of climate change that are likely to affect water bodies and freshwater ecosystems. These issues would be informed by an assessment of the degree to which climate change will cause a shift in REC classes due to changes in effective rainfall and air temperature.
- Amendments to classification systems may be required to represent habitats or landscape settings that are of interest to river managers, but which were not included in the original REC system. For example, springs and wetlands.

From Figure 3-2 it should be noted that improvements and updates to the DN would have automatic knock-on effects for maps of REC classes.

4 A proposed framework for operational upgrading of national DNs and river classifications

4.1 What is the status quo?

Development of LiDAR-derived DNs (for some locations within DN version 3) has been funded by NIWA's Strategic Science Investment Fund (SSIF) under the umbrella of NZWaM in recent years. NIWA SSIF funding has effectively been reducing over the past 10 years.

DN version 3 uses LiDAR-derived DEMs where they are available (Figure 2-2), but also uses DEMs with coarser resolutions in locations where LiDAR-derived DEMs are not available. The latest sub-version of DN version 3 was therefore not produced using consistent data sources across catchment and regions.

4.2 Is the most recently produced DN version fit for environmental management or reporting purposes?

National DN version 3 contains more spatially detailed segment alignment than its predecessors partly because it has been developed from LiDAR-derived DEMs in some locations. DN version 3 legitimately includes high density of segments and fine detail in segment alignment because it has been developed with an emphasis on biophysical modelling that aims to simulate fate and flux of substances within watersheds and between segments. Biophysical modelling purposes that require a DN include hydrological (including flood modelling) and water quality modelling. Despite being devised from spatially-inconsistent DEMs, DN version 3 is the best available national surface flow pathway network for biophysical modelling purposes.

The issue of correspondence between positioning of segments and real river channels is a challenge for DNs when they are used for river management purposes. Inclusion of surface flow pathways that do not represent river channels within a DN is inconsistent with the need to represent "only the positioning and alignment of rivers in the real world" as was expressed by some participants in our workshop. These participants articulated the view that segments representing flow pathways that do not represent river channels were at best superfluous and at worst erroneous for some river management purposes.

Segments representing river channels are not distinguished from segments representing other surface flow pathways within national DN version 1, 2, or 3. Tests of correspondence between positioning of DN segments and real river channels are currently not available. It is therefore not possible to quantify the overall degree of correspondence between DN segments and real river channels, whether there are spatial patterns in correspondence, or how correspondence differs between national DN versions 1, 2, and 3.

Fine detail in segment alignment means that DN version 3 has a better potential for aligning flow pathways correctly compared to versions 1 or 2 (see Figure 2-5). However, high density of segments means that DN version 3 is also more likely to include segments that do not represent river channels compared to versions 1 or 2. National DN version 3 therefore has potential to be poorly suited for several river management and policy development purposes (e.g., national environmental reporting of water quality state across NZ's rivers) despite these purposes relying on a DN of river channels.

4.3 Who could be involved in advising about upgrades to the DN and REC?

A multi-agency initiative to facilitate stewardship, maintenance and upgrading of national DN and the REC could include the agencies listed in Table 4-1.

Table 4-1: Agencies that could be involved in the stewardship, maintenance and upgrading of national digital network and river classifications.

Agency	Potential role
MfE	Project steering.
NIWA	Project steering. Project management. Technical development. Comms. Users.
Regional councils	Project steering. Users. Testers. Data suppliers.
Territorial authorities	Users. Testers. Data suppliers.
Department of Conservation	Project steering. Users. Testers. Data suppliers.
Other CRIs	Data providers (e.g., MWLCR for soils etc, GNS for geology and groundwater information etc)
LINZ	Distribution. Communications.

4.4 A proposed framework

We suggest that emphasis for the ongoing stewardship, upgrading, and maintenance should be placed on national DNs and the REC whilst guiding and reacting to updates to input data and accommodating the requirements of derived products. Upgrading and maintenance of national DNs and the REC should incorporate information derived from sources that are both internal and external to the participating organisations. For example, processes for generating national DNs should be able to ingest DEM data from any source, and processes for recalculating REC classes should be able to ingest rainfall or temperature data from any source.

A framework consisting of the entities listed in Table 4-2 is proposed to operationalise the conceptual design presented in Figure 4-1.

Table 4-2: Proposed entities of a framework for ongoing stewardship and upgrading of the REC system. Note; options for each row are independent of options from other rows.

Entity	Purpose	Example options
Project steering	Provide oversight on aims and objectives	1) Form bespoke steering group. 2) Incorporate with existing committee such as EMaR or SWIM
Project management	Prioritise tasks. Distribute resources to complete tasks. Report on delivery.	1) Delivered by NIWA. 2) Delivered by MfE.

Entity	Purpose	Example options
Technical work	Advance tasks. Progress technical work. Deliver outputs and operationalise services.	1) Development and delivery by NIWA. 2) Development by NIWA. Delivery of services by LINZ.
Testing and community feedback	Test outputs and services before general release.	1) Form groups of testers. 2) Release beta version for open testing
Communications	Ensure users are aware of outputs and services, and also receive general feedback.	1) Delivered by LINZ. 2) Delivered by NIWA.

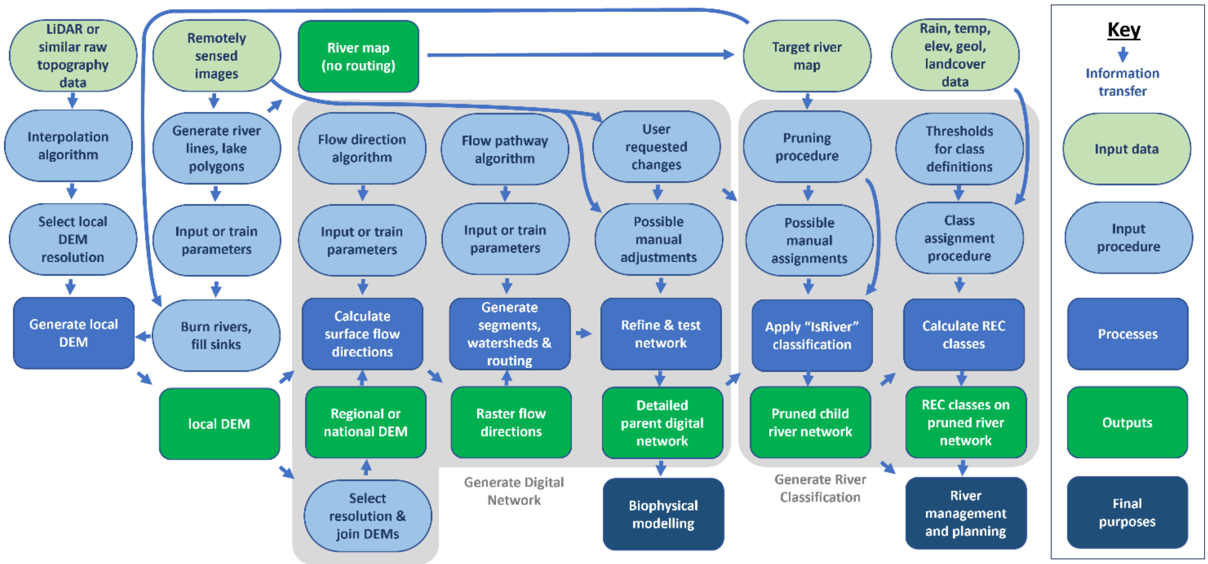

Figure 4-1: Graphical depiction of a framework for maintenance and upgrading of the DN and REC.

If enacted, the proposed framework would be used to:

- produce DNs that are consistent with each other and fit for purposes ranging from local-scale flood modelling to national-scale river classification by producing parent DNs comprising highly detailed flow pathways and child DNs comprising only flow pathways that are classified as river channels;
- encourage consistency in use of DNs across applications by ensuring that segment alignment and identifiers are comparable between parent and child DNs;
- efficiently utilise improvements in data availability and methodological advancements by developing an automated procedure to produce DNs and DN-derived outputs following updates to inputs;
- produce DNs in a replicable and transparent way by applying best practices for version control;

- reduce unnecessary duplication of effort and confusion at the national level by removing the need for various agencies to create bespoke DNs because they have provided input about their needs for DNs and river classifications; and
- react to user needs by ingesting and responding to requests for amendments to segment alignment or network routing.

In addition, several types of documentation would be produced to:

- Clearly describe the framework and related material.
- Clearly describe the concepts underlying DNs, the REC and the applications of these products in plain English.
- Ensure that non-expert users understand the concept of a DN, the relationship between a DN and the REC, and the tradeoffs, benefits and limitations associated with choice of spatial scales.
- Ensure that terms, uses and concepts are unambiguously defined.
- Graphically summarise the processes followed.
- Comprehensive documentation will be provided for technical users.

Possible tasks that would fit inside the proposed framework are listed in Table 4-3.

Table 4-3: Possible tasks that would fit inside a framework for ongoing stewardship and upgrading of the REC system.

Entity	Example tasks
Project steering	1) Form bespoke steering group. 2) Incorporate with existing committee such as EMaR or SWIM. 3) Questionnaires. 4) Workshops.
Project management	1) General project management. 2) Annual report on delivery.
Technical work	See components of Figure 4-1 and tasks listed in Section 4.5. 1) Research. 2) Operationalise.
Testing and community feedback	1) Test outputs and services before general release. 2) Collate user feedback and apply updates if required.
Communications	1) Advertise outputs and services. 2) Receive feedback.

4.5 Possible tasks

Possibly future technical tasks that the proposed framework could facilitate and co-ordinate fall into two categories as follows.

- Operational tasks (methods are known but not currently implemented)
  - Transparent and version controlled workflow to produce or upgrade DNs using DEM as input.
  - Tool for users to submit recommended changes to DN alignment or routing.
  - Procedure to ingest, assess, verify, and apply recommended changes.
  - Procedure to calculate REC classes on any DN and using any input environmental data.
  - Tool for users to apply routing (e.g., downstream accumulation to calculate conditions in the area upstream of each segment).
- Research tasks (methods are currently unknown or untested)
  - Procedure to identify river channels from remotely sensed images.
  - Procedure to classify flow pathways as being inside or outside of river channels.
  - Procedure to quantify correspondence between positioning of DN segments and real river channels.

4.6 Limiting factors and suggested solutions

Intellectual Property (IP) issues around ownership of data and procedures would have to be clarified. We suggest that ownership of various inputs, outputs, and procedures, should be documented and assigned so that organisations understand terms of use, and who owns what. This includes clarification of which items are open access to all.

Resource limitations will mean that all issues relating to national DNs and the REC cannot be covered in one project. The proposed framework should be used to assess the benefit of making an operational procedure that allows potential users to join their own data to the network. We suggest that, if a procedure for joining data to the network (e.g., using downstream accumulation to calculate average conditions upstream of each segment) were operationalised, then it needs to be clear that the data contributor would be responsible for quality assurance for the data being joined to the network.

If it is deemed beneficial to use remotely sensed images and very high resolution data, then data storage and easy access may be a limitation. Additionally, if it is deemed beneficial to use machine learning for image recognition of river channels, compute power may be a limiting factor. We suggest that NIWA's high performance computing facilities are well suited to deliver the functionality required to store, distribute, and process large volumes of data.

Funding may be limited. We suggested that trialling updates and mechanisms for receiving feedback in one region (with LiDAR) may be beneficial.

5 Acknowledgements

Many thanks to all those who participated in the workshop associated with this project. Thanks to Christian Zammit, Lawrence Kees, Matt Wilkins, Rose Pearson, and Ude Shankar for their input for this project.

6 Glossary of abbreviations and terms

Table 6-1: Definitions of technical terms used in this report.

Term	Definition
Digital Network (DN)	The network comprises segments, watersheds, and routing information. Segments represent river lines. Watersheds represent areas draining to segments. Routing information describes connections between segments. Routing information can be used to find which segments are upstream or downstream of a segment of interest.
River segment	A part of the river network that is positioned between confluences (where two or more segments meet), a river terminal (where a river catchment ends usually because it flows into the sea, but possibly because it flows into a lake with no outflow, or it disappears underground).
Terminal segment	A river segments that marks the most downstream point of a catchment. Terminals usually occur where a river flows into the sea, but possibly because a river flows into a lake with no outflow, or a river disappears underground.
Watershed	The polygon surrounding a river segment that indicates the area of surface land draining towards the segment. Watersheds are typically derived from surface topography. Sometimes referred to as "catchments" in the literature.
Routing information	Information used to determine which segment(s) are upstream of a segment of interest, and which segment is downstream of a segment. Typically, routing information is represented by a "From node" and "To node" for each segment, which collectively can be used to produce routing matrices or routing tables.
River Environment Classification (REC)	A deductively defined hierarchical classification of New Zealand's rivers (Snelder and Biggs, 2002). The first and the second hierarchical levels of the REC are called the climate and source-of-flow levels, respectively. These levels are based on a conceptual model that postulates that large-scale variation in climate and topography discriminate hydrological variation at two levels of classification detail. Further levels of the classification represent classes based on upstream geology, landcover, network position (derived from stream order) and valley landform (derived from valley slope). REC classes were calculated using spatial information on rainfall, air temperature, elevation (DEM).
Digital Elevation Model (DEM) or digital terrain model (DTM)	A representation of the ground topography. A DEM would usually exclude the influence of trees, buildings, and other surface objects such as boulders, fences, vegetation etc. However, very detailed DEMs or urban areas may include buildings for flood routing purposes, and very detailed DEMs of river topography may include boulders for roughness calculation purposes.
Land Cover DataBase (LCDB)	A spatial representation (GIS) of NZ's landcover.
Land Resource Inventory (LRI)	A spatial representation (GIS) of NZ's geology.

Term	Definition
Light Detection and Ranging (LiDAR)	A low-level remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses can be combined with position and time data recorded by the airborne system to generate precise, three-dimensional localised information about the shape and characteristics of the land surface.
FMU	Freshwater Management Unit.
FWENZ	FreshWater Environments of New Zealand database.
CLUES	A water quality “catchment model”.
TopNet	A hydrological model.
SWAT	The Soil & Water Assessment Tool is an example of an open source internationally developed, small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water.
NOF	National Objectives Framework.
NPS-FM	the National Policy Statement for Freshwater Management.

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Appendix A Responses to questionnaire

See attached file "Survey Responses_REC_MFE.pdf" complied by Lawrence Kees of NIWA, Christchurch.