Roadmap to an updated ecosystem typology for rivers

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Executive summary

Which domain does this report cover?

This report covers the rivers domain, which includes lotic (running water) ecosystems that flow from elevated uplands or underground springs toward sink holes, deltas, estuaries, lakes, and/or coasts. Rivers are defined primarily by their linear structure and unidirectional flow direction.

What typologies already exist?

The scope of this project dictated that two existing New Zealand (NZ)-specific river typologies, the River Environment Classification (REC) and Freshwater Environments of New Zealand (FWENZ), were assessed for their suitability to fulfil principles for an ecosystem typology that were predetermined by the Ministry for the Environment (MfE) and other stakeholders, and their alignment with the International Union for Conservation of Nature (IUCN) Global Ecosystem Typology (GET).

Do existing typologies adhere with the Principles for a standardised ecosystem typology?

The REC and FWENZ both align well with some of the principles for a standardised typology derived from previous engagement with end-users, but neither aligned well with all principles. The REC meets more principles than FWENZ, including some of those considered most critical (e.g., updatable, adaptable, reproducible) for an effective ecosystem typology. Both typologies have a hierarchical structure and are spatially explicit when mapped onto a river network. However, presently available river networks represent river length, but do not represent river width which may be important for some purposes. The REC adheres reasonably well to principles relating to flexibility/adaptability, updateability, compatibility, transparency, reproducibility, parsimony, ecotones, and being easily understood. The utility of the REC has been demonstrated through its use in the National Objectives Framework and regional planning. The data driven nature of FWENZ is a strength due to objectivity in its outputs and a weakness due to biases in the observed data, reliance on various technical decisions for generation, dependence on the river network from which classes are calculated, and the entire classification would change if regenerated. Neither typology adhered well to principles relating to consistent use of species concepts and accommodation of artificial ecosystems.

Do existing typologies align with IUCN GET?

IUCN GET Level 3 ecosystem functional groups (EFGs) relating to rivers were assessed. Only two GET EFGs are likely to be commonly occurring for NZ rivers (F1.1 Permanent upland streams and F1.2 Permanent lowland rivers). There is some ambiguity in the definition of these two EFGs because they confound river size with hydraulic/sediment conditions when these characteristics are not mutually exclusive. It was demonstrated that it is possible to cross-walk from REC (Level 2 source-of-flow) and FWENZ (20-group level) to EFGs after having applied subjective matchings. Cross-walking was not straightforward because it produced one-to-many joins due to ambiguous membership of REC and FWENZ groups to EFGs (e.g., the REC Hill group falls between upland and lowland EFG groups).

What are the next steps for national ecosystem typologies in this domain?

A roadmap outlining the next steps for development of national ecosystem typologies for rivers is provided. We identify several additional requirements for a river ecosystem typology; particularly the need to account for the dendritic, spatially accumulating nature of river systems between their source and the sea, and the necessity to account for the impact of both proximate and distal drivers of ecosystem type. A pre-requisite for the development of any revised/new river ecosystem typology is an updated digital river network and the collation/creation of associated environmental and biotic data; we and the stakeholders we consulted (DOC/HBRC) consider this a priority action.

Our recommendation to assist river management for NZ is to adopt an environmentally driven river classification that is based on ecological principles and concepts and is validated based on its ability to effectively discriminate biological and physical patterns. It is our assessment that the REC currently better fulfils the end-user principles compared to FWENZ and is more readily adapted to more closely align with the principles. Based on discussion with stakeholders, it is also our view that amending the REC structure and class definitions is not straightforward. Challenges include deciding amongst the wide scope of changes that could be made, obtaining necessary data to apply desired changes, and trialling the utility of changes for particular use cases. To maximise the legitimacy and relevance of any updated river ecosystem typology we recommend working with user groups to obtain input data, identify priority use cases, co-develop the typology, and trial outputs.

1 Background

This report sets out a roadmap towards the development of a national river ecosystem typology (aka classification) that will fit within a 'global' typology across all ecosystems in New Zealand. In developing this roadmap, consideration has been given to fulfilling the end-user principles developed during collaborative workshops as set out in Collins (2024). Additionally, attention has been given to the potential purposes and application of river ecosystem typologies for freshwater management and biodiversity conservation in New Zealand, and the practicalities of both developing and implementing a credible, relevant, and justifiable typology. Roadmaps towards the development of national ecosystem typologies for terrestrial, marine and estuarine, lakes, wetlands, and groundwater ecosystems were developed as part of the same project but are reported separately.

River ecosystems present a challenge for establishing functional typologies for several reasons:

- The linear, dendritic, hierarchical nature of river networks where conditions in upstream locations influence conditions in downstream locations (cf. the matrix form of the terrestrial and marine realms) acts as a critical constraint on the dispersal of aquatic species requiring a ki uta ki tai approach.
- The unidirectional, spatially accumulating nature of river systems between their source and the sea is a key driver of ecosystem processes.
- River character is a function of both proximate (reach scale) and distal (upstream catchment) drivers. Proximate drivers manifest at small scales (e.g., local shear stress is a function of velocity, depth, and substrate at the patch-scale). Distant drivers manifest at large scales (e.g., flow regimes are a function of climate, topography, geology, and landcover across the upstream catchment).
- Rivers are highly dynamic systems meaning that disturbance regimes (i.e., flow regimes) are a critical control on biotic communities.
- There is a long history of physical modification of river systems and their catchments.
- Biological states in river ecosystems (e.g., fish and macroinvertebrate community composition) are transient and relatively difficult to discern compared to environmental drivers (e.g., catchment size, climate), which are relatively steady and easy to discern in river ecosystems. This situation contrasts with terrestrial ecosystems where biological states of keystone species (e.g., vegetation) are relatively easy to discern compared to environmental drivers (e.g., soil characteristics). Difficulty discerning ecosystems states in rivers presents a challenge to establishing functional ecosystem typologies directly. Relative ease discerning environmental states in rivers leads to a tendency to develop environmentally-driven typologies that can be subsequently tested for their ability to distinguish ecosystem patterns for rivers.

In Aotearoa-New Zealand (NZ), these challenges are exacerbated by the prevalence of diadromy in the freshwater fish communities (many fish species have a marine phase in some part of their life cycle), necessitating a ki uta ki tai approach to river management. Furthermore, the aquatic biota is characterised by a high level of endemism and the occurrence of geographically restricted species (some fish and macroinvertebrates species are only found in a few catchments or across narrow geographical ranges). The influence of non-native salmonids is also known to be a strong influence on native fish communities. Fish species that occupy a broad range of locations across the landscape as they migrate, and disruption of native ecosystems by invasive species, both make it difficult to match individual locations on rivers onto types (aka groups or classes) within typologies. Macroinvertebrates communities typically better reflect local environmental conditions and so may be a more appropriate indicator group, but are still subject to regular disturbance due to flow variability and are often not identified to species level in routine monitoring.

The scope of this project dictated that two existing NZ specific river typologies, the River Environment Classification (REC; Snelder and Biggs 2002) and Freshwater Environments of New Zealand (FWENZ; Leathwick et al. 2008a), would be assessed for their suitability to fulfil the predetermined principles for a national river ecosystem typology and their alignment with the IUCN Global Ecosystem Typology (GET). The REC and FWENZ were identified as potential candidate river typologies in a previous report by Collins (2024).

2 Methods

The project scope required that three key steps were addressed:

1. The existing typologies, in our case REC and FWENZ, were to be evaluated for their fit to the principles for a national ecosystem typology.
2. The REC and FWENZ were to be assessed for their suitability to be cross walked/mapped to the IUCN GET (Level 3).
3. A draft roadmap was to be developed outlining the key steps required to deliver a national river ecosystem typology that meets both the principles, and aligns with the IUCN GET.

2.1 Assessment of how well the existing typologies meet the Principles

In a series of workshops in 2023, stakeholders and end users from DOC, regional councils, the Ministry for Primary Industries (MPI) and the Ministry for the Environment (MfE) identified and developed nine national principles and five additional requirements for a standardised typology (Collins 2024). These principles were initially reviewed by the whole project team during a workshop on 29 May 2024. Clarification was subsequently sought from MfE and the Steering Group regarding the intent and meaning of several of the principles. For this assessment, we adopted the interpretation of the principles set out in an accompanying report to MfE entitled "Investigating a unifying ecosystem typology for all of New Zealand" (Sprague and Wiser 2024) and described in Table 2-1.

Table 2-1: Principles for ecosystem typologies derived from previous engagement with stakeholders and defined in Sprague and Wiser (2024). Revised after consultation with MfE during the course of this project. Inset principles indicate sub-categories sitting under wider principles.

Principle	Definition
Hierarchical Structure	Standardised typologies have a structure with levels, with lower levels nested within higher ones. Higher levels of the hierarchy usually encompass more variation than do lower levels, and usually, but not always, correspond with a greater spatial extent. Thus, higher levels are more generic (e.g., forest (terrestrial); warm-wet climate (rivers)) and lower levels are more specific (red-silver beech forest (terrestrial); warm-wet lowland (rivers)).
Spatially explicit	Distributions of typological units should be mappable through any practical combination of ground observation, remote sensing and spatial modelling.
Accommodates increased knowledge and change over time	
Updateable	This principle pertains to the products derived from typologies (e.g., maps). Typology-derived products should be able to be changed or updated. This could include the following types of changes: changes to spatial boundaries of ecosystem types based on both improvements in underlying data and real change over time (these two types of change should be able to be distinguished); and temporal changes to attributes (e.g., condition) of the defined ecosystem types.

Principle	Definition
Flexibility/adaptability	This principle pertains to the typology itself. The typology should be able to be modified, with clear and transparent version history. Changes to a typology could include the following: i) new ecosystem types can be added to the typology as more data becomes available; ii) ecosystem types can be split or combined when justified by new data - these may be ecosystem types that were present, but not defined in the typology or ecosystems that did not exist previously; and iii) methodological changes to the typology to define the ecosystem types more clearly – particularly applies to domains where ecosystem types are defined by environment.
Temporally explicit	This principle pertains to both the typology itself and the derived products. Both the typology and the derived products should be explicit about when the typology was created, when the underlying data were collected, and the time period to which derived products apply and when they have been updated.
Compatibility across domains and typologies	
Compatible	Ecosystem types in a typology are required to have clear relationships with the ecosystem types of other typologies for the same domain that are in use or were widely used in the recent past. This facilitates the transfer information from one typology to another and enables comparisons across typologies.
Consistent use of species concepts	The typology can accommodate that species names or the taxonomic concepts they represent can change through time.
Nesting under IUCN GET	The typology should be able to crosswalk to the IUCN GET, particularly to Level 3 Ecosystem Functional Groups.
Robust	
Parsimony and utility	The typology should be no more complex than required to achieve its specified purposes and should use simple, accessible and clearly defined terminology (Keith et al. 2022 – Appendix 1).
Transparent and reproducible	How the typology itself was created is transparent and is either sufficiently well described that it could be repeated by a different person and achieve the same result, or it is defensible. It should be clear whether the typology is derived from data by quantitative analysis, informed by data, or expert-derived.
Comprehensive	
Coverage for ecotones	The typology should allow areas of transition between ecosystems to be depicted, both by their relationship to the classification units and in mapping.
Accommodates transformed ecosystems	The typology should include ecosystem types that encompass, as much as possible, the full range of ecosystem variation within their spatial, temporal and ecological extents. Transformed ecosystems include the following: human engineered ecosystems; those created by passing an ecological tipping point; successional; and novel ecosystems.

After familiarising ourselves with the two typologies, and with reference to the typology documentation (e.g., Snelder and Biggs 2002, Leathwick et al. 2008a), we undertook a systematic assessment of the typologies against each of the principles. Results were populated in an accompanying spreadsheet (Appendix A) and are summarised qualitatively below.

Additionally, we held a stakeholder meeting on 19 June 2024 with representatives from MfE (Graeme Clarke) and the Department of Conservation (DOC) (Dave West) to discuss the principles and their overarching suitability for evaluating a river specific typology. We also enquired about whether any other typologies should be considered, but the stakeholders did not suggest any further alternatives.

2.2 Assessment of how the existing typology maps to the IUCN GET, or the challenges in doing so

We read "Appendix S4. The IUCN Global Ecosystem" of Keith et al. (2022). We identified a subset of EFGs that we interpreted as being relevant to the river domain. We read the descriptive profiles of these EFGs and summarised their characteristics (Table 2-2). We read descriptions of groups comprising the REC and FWENZ classifications from Snelder and Biggs (2002) and Leathwick et al. (2008a) respectively. We qualitatively assessed the degree to which REC and FWENZ groups could be cross-walked to IUCN GET EFGs. Cross-walking involves groups from one typology being associated with groups from another typology. We considered whether cross-walked relationships would manifest as one-to-one, one-to-many, or many-to-many joins.

Table 2-2: A brief interpretation of the description of IUCN GET Level 3 ecosystem functional groups that may be relevant to rivers. Summarised from Appendix 4 of Keith et al. (2022).

IUCN GET v2.1 ecosystem functional group within functional biome	Summary of description
Rivers and streams biome	
F1.1 Permanent upland streams	1^{st}–3^{rd} order, steep, fast, coarse, riffle-pool periodic high-flows.
F1.2 Permanent lowland rivers	4^{th}–9^{th} order, shallow slope, slow, low turbulence, flow (<10,000 $m^3 s^{-1}$).
F1.3 Freeze-thaw rivers and streams	Surfaces of both small streams and large rivers freeze in winter.
F1.4 Seasonal upland streams	1^{st}–4^{th} order, highly seasonal flows, wet & dry seasons.
F1.5 Seasonal lowland rivers	5^{th}–9^{th} order, floods (tropics = summer, temperate latitudes = winter).
F1.6 Episodic arid rivers	Long dry periods, temporal variability in flows, mostly lowland.
F1.7 Large lowland rivers	8^{th}–12^{th} order, shallow, slow, low turbulence, flow (>10,000 $m^3 s^{-1}$).
Subterranean freshwaters biome	
SF1.1 Underground streams and pools	Subterranean streams, pools, & aquatic voids (flooded caves).
SF1.2 Groundwater ecosystems	Within or below groundwater (phreatic) zones.

IUCN GET v2.1 ecosystem functional group within functional biome	Summary of description
Anthropogenic subterranean freshwaters biome	
SF2.1 Water pipes and subterranean canals	Engineered structures, move waters between sources.
Artificial wetlands biome	
F3.1 Large reservoirs	Rivers are impounded by the construction of dam walls.
F3.2 Constructed lacustrine wetlands	Shallow, open water bodies that have been constructed.
F3.5 Canals, ditches and drains	Artificial streams with low horizontal and vertical heterogeneity.
Semi-confined transitional waters biome	
FM1.2 Permanently open riverine estuaries and bays	Mixed saline marine waters versus freshwater inflows.
FM1.3 Intermittently closed & open lakes and lagoons	Shallow coastal waterbodies intermittently connected with ocean.

We noted that there are two GET EFGs within the rivers and streams biome that are likely to be commonly occurring for NZ rivers (F1.1 Permanent upland streams and F1.2 Permanent lowland rivers). GET descriptions of F1.1 and F1.2 both reference stream order, which we presumed refers to the Strahler stream ordering system (Strahler 1957). Although Keith et al. (2022) did not provide a technical method for stream order calculation or river network generation, they did produce maps based on stream orders taken from the RiverATLAS database of Linke et al. (2019), which indicates that GET descriptions refer to Strahler stream order. Permanent upland streams are described in Keith et al. (2020) Appendix 4 as being 1st–3rd order, fast and turbulent with coarse substrates. Permanent lowland rivers are described as being 4th–9th order, slow and low turbulence with depositional (fine) substrates. We suggest that stream size (represented here by stream order) and stream hydraulics/substrate should not be viewed as mutually exclusive, because larger rivers can be relatively fast with coarse substrates in steeper upland locations, whereas smaller rivers can be relatively slow and silty in low slope lowland locations. This is true in NZ, where larger (order>3) braided rivers that are relatively fast with coarse substrates are present in mountainous locations, and small channelised rivers that are relatively slow and silty are common in lowland locations. The relevance to ecosystem functioning of relatively high water velocities, high turbulence, and coarse substrates is alluded to in GET descriptions. The relevance to ecosystem functioning of stream order is not explained in GET descriptions. We therefore chose to down-weight the importance of stream order within the definitions of F1.1 and F1.2 when seeking to cross-walk NZ river typologies to GET EFGs. As such, we placed most emphasis on the upland-lowland, fast-slow, and coarse-fine parts of the definitions of F1.1 and F1.2. A similar situation was noted for F1.4 (Seasonal upland streams) and F1.5 (Seasonal lowland rivers), because F1.4 are described as 1st–4th order with coarse substrates and F1.5 are described as 5th–9th order.

We noted the following details within the definitions supplied by Keith et al. (2020) Appendix 4:

- For F1.3 (Freeze-thaw rivers and streams), freezing refers to freezing of stream water rather than freezing of water on land as snow or ice. GET world map within Keith et al. (2020) hints this group may occur in the Central Southern Alps of NZ.
- For F1.4 (Seasonal upland streams), marked wet and dry seasons are described. Seasonal intermittence with flows ceasing and water persisting in isolated stagnant pools are also described. GET world map indicates this group does not occur in NZ.
- For F1.5 (Seasonal lowland rivers), cyclical/seasonal flow regimes are described with low and disconnected flows during the dry season. Connections between river and floodplain during the wet season are mentioned. GET world map indicates this group does not occur in NZ.
- For F1.6 (Episodic arid rivers) short duration flows (days to weeks, rarely months) punctuated by long dry periods are described. GET world map indicates this group does not occur in NZ.
- For F1.7 (Large lowland rivers), very large flows (>10,000 $m^3 s^{-1}$) and stream orders (8^{th}–12^{th} order) are described. GET world map indicates this group does not occur in NZ.

We noted that one EFG (F3.5 Canals, ditches and drains) from the artificial wetlands biome is also likely to occur commonly across the NZ landscape. Whilst F3.5 does not fall within the rivers and streams GET biome, this EFG was relevant to our brief because some canals support ecological values (e.g., fish and macroinvertebrates), and some current ditches/drains may have been created after engineering or removal of historical river channels (Brierley et al. 2023).

2.3 Roadmap of steps to develop an updated river ecosystem typology to meet the Principles and align with the IUCN GET

In developing the roadmap for a national river ecosystem typology, we considered:

- The potential purpose(s) and use of a New Zealand river ecosystem typology.
- Pre-requisites for the development of an operational river ecosystem typology.
- Key requirements for a credible and relevant river ecosystem typology.
- The alignment of the existing typologies with the principles.
- The ease of cross-walking the existing typologies to the IUCN GET.
- Cross-domain considerations (do the river, lake, and wetland typologies need to intersect?).

When creating the roadmap, we took the following key steps:

- Read and acknowledged previous comments from MfE and various stakeholders as described in Collins (2024).
- Reviewed the background documentation for REC and FWENZ.
- Undertook a rapid literature search for river typologies in use globally.
- Considered key challenges in deriving and implementing a national river ecosystem typology.
- Identified how the shortcomings of REC and FWENZ relative to the principles could potentially be overcome.
- Identified critical steps for the development of a revised national river ecosystem typology.
- Considered future practical applications of the typology.
- Sought feedback from stakeholders (Dave West of DOC, Sandy Haidekker of HBRC) on the draft roadmap.

3 Results

3.1 Overview of the REC and FWENZ river typologies

3.1.1 River Environment Classification (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 hypothesised 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. Groups within levels 1 (climate), 2 (topography), 5 (network position), and 6 (valley landform) of the REC can be expressed sequentially (e.g., mountain-hill-lowland), whereas groups within levels 3 (geology) and 4 (landcover) cannot be expressed sequentially. REC classes are defined by concatenating classes at the level of interest with all classes from higher levels. Classes at lower levels are, therefore, not independent of classes at upper levels.

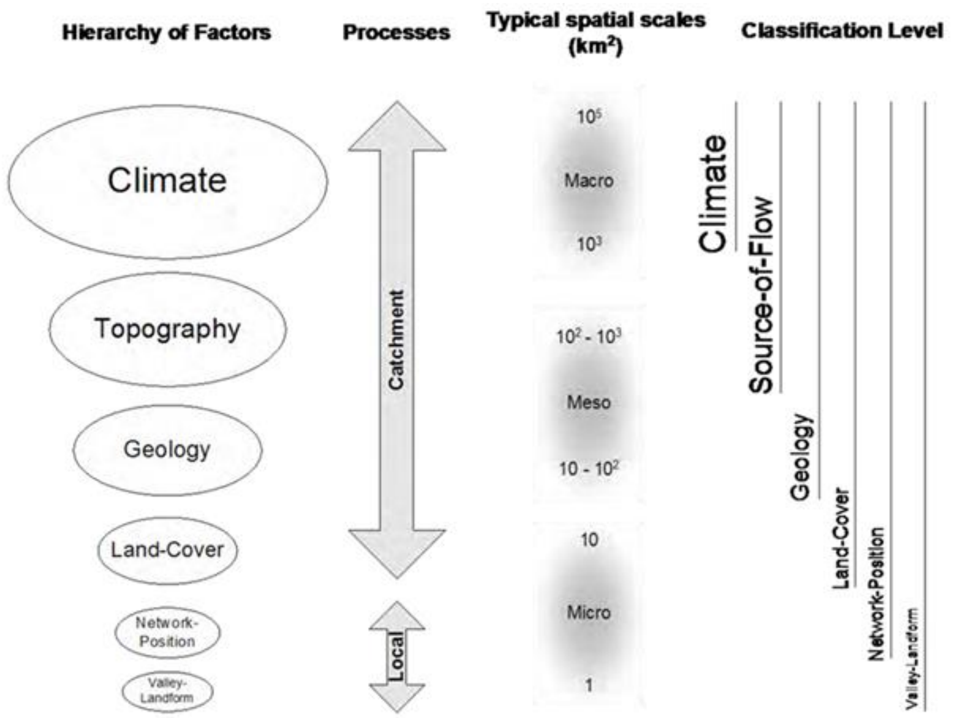

Figure 3-1: Diagram of the REC levels. Levels are based on the controlling factors, differentiated at three general scales and the patterns of physical characteristics discriminated at each classification level. Taken from Snelder and Biggs (2002).

Datasets used to produce maps of REC classes are fully described in Table 3-1 of Booker (2023) and summarised as follows.

- Rainfall; a grid of mean annual precipitation (mm/year).
- Potential evapo-transpiration (PET); a grid of mean annual PET (mm/year). Likely using Priestley-Taylor method for PET calculation method, rather than Penman calculation method.
- Temperature; a grid of mean daily air temperature (°C).
- Elevation; a grid of elevation (m).
- Snow and ice cover; polygons of permanent coverage by snow and ice.
- Lakes; polygons of lakes.
- Geology; polygons of simplified geology categories.
- Landcover; polygons of simplified landcover categories.

The above listed spatial datasets must be intersected with the polygons that identify areas draining to each segment of a Digital Network (DN) in order to calculate and map REC classes. A DN is required to calculate and map REC classes, but the class definitions are independent of the DN. Each of the above datasets and the national DN has been updated since calculation of the original REC classes (circa 1998–2000), but REC classes have not been calculated using updated datasets.

The REC classes have been used for delineation of Freshwater Management Units as required by the National Policy Statement for Freshwater Management (NPS-FM). 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 fine sediment in the National Objectives Framework (NOF) within the NPS-FM. Inclusion of REC in the NOF means that regional councils are obliged to assign a REC class to each site where deposited and suspended sediment are being monitored.

3.1.2 Freshwaters Environments of New Zealand (FWENZ)

The FWENZ is a biologically tuned data-driven hierarchical classification of New Zealand's rivers (Leathwick et al. 2008a). The FWENZ classification was developed using two biological data sets describing the distributions of freshwater fish and macroinvertebrates, and a candidate set of functionally relevant environmental variables. The method used Generalised Dissimilarity Modelling (GDM) to identify the environmental variables, weightings and transformations that best explain biological dissimilarities across sites. The environmental variables were then used as inputs to a multivariate classification of the stream segments comprising the NZ national DN (version 1). Weightings and transformations of these variables were also specified from the GDM analysis. The matrix of transformed environmental predictors was classified in a two-stage process, using non-hierarchical medoid clustering to define an initial set of 400 groups, with relationships between these groups then defined using hierarchical clustering to identify a 20-group classification (Figure 3-2) and a 100-group classification. FWENZ is used for conservation planning purposes by the Department of

Conservation and is used by some regional councils and researchers. Groups within the 20-group level of the FWENZ classification are not ordered and do not have meaningful names. However, Leathwick et al. (2011) did create brief descriptions of class at the 20-group level after having inspected the spread of values for environmental variables for segments assigned to each group. These descriptions were subsequently expanded to include the 100-group level by Storey (2012).

The GDM method used to produce the FWENZ classification is most appropriate for application when all biological variables (species/taxa) are relevant across all locations. Several NZ native fish and macroinvertebrate species have restricted ranges or are very rarely observed, including some that were used to create FWENZ classes. For example, Leathwick et al. (2010) indicates that 13,369 records covering 30 fish species described in Leathwick et al. (2008b) were used to create the FWENZ classification. Leathwick et al. (2008b) indicated that 9 of the 30 species were present in less than 10 catchments, and 10 of the 30 species had less than 100 presences amongst the 13,369 records. It is unclear whether it is valid to develop a FWENZ-type classification using data for species that cannot access all locations because they have restricted ranges or that are very rarely observed.

Datasets used to produce maps of FWENZ classes are described in Leathwick et al. (2008a) and summarised as follows.

Biological data - observed data as follows:

- Freshwater fish presence-absence extracted from the New Zealand Freshwater Fish Database (NZFFD).
- Macroinvertebrates presence-absence collated from compilation of samples collected by Regional Council staff throughout New Zealand as part of routine monitoring of water quality.

Environmental data - estimates of the following:

- Average minimum river flow (Pearson 1995).
- A metric of low flow variability (Pearson 1995).
- Summer air temperature (Leathwick and Stephens 1998).
- Seasonal air temperature range (Leathwick and Stephens 1998).
- Riparian shading (Leathwick et al. 2005).
- Segment slope (Snelder and Biggs 2002).
- Average sediment size expressed as a weighted average after having assigned ordinal values to descriptive classes (modelled from field observations stored in the NZFFD).
- Habitat conditions expressed as weighted average after having assigned ordinal values to habitat classes (modelled from field observations stored in the NZFFD).
- In-stream nitrogen load (Woods et al. 2006).

Some, but not all, of the above datasets (either raw observed data or estimated values across a DN) and the national DN itself have been updated since calculation of the original FWENZ classes (circa 2008–2010). However, FWENZ classes have not been calculated using updated datasets. For example, several methods for predicting low river flows across the landscape were compared by Booker and Woods (2014). If updated datasets were available to recalculate FWENZ classes, then the machinery (original R data objects) used to define FWENZ classes would have to be available and applied because FWENZ classes are based on clustering of transformed environmental variables.

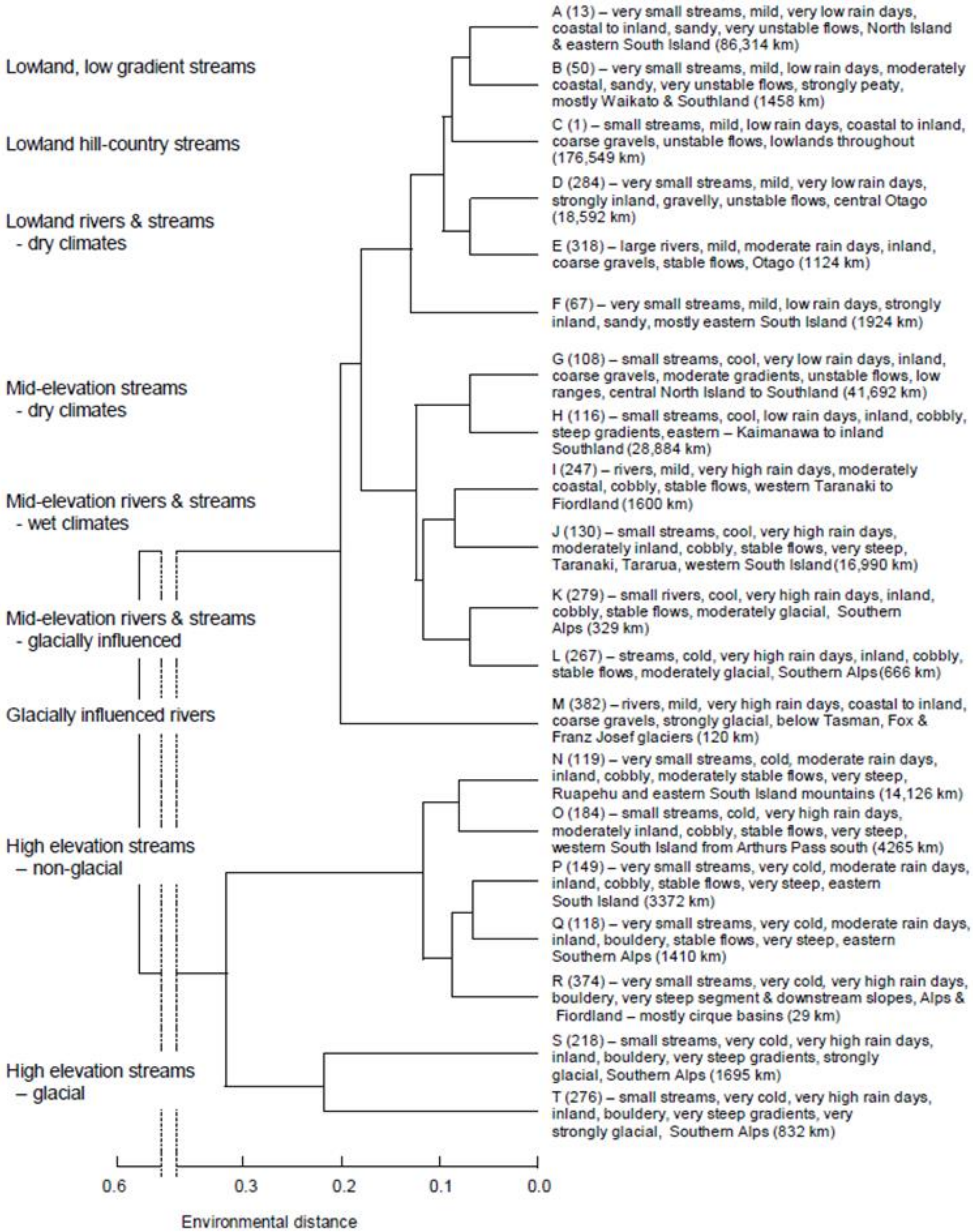

Figure 3-2: Dendrogram describing relationships between groups of the final combined classification at a 20-group level. Taken from Leathwick et al. (2008a).

3.2 Assessment of how well the existing typologies meet the Principles

The REC and FWENZ both align well with some of the principles, but neither aligned well with all principles (see Appendix A for details). The REC meets more principles than FWENZ, including some of those considered most critical for an effective ecosystem typology by Collins (2024). Both typologies have a hierarchical structure and are spatially explicit when mapped onto a river network. The REC adheres reasonably well to some of the principles for the following reasons:

- Flexibility/adaptability because REC thresholds defining classes at each level could be changed or expanded without fundamentally altering the structure of the classification.
- Updateability because new maps of classes could be generated if input data (e.g., landcover) changes.
- Compatibility because class labels were somewhat relatable to those of other classifications (e.g., REC Level 2 describing climate and topography is somewhat relatable to IUCN GET Level 3).
- Transparency because the definitions of classes are well described.
- Reproducibility because methods for attributing locations to classes can be reproduced.
- Parsimony because there are fewer classes at higher levels of the classification with complexity being added at lower levels, although the method of using concatenating labels can be cumbersome.
- Ecotones because some (but not all) levels have sequential labels.
- Being easily understood because the labels of classes are meaningful to ecologists and environmental managers (labels describing wetness, warmth, topography, e.g., cool-wet-mountain).

However, the REC does not adhere well to the principles for temporal explicitness, consistent use of species concepts, comprehensiveness nor accommodation of artificial ecosystems. In large part this is because the REC is an environmentally driven classification and does not explicitly include any biotic drivers/descriptors.

The utility of the REC has been demonstrated through its use in the National Objectives Framework and regional planning (e.g., definition of Freshwater Management Units).

The FWENZ generally adheres well to the principles relating to compatibility, transparency, and reproducibility for the following reasons:

- Compatibility because the class descriptions were somewhat relatable to those of other classifications.
- Transparency because the classes are qualitatively described.
- Reproducibility because the methods used to derive the classification are relatively well documented.

The data driven nature of FWENZ is a strength due to objectivity in its outputs, and a weakness due to biases in the observed data, reliance on various technical decisions for generation, stochasticity (an element of random sampling of network segments is applied), river network dependence, and, importantly, the entire classification would change if regenerated. An area where the FWENZ outperforms REC is in the use of species concepts in the classification process, although it is still not strong in this respect. Biotic data were used to train the environmental classification process. However, the biotic datasets used are subject to known biases in representation and spatial coverage, for example. Furthermore, species concepts are not an integral component of the class descriptions; they are still inherently abiotic. As with the REC, FWENZ did not adhere well to principles relating to temporal explicitness, comprehensiveness nor accommodation of artificial ecosystems. Importantly, FWENZ did not adhere well to the flexible/adaptable principle because if the biological data input to the GDM model fitting are updated, then the GDM could be re-fitted, but this would result in a fundamentally different classification and the meaning of each class would have to be re-interpreted/defined and cross-walking performed.

Leathwick et al. (2011) indicates that the FWENZ classes and their subsequent mapping was river network dependent since transformed environmental values predicted across all 567,000 segments of a river network (rather than just observed data locations) were clustered to define classes. This method has the advantage of attempting to remove bias in observed data locations, but implies a bias towards representing smaller channels because the network used to calculate FWENZ classes (Digital Network version 1) contains far more segments representing smaller streams than segments representing larger rivers. It also means that the FWENZ is river network specific, i.e., if the representation of the river network is updated and FWENZ classes are regenerated, then a new classification with new labels is produced.

3.3 Assessment of how the existing typology maps to the IUCN GET, or the challenges in doing so

Table 3-1 indicates how REC Level 2 (topography) classes could be cross-walked to GET EFGs. It should be noted that, according to Snelder and Biggs (2002), REC Level 2 classes should be applied in conjunction with REC Level 1 (climate) classes. We chose not to include REC Level 1 in Table 3-1 because descriptions of REC topography classes relate much more strongly to GET EFGs descriptions, whereas descriptions of REC climate classes relate weakly with GET EFGs descriptions.

The cross-walking process was not straightforward for two main reasons:

1. Complications arose due to the lack of clarity and possible lack of mutual inclusivity within the GET EFGs. For example, it is possible for a river to be fast and coarse (implying F1.1) as well as having marked wet and dry seasons (implying F1.4).

2. Complications arose because of possible one-to-many mappings for some REC Level 2 classes to EFGs. If we ignore stream size in the EFG descriptions, then some REC classes mapped solely to one EFG. For example, both Glacial Mountain and Mountain classes map solely to F1.1. Similarly, the Lowland class maps solely to F1.2. However, it is unclear whether Hill maps to F1.1 or F1.2, and Lake-fed can clearly map to either F1.1 or F1.2 because lakes appear in both upland and lowland locations. The algorithm that attributes river reaches to topography classes is sequential, and Lake-fed is the last class to be assigned (see Figure 3-3), thus it is possible to calculate which topography

class a reach was assigned to before it was assigned to the Lake-fed class. However, this determination could only be made inside the REC calculation algorithm.

Table 3-1: Possible cross-walking between IUCN GET Level 3 ecosystem functional group and REC Level 2 classes irrespective of their concatenation with REC level 1 (climate). Square brackets indicate possible many-to-one join from GET to REC. Round brackets indicate possibility for cross-walking after amendments to REC have been applied.

IUCN GET v2.1 ecosystem functional group	REC level 2 classes	Comments
F1.1 Permanent upland streams	Glacial Mountain, Mountain, [Hill, Lake-fed]	REC classes based on upstream average conditions rather than local altitude.
F1.2 Permanent lowland rivers	Lowland [Hill, Lake-fed]	See comment in row above.
F1.3 Freeze-thaw rivers and streams	(could be incorporated if Extremely-cold class is defined within REC Level 1)	Not likely to be present in NZ climates where snow and ice can influence hydrology, but river water rarely freezes.
F1.4 Seasonal upland streams		Although low flows in NZ streams are likely to occur in late summer or early autumn (or mid-winter in very cold catchments due to freezing), high flows can occur year-round due to small catchment sizes and dominance of pluvial over nival water precipitation. Drying may occur in some headwater streams during dry periods.
F1.5 Seasonal lowland rivers		See comment in row above. Note drying may occur in NZ lowland rivers flowing across aquifers due to a combination of geology and anthropogenic streamflow depletion.
F1.6 Episodic arid rivers		NZ rivers are unlikely to have sufficiently short duration of natural flows to meet GET description. Possibility of longer drying periods through anthropogenic actions such as drainage or groundwater abstraction to reduce flow and groundwater levels.
F1.7 Large lowland rivers		No NZ rivers are large by global standards.
F3.5 Canals, ditches and drains		Not defined as a REC class, and not necessarily mapped in present national digital river networks.

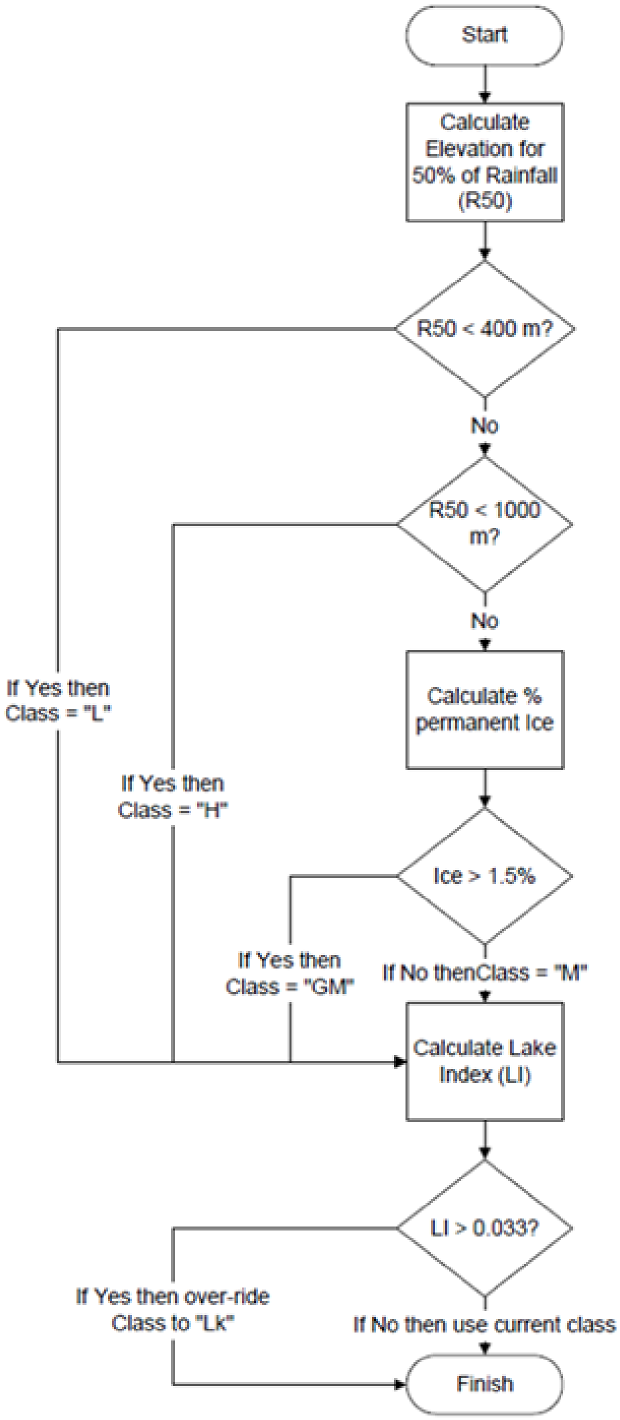

Figure 3-3: Schematic showing how REC topography classes are calculated.

Cross-walking of FWENZ 20-groups to EFGs is possible (Table 3-2) but also involves applying subjective decisions and suffers from similar complications to those mentioned above for cross-walking of REC topography classes to EFGs. Lack of clear mapping from FWENZ to EFG is exemplified by the description for FWENZ class C that states “small streams, mild, very low rain days, coastal to inland, coarse gravels, unstable flows, lowlands throughout”. For group C, “coarse gravels” (and “small streams” if stream size was being considered as a factor for cross-walking) would imply mapping to F1.1, whereas “lowlands” would imply F1.2.

Table 3-2: Possible cross-walking between IUCN GET Level 3 ecosystem functional group (F1.1 and F1.2 only) and FWENZ groups. Square brackets indicate possible many-to-one join from GET to FWENZ.

IUCN GET v2.1 ecosystem functional group	FWENZ 20-group classes	Comments
F1.1 Permanent upland streams	[C], [D], [G] H, I, J, K, L, M, N, O, P, Q, R, S, T	Classes C, D and G all mention coarse substrates as a defining characteristic, which aligns with the qualitative description of F1.1. However, classes C, D and G are also primarily associated with lowlands, which contradicts with the F1.1 description.
F1.2 Permanent lowland rivers	A, B, [C], [D], E, F, [G]	See note above.

We noted that F3.5 (Canals, ditches and drains) do exist in NZ, but could not be cross-walked from either REC or FWENZ because neither classification contains groups that describe ditches/drains. We also noted that canals, ditches, and drains are not explicitly represented in the digital river network onto which REC and FWENZ are currently mapped.

3.4 What could modifying the REC look like?

It is our assessment that the REC currently better fulfils the principles compared to FWENZ, including being more amenable to being cross-walked to GET Level 3. However, REC does not currently fulfil all the principles. In our view, REC is also likely to be more readily modified to be fit-for-purpose (as expressed to us in our discussion with MfE and DOC) and better fulfil the principles than FWENZ. If modification of REC was selected as the best option for creating a national river ecosystem typology (see roadmap steps below), there are several ways in which the REC system could be adapted or replaced to increase its utility. Ideally, options would be co-developed with users. Below we outline some potential options for future improvement to the REC-type system to be used as an ecosystem typology relating to rivers. A pre-requisite for any updated/new river ecosystem typology is improved mapping of the river network and collation/creation of associated attribute data (environmental and biological) (see Section 4.3).

3.4.1 Recalculate using updated environmental data

REC classes were originally mapped onto DN version 1 but have recently been recalculated onto DN version 2.4 using methods described in Booker (2023). Since a map of existing REC classes is required to distinguish target attribute states under the existing NOF, data and algorithms were devised to emulate calculation of the original REC classes onto the newer DN. REC classes were, therefore, calculated using data that are at least 25 years old. If updated datasets were used to recalculate REC classes, then thresholds used to define REC classes may also have to be revisited (e.g., if a different method for calculating PET has been applied, then the original thresholds defining wetness may not be relevant). There are three connected issues relating to new data and use of thresholds defining classes that should be carefully considered but can be resolved by applying technical solutions:

1. Are the newly available data comparable to the original data? If new data are comparable with original data, then the original thresholds for defining classes are suitable for use with the new data to delineate the original classes. If the new data are

not comparable with the original data (because measurement or interpolation/extrapolation methods have changed), then the original thresholds for defining classes may have to be revisited to best delineate the original classes. It should be noted that comparisons between spatial datasets of environmental variables and adjustments to thresholds are non-trivial tasks.

2. Is the original set of thresholds for defining classes still relevant (regardless of changes to the data)? One example is the threshold for warmth (<12°C is cold, >12°C is warm). It may be desirable to introduce a new threshold to define an Extremely Warm class to reflect the possible effect of increasing air temperatures on rivers flows (e.g., Booker and Snelder 2022).

3. REC levels using categorical data (geology, landcover) could be recalculated using newly available data, but the new data categories would have to be cross-walked onto the original data categories if continuity with the original Snelder and Biggs (2002) classes were desirable.

3.4.2 Change definitions of existing classes/levels

Snelder and Biggs (2002) used the elevation above which 50% of rainfall falls (R50) to assign segments to be Lowland (R50 < 400 m), Hill (R50 < 1000 m), or Mountain (R50 >= 1000 m) (Figure 3-3). This definition resulted in some low-lying, segments being assigned as Lowland even though their topography was steep. Thus, segments on Banks Peninsula and the Canterbury Plains were both assigned to the Lowland class even though the former may be more hill-like than the latter. Information describing slope could be used to create a system with improved discrimination of topography that may also be more ecologically meaningful. Improved DEMs derived from LiDAR data may allow a more accurate or nuanced representation of slope than was previously available.

Snelder and Biggs (2002) devised a metric called Lake Index which used lake area and catchment area to approximate the influence of lakes on river flows when defining the REC Lake-fed class. Snelder and Biggs (2002) stated that Lake Index was applied because storage-discharge relationships were unavailable for most lakes. The Lake-fed class within Level 2 of the REC (Topography / Source-of-flow) could be better represented if storage-discharge relationships were available for lakes.

Snelder and Biggs (2002) used the Strahler stream ordering system to define network position. Booker et al. (2024) proposed application of a negative stream ordering system to negate the influence of DN resolution on calculated stream orders. Network position could be represented independently from DN resolution if the negative stream ordering system were applied or catchment area was used to define network position.

Snelder and Biggs (2002) assigned all segments of their DN to REC classes to map each REC level across the landscape. This approach produces a map with appropriate coverage if all segments comprising the DN represent river channels. This approach would produce a map with inappropriate coverage if some DN segments represent ephemeral flow pathways rather than river channels. Booker et al. (2024) proposed a multi-coloured labelling system that could be used to distinguish between river, artificial, and ephemeral channels to overcome this issue by allowing REC classes to only be mapped to river channels, which are labelled “blue” in the multi-coloured labelling system.

3.4.3 Introduce new and/or replace existing classes/levels

Snelder and Biggs (2002) set out a clear rationale for their selection of the current REC levels and classes. However, stakeholders have noted that the REC fails to discriminate some river types that are considered ecologically and functionally meaningful. For example, the REC does not differentiate between braided and non-braided rivers despite their significant differences in ecosystem structure and function compared to single-channel rivers. Additionally, the REC does not currently incorporate reach-scale environmental descriptors (e.g., meso-habitat types) that can have an important influence on the local physical characteristics (e.g., deposited fine sediment, hydraulic conditions) and abundance and distribution of aquatic organisms (e.g., macroinvertebrates, periphyton, fish). Modifying the REC would offer the opportunity to add new levels, or replace existing levels, to address these perceived shortcomings in the REC for some purposes.

Channel planform (as a function of valley confinement) has been used internationally as a key driver for delineating river types morphologically. For example, Rinaldi et al. (2016) used a combination of valley setting (confined and unconfined) and morphological types (single-thread, transitional, multi-thread) to define seven basic river types. Metrics of sinuosity, braiding and anabranching were used to help delineate different planforms based on remote sensing data. A similar class could potentially be incorporated into a revised REC to better differentiate important morphological differences in river type in New Zealand. Incorporating channel planform would strengthen the REC's representation of ecological processes in alignment with the principles. Channel planform is also used qualitatively in the descriptors of GET Level 3 classes, which may assist with cross-walking from a modified REC to GET. Inclusion of channel planform would also potentially improve the relevance of the classification for some users and purposes. A challenge in implementing channel planform may be developing an automated pipeline for quantifying these characteristics across the national river network in a way that they can easily be incorporated into a national typology. Sourcing and applying the appropriate remote sensing data to quantify or verify river planform characteristics is also a challenge.

River ecologists will often use meso-habitat units (e.g., pools, riffles, runs, etc.) to characterise river habitat quantity and quality. Physical habitat provides the template for life and, therefore, shapes ecological communities. Consequently, there is a functional basis for considering incorporating a classification of meso-habitat units into REC. Incorporating meso-habitat types into REC may be advantageous in terms of the principles (about reflecting NZ's ecological processes and being understood by New Zealanders), but it would require nationwide estimates of these meso-habitat types to be mappable at a national scale. Meso-habitat units should be incorporated at the lowest level of the classification, reflecting the scale at which they are relevant. Again, meso-habitat units are used in the qualitative descriptions of the GET Level 3 classes, so incorporating them into a national river typology may assist with cross-walking.

A range of other drivers have also been used as the basis of river typologies globally (see for example Fuster et al. 2015, Rinaldi et al. 2016, Ouellet Dallaire et al. 2019, or Solheim et al. 2019). There would be value in exploring whether any of these make a more logical basis for delineating classes within the REC and/or could improve the discrimination of biotic communities between classes.

Improved landcover data and LiDAR data may allow a metric representing shade to be incorporated into a REC-type river classification. Representation of shade may be beneficial for describing water temperature and periphyton growth.

Field observations combined with spatial modelling (e.g., Haddadchi et al. 2018) or remotely sensed data may allow incorporation of bed substrate size into a REC-type river classification. Representation of bed substrate sizes may be beneficial for discrimination of ecological processes such as periphyton growth/removal, fish habitat, suspended sediment etc. Options for representing substrate size might include classes representing the dominant substrate class (e.g., silt/sand, gravel, cobble, boulder, bedrock).

4 Roadmap of steps to update existing typologies to meet the Principles and align with the IUCN GET

4.1 Purpose(s) and use of a river ecosystem typology

The primary goal of a classification system or typology is to group entities with common characteristics in a way that minimises within group variation and maximises between group differentiation. Landscape-scale typologies are often used in environmental management to define management units. The use of environmental typologies in this way assumes that structure and/or function within a class can be treated as equivalent, while there are meaningful differences in structure and/or function between classes and, consequently, that class membership can dictate the nature of required management interventions. The implication is that different management actions, environmental targets, conservation status levels, etc can be devised for, and applied to, different classes to achieve optimal outcomes. As such, derivation of environmental typologies for the purpose of management, policy or environmental reporting must be both informed by the intended purpose for the typology and cognisant of how their use can be "productive of the outcomes of environmental governance" (Tadaki et al. 2014).

Solheim et al. (2019) defined a water body type as "a group of lakes or rivers having common natural ecological conditions in terms of geomorphological, hydrological, physico-chemical, and biological characteristics." It is apparent from this definition that there is a wide range of characteristics that can be used to delineate river types. The relative importance of these different characteristics can vary considerably over both space and time, and with different intended purposes. As such, there is a need to make value-laden decisions and contestable choices regarding the selection of procedures, methods, and rules to delineate and classify river ecosystems (Tadaki et al. 2014). To ensure that a typology is credible, relevant, and legitimate (sensu Cash et al. 2003) it is important that these decisions and choices are made transparently and in collaboration with those required to implement and use the typology (i.e., following a co-design model).

River typologies are used globally for a wide variety of purposes. For example, Ouellet Daillaire et al. (2019) reviewed 60 river classifications in developing their Global River Classification Framework. Example uses include for scientific purposes (e.g., building conceptual or predictive models), for river management (e.g., designing monitoring systems, defining limits and management interventions), and for conservation planning (e.g., identifying unique/rare river types, protected area design). In New Zealand, river typologies are embedded in national policy frameworks (e.g., the REC is used to define management classes for sediment in the National Policy Statement for Freshwater Management), are used by regional councils for strategic decision making, by the Ministry for the Environment for national environmental reporting, and by the Department of Conservation for conservation planning and in the resource management process (Collins 2024). The diversity of uses and applications can result in differing and potentially conflicting requirements of river typologies; for example, the scale at which they apply, or the key drivers used to delineate classes (e.g., hydrological versus biological). Having a clearly defined purpose(s) and understanding how the typology is to be used is, therefore, critical for ensuring that the resulting typology is fit for purpose and is adopted and applied by practitioners.

No specific purpose for the domain typologies was specified in our project brief, except for enabling international reporting in alignment with the IUCN GET. Rather, there was an emphasis on the typologies fulfilling the pre-defined principles, with a presumption that any typology that met the principles would be fit for multiple unstated purposes. The Steering Group and MfE subsequently indicated that some potential uses could include conservation planning, protected area design, state of the environment reporting, and Red Listing of ecosystems. MfE particularly mentioned the need to represent spatial extent of braided river channels as an example use. In the context of the rivers domain, additional potential uses (many of which were identified as potential use cases in Collins (2024)) include defining planning units (e.g., Freshwater Management Units as required by the NPS-FM), applying water resource use limits (e.g., Target Attribute States or National Objectives Framework limits also required by the NPS-FM), implementing adaptive management, developing freshwater monitoring programmes, identifying the habitats of threatened species, flood hazard identification, or planning and prioritising river restoration efforts (amongst others).

It is our view that application of a single typology and associated river/freshwater mapping system to fulfil multiple uses would be desirable for reasons of efficiency, however, it is highly improbable that a single river ecosystem typology can serve all possible use cases. They each have differing requirements in terms of the spatial and temporal scales they operate at and the key functional drivers that will be of primary importance. While a hierarchical classification may help to address the challenge of operating over different spatial scales (e.g., broad scale uses might use a higher level of the classification and local scale uses might use a lower level of the classification), the relative importance/ordering of different functional drivers (e.g., climate, geology, flow regime, topography, meso-habitat, substrate, biological communities) will differ (potentially significantly) between different intended use cases. We envisage that there are multiple pathways towards establishing a typology that meets (most of) the principles (although see Section 4.2 for commentary on the applicability of the principles for rivers), but that the typologies resulting from different pathways could take forms that will vary in their suitability for different purposes. **Consequently, clarifying with users their primary use cases for the river ecosystem typology and associated mapping system is important for ensuring that key choices on typology form and function are justifiable and relevant.**

4.2 Applicability of the principles to rivers

The principles were derived via consultation with stakeholders as described in Collins (2024). It is our understanding that the intent was that a typology that met the principles would be fit for many purposes. The identified principles are logical, and a good typology is likely to incorporate/reflect many of these principles. However, in many cross-domain ecosystem management initiatives there is a tendency for concepts from the terrestrial domain to have a strong influence on shaping thinking, with some of the unique characteristics of aquatic ecosystems commonly ignored or underrepresented (Birnie-Gauvin et al. 2023). It is our view, and that of our DOC stakeholders, that the current principles fail to adequately consider some of the key features of freshwater ecosystems that may be important in developing a fit-for-purpose river ecosystem typology (e.g., the need for a mountains to sea approach).

For both classifications, the primary departure from the current principles relates to the incorporation of consistent species concepts. This is because both REC and FWENZ are fundamentally environmental classifications. This characteristic is common to most river typologies globally and reflects the dominance of environmental drivers in river ecosystems, and relatively sparse data on biotic composition in aquatic systems that can be used either to drive bottom-up classifications or as definitive descriptors of river types (Gurnell et al. 2016, Solheim et al. 2019, Ouellet Daillaire et al. 2019).

Many of the high-level environmental drivers used in top-down river typologies (e.g., elevation, stream slope, geology) are effectively static over time. Changes to river typologies can arise through improved mapping precision and accuracy (e.g., increasingly fine resolution digital elevation models) rather than real changes in landscape conditions. This situation is beneficial in so far that class delineation is relatively stable over time. However, it also means that classes cannot be re-mapped to reflect changes in biotic composition or quality over space or time; that is, they are not very updateable with respect to biotic changes. Lower-level environmental drivers that may be incorporated in top-down river typologies (e.g., river planform or mesohabitat composition) can be more temporally dynamic (although over varying temporal scales). As such, they may be more updateable, but class definitions still do not respond to changes in biotic composition or quality.

Biologically driven, or bottom-up, river typologies are relatively uncommon (although see Jusik et al. 2015 for one example). One of the main reasons for this is that biological data from rivers tend to be relatively sparse and are frequently strongly spatially (e.g., to wadeable streams where sampling is more practicable) and temporally (e.g., summer only sampling) biased. Furthermore, because of the dynamic nature of river systems, biotic communities are often in flux and rarely reach a stable climax community that can be used as the basis of consistent class delineation or description. In New Zealand, for fish this is exacerbated by the importance of diadromy in structuring fish communities both spatially and temporally. These significant gaps and biases in biological data from rivers makes development of spatially explicit and comprehensive bottom-up river typologies virtually impossible.

A critical aspect of river ecosystems that is not captured in the current principles is the dendritic, spatially accumulating nature of river systems between their source and the sea, and the necessity to account for the impact of both proximate and distal drivers of ecosystem type. Furthermore, rivers are highly dynamic (due to the dynamism of flow regimes) meaning that, particularly at the reach to sub-reach scale, habitat mosaics can vary regularly in their spatial extent and configuration. Rivers are also typically mapped as line features rather than as polygons. Line features will be suitable for many purposes (e.g., calculating the length of river that has been fenced or is estimated as being in good or bad condition) but may not meet the principles for spatial explicitness (e.g., the spatial boundaries of a class may not be represented) or updatability (e.g., quantifying changes in spatial extent). In contrast, line features may not be suitable for some purposes, for example flood mapping or measuring encroachment of braid plains.

In our view, it is highly likely that neither a bottom-up (biologically driven) nor a top-down (environmentally driven) river typology can fulfil all the principles. Furthermore, additional principles may be required for a fit-for-purpose river typology. Our recommendation is that the best pathway forwards for New Zealand is to adopt an environmentally driven river classification that is based on ecological principles and concepts and is validated based on its ability to effectively discriminate biological and physical (e.g., deposited sediment) patterns. The goal should be to maximise utility by ensuring it is fit-for-purpose(s) while ensuring it meets as many of the principles as possible.

4.3 Pre-requisites for mapping a river ecosystem typology

Maps of rivers are a prerequisite for mapping a river typology. REC and FWENZ were mapped onto national Digital Network (DN) version 1 around 2000–2002 and 2006–2008 respectively. DNs are virtual representations of spatially explicit connections across coupled freshwater-land systems. DNs are not just maps of river lines because they must comprise representations of surface flow pathways (segments), areas contributing to each surface flow pathway (watersheds), and connections between surface flow pathways (routing).

Maps of REC and FWENZ classes were calculated using input data available at the time of their development. We have recently devised machinery (computer code and data) to calculate REC classes onto newer versions of the national DN (or any functioning DN). The current procedure emulates the original results by using the original REC data, but newer data could be entered into the calculations. 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) regardless of which DN they are projected onto.

Questionnaire results provided by regional councils and Department of Conservation staff have indicated that the currently available national DN (e.g., v2.4) is used for many purposes, but there are concerns over whether all segments represent rivers (rather than ephemeral flow pathways) and inaccurate segment alignment in some locations (Booker 2023). Booker et al. (2024) proposed use of LiDAR data to generate national DNs and a multi-coloured classification system to overcome these issues by distinguishing DN segments as representing rivers rather than ephemeral channels. If implemented, the multi-coloured classification system would also distinguish artificial segments (e.g., canals) and realigned segments.

The methodology for producing the FWENZ classes was DN-specific since it includes a step which classified the transformed environmental values after they had been predicted onto the 567,000 segments in the DN.

Regardless of the preferred pathway for defining a revised or new river ecosystem typology, two items are essential for progressing functional river ecosystem typology: a) derivation of an improved digital river network that utilises recently acquired high-resolution LiDAR data; and b) collation of associated environmental and biotic attribute data. Ideally, both these items would be updateable over time.

4.4 Some key needs of a river ecosystem typology

Because river typologies are used for a diversity of applications across science, policy, and management, it is likely that any typology must fulfil multiple functions if it is to receive widespread adoption. Consequently, the river typology must be comprehensive (i.e., have full coverage of the New Zealand river network) and flexible (i.e., reflect a range of functional drivers and operate across a range of scales).

A critical feature of a river typology that is unique compared to the other domains is the need to account for the unidirectional, accumulating nature of river systems from their source to the sea. This means that a river typology must incorporate the influence of both proximate and distant drivers of ecosystem character, and recognise that the importance of these drivers likely varies between different ecosystem components (e.g., periphyton and macroinvertebrates may be more strongly influenced by proximate variables than highly mobile migratory fishes). One consequence of river typologies being influenced by distal drivers is that classes can sometimes be expressed sequentially (e.g., mountain-hill-lowland or dry-wet-extremely wet or small-medium-large), however other classes are not sequential (e.g., urban-pastoral-forest).

Another key element is that the typology should effectively discriminate biotic communities. Most existing river typologies take a top-down (i.e., environmentally driven) rather than bottom-up (i.e., biotically driven) approach to defining classes or types (Gurnell et al. 2016, Ouellet Daillaire et al. 2019). This reflects both the strength of environmental controls on aquatic biota in rivers and the relative availability of environmental versus biotic data that can be used as the basis of deriving classifications. A strength of environmentally driven top-down classifications is that they are reproducible, transparent, and can be mapped onto any network provided the necessary environmental data are available. Environmentally driven top-down classifications also often have the benefit of using recognisable class names. A weakness of environmentally driven top-down classifications is that they rarely explicitly incorporate biological data in their generation. Thus, if the selected environmental drivers do not represent key abiotic controls on biotic communities, they may not effectively discriminate community composition. Consequently, environmentally driven top-down classifications are often tested for their ability to discriminate observed biological (or chemical e.g., nutrients) patterns.

Whilst it should be a goal to aligning a revised/new river typology with the principles as far as practicable, it is essential that the river typology also recognises and directly accounts for the explicit requirements of freshwater ecosystems (e.g., taking a mountains to sea approach).

4.5 Preliminary roadmap

Below we propose some critical steps towards development of a national river ecosystem typology. The proposal is informed by our recommendation that the best pathway forwards to assist river management for New Zealand is to adopt an environmentally driven river classification that is based on ecological principles and concepts that can be mapped using improved input data or digital network and is validated based on its ability to effectively discriminate biological and physical patterns.

It is our assessment that the REC currently better fulfils the principles when compared to FWENZ and is more readily adapted (compared to FWENZ) to increase its consistency with the principles. However, it is also our view that adapting the REC or FWENZ to better fulfil the principles may not be the only or best pathway towards an improved national river ecosystem typology for New Zealand. Our roadmap reflects this view.

Some critical steps in developing a national river ecosystem typology include:

1. Establish a river ecosystem typology governance/working group.
2. Devise workflow to produce a digital river network needed to map groups of any typology, including considerations of how “rivers” (rather than ephemeral channels) should be defined and mapped. Consider whether rivers should be represented with lines or polygons or a mixture or lines (e.g., for smaller channels) and polygons (e.g., for larger or braided channels). Also, determine whether artificial channels (e.g., canals and raceways) need to be mapped so that they can be subsequently classified if artificial environments are recognised within the classification.
3. Undertake a global literature review of river typologies.
4. In consultation with the governance/working group and informed by the literature review and agreed use cases, determine whether the best option is to:
    A. Use REC even though it does not meet all the principles.

B. Review and modify REC to better fulfil the principles and ensure it meets the requirements of the agreed use cases. For example, consider addition of layers that describe river planform (e.g., braided, meandering), meso-habitat structure (e.g., pool-riffle, run, glide), bed substrate (e.g., silt/sand, gravel, cobble), and/or suspended sediment.

C. Develop a new river ecosystem typology for New Zealand that fulfils the principles and meets the agreed use cases.

5. Determine data requirements and availability for selected option.

6. Source data required for mapping and validation of a classification, including biological data and digital river network fulfilling requirements as determined in #5 above.

7. In collaboration with the governance/working group, develop and test the updated/new river ecosystem typology for agreed use cases.

8. Map new typology and develop GET reporting framework (including a framework for cross-walking to IUCN GET Level 3).

These steps are not necessarily sequential, but there are dependencies between some of them (Figure 4-1). The rationale and future options for each of these steps are elaborated in the following sub-sections.

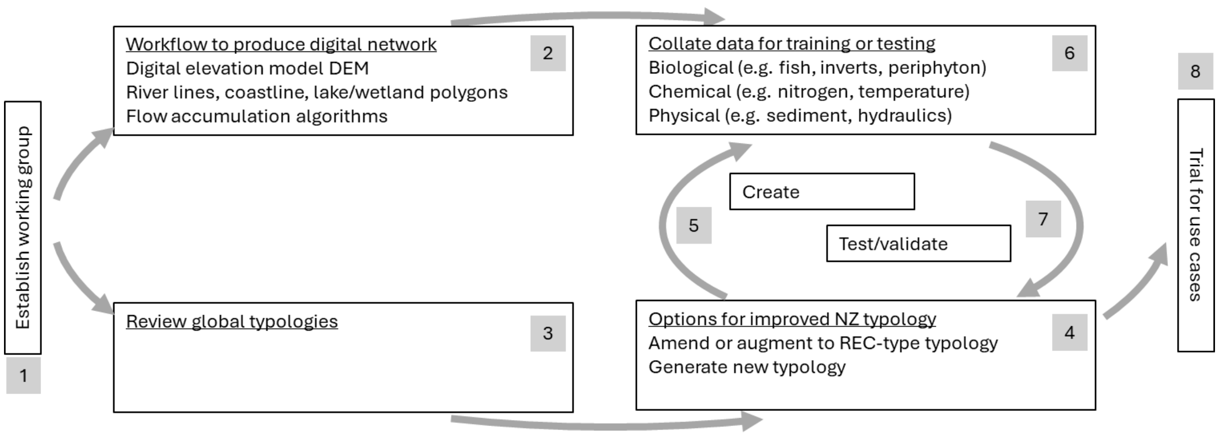

Figure 4-1: Diagram showing roadmap towards a river ecosystem typology. Grey boxes correspond to numbered items described in the text of this report.

4.5.1 Establish a river ecosystem typology governance/working group

Why do we need this step?

- Uptake of the typology will require buy-in from potential users.
- Co-design will be critical for ensuring the relevance and legitimacy of the typology.

Things we need to consider:

- Greater relevance and legitimacy will increase the likelihood of the typology being adopted by users.
- Confirmation of typologies being fit-for-purpose should come from users.

Proposed actions:

- Establish a river ecosystem typology governance/working group including representatives from:
  - Ministry for the Environment
  - Department of Conservation
  - Regional councils
- Consider utilising existing groups such as Resource Managers Group (RMG), Surface Water Integrated Management group (SWIM), or other appropriate Special Interest Groups (SIGs).
- Define terms of reference.

4.5.2 Determine the prerequisites for a digital river network

Why do we need this step?

- We must be able to map the river ecosystem typology to a river network to enable practitioners to use it.
- The precision and accuracy of the river network will impact both mapping of the typology and user confidence in the typology.

Things we need to consider:

- The river network may need to represent current river locations, and/or historic (natural, or non-engineered) river locations.
- Accuracy of river network alignment should benefit from high-resolution elevation data (e.g., LiDAR) but these data are not yet available for the entire country, therefore, production of river networks should be automatically updateable, version controlled, spatially consistent, and functionally.
- The river network would include mapping of lakes and could include mapping of wetlands, and could also be used to map the typologies devised for these domains.
- Some purposes may need the river network to represent river width and, therefore, area (e.g., purposes relating to “room for the river” or “encroachment” on braided rivers).
- The river network should be multi-purpose so that it is consistent with outputs from biophysical models that are often used alongside maps of classifications.

Proposed actions:

Consider implementing recommendations of following reports:

- Booker, D.J. (2023) National river digital networks and the River Environment Classification: future pathways for stewardship, maintenance, and upgrading of products and services for national benefit. NIWA client report 2023272CH prepared for the Ministry for the Environment. 39p.
- Booker, D.J., Wilkinson, C., Wilkins. M. (2024) Digital Networks: challenges, solutions, and case studies to inform nationwide integrated freshwater-land mapping. NIWA client report 2024138CH prepared for the Ministry for the Environment. 90p.

4.5.3 Global review of existing river ecosystem typologies

Why do we need this step?

- Neither REC nor FWENZ (or modifications thereof) may be the best solution for a national river ecosystem typology.
- There are lessons to be learned from the development of existing typologies that may be relevant to establishing a national river ecosystem typology for New Zealand.

Things we need to consider:

- Neither the REC nor FWENZ meet all the principles.
- There are many existing river typologies globally that may fulfil the principles.
- This step should both inform, and be informed by, potential use cases for the typology.

Proposed actions:

- Undertake a literature review of existing river ecosystem typologies.
- Use the literature review to:
  - Identify any existing typologies that may fulfil the principles
  - Identify key drivers used in developing existing typologies
  - Record the features of existing typologies that effectively discriminate ecological communities
- Present the results of the literature review to the river ecosystem typology governance/working group.

4.5.4 Determine the best option for creating and maintaining a national river ecosystem typology

Why do we need this step?

- Achieving consensus on the best option will help to improve legitimacy.
- How the river ecosystem typology is to be used will dictate contestable decisions on the form and function of the typology.
- Identifying a best option will enable improved specification and definition of subsequent steps.

Things we need to consider:

- What are the agreed use cases for the river ecosystem typology.
- Who are going to be the main users of the river ecosystem typology.
- How is the river ecosystem typology going to be delivered to users.
- What is the timeline for delivering the river ecosystem typology.
- What resourcing is available to deliver the river ecosystem typology.
- What are the data requirements for creating the river ecosystem typology and are those data readily available.

Proposed actions:

- Run an in-person workshop with the river ecosystem typology governance/working group to decide on the agreed use cases and preferred option for creating a river ecosystem typology.
- We propose that the decision should be based on selecting one of three options:
  a. Use REC even though it does not meet all the principles.
  b. Review and modify REC to better fulfil principles and ensure it meets the needs of the agreed use cases. For example, consider adding a meso-habitat level to the REC classes that can be used to identify local habitat conditions such as braided, pool-riffle, etc.
  c. Develop a new river ecosystem typology for New Zealand that fulfils the principles and meets the needs of the agreed use cases.

4.5.5 Determine the data requirements for creating and maintaining a national river ecosystem typology

Why do we need this step?

- Developing, validating, and delivering a river ecosystem typology requires data on environmental drivers, biotic response variables, and a functioning digital river network.

Things we need to consider:

- Data requirements will be influenced by the preferred option for creating a river ecosystem typology, but may also influence which options for creating a river ecosystem typology are available and practicable.
- Existing datasets are often spatially biased because they have been collected for specific purposes (e.g., consent compliance monitoring).
- Existing datasets are often not consistent or quality controlled.
- Datasets that could feed into production or validation of river typologies may exist inside an institution but not be available for analysis.

Proposed actions:

- Determine what data would benefit development, validation, and delivery of the preferred river ecosystem typology.
- Establish whether the required data are available, and from where.
- If the data required for the preferred river ecosystem typology are unavailable, consult with the river ecosystem typology governance/working group as to the next preferred option.

4.5.6 Source required data for creating and maintaining a national river ecosystem typology

Why do we need this step?

- Data are required to develop, validate, and deliver the preferred river ecosystem typology.
- These data need to be available and readily accessible for the modification/creation of the preferred river ecosystem typology.

Things we need to consider:

- What agreements may need to be put in place to access and use the data?
- How can data be accessed, e.g., Application Programming Interface (API) v manual download?
- Will data need to be continuously updated, implying processes for data collation and quality control are needed?

Proposed actions:

- Identify sources of required data.
- Secure access to required data.
- Collate data in a form suitable for typology development, validation, and delivery.

4.5.7 Develop and test a new national river ecosystem typology

Why do we need this step?

- This is required to deliver the new river ecosystem typology and ensure it meets the agreed use cases.

Things we need to consider:

- Ensuring that the typology meets the principles.
- Ensuring that there is a system for cross-walking the typology to Level 3 of the IUCN GET.
- Ensuring that the typology is fit-for-purpose(s).

- Validating the typology to ensure that it effectively discriminates ecological communities.
- Testing application of the typology for the agreed use cases.
- How the river typology will integrate with the other domains.
- Whether measures of river state/quality are required and what those measures might be.
- Whether a one-off data collation exercise is needed versus support for a platform for data collation that can be continuously updated.

Proposed actions:

- Project team to undertake analyses required to modify/create the river ecosystem typology to meet the specifications.
- Undertake biological validation to ensure the typology effectively discriminates ecological communities.
- Liaise with river ecosystem typology governance/working group to ensure development aligns with expectations of users.
- Work with river ecosystem typology governance/working group to test the modified/new river ecosystem typology, e.g., through a case study.
- Develop protocols for integrating the river typology with the other domains (e.g., alignments and linkages with lakes, wetlands, estuaries, groundwater and terrestrial).
- If required, develop measures of state/quality.
- Establish the preferred method for deployment of the typology to practitioners.

4.5.8 Map new typology and develop IUCN GET reporting framework

Why do we need this step?

- The typology needs to be mappable to support implementation and use.
- A framework is required to cross-walk the river ecosystem typology to the IUCN GET Level 3 for the purposes of international reporting.

Things we need to consider:

- How will the typology be made available to users?
- How will the typology be kept up to date?
- How will ongoing hosting and maintenance be resourced?
- How will the river typology integrate with the other domains?

Proposed actions:

- Map the river ecosystem typology to the digital river network and make available open access to users (options include https://shiny.niwa.co.nz/nzrivermaps/, LINZ, etc.).
- Develop a key for cross-walking the modified/new river ecosystem typology to IUCN GET Level 3.

5 Conclusions

The REC and FWENZ both align well with some of the predetermined principles, but neither aligned well with all principles. The REC meets more principles than FWENZ and is in wider use within New Zealand. Some of the strengths of the REC relative to FWENZ are that it can be projected on to any version of the digital river network, it is more easily updated or amended, and it is simpler to describe the REC classes. In comparison, it has been argued that because FWENZ is a data-driven, bottom-up classification that is tuned to biological data, it has greater biological relevance than REC, i.e., it better meets the principle to include species concepts. However, the data-driven methods used to derive FWENZ classes mean that it is river network specific and changes to the underlying data will result in a fundamentally different classification if it were updated, which is inconsistent with principles relating to updatable, transparent and reproducible.

It is our view that of the two classifications evaluated here, REC is likely more readily modified to meet more of the principles than FWENZ. Snelder et al. (2012) evaluated how well bottom-up stream classification procedures performed compared to top-down classifications. While they found that bottom-up procedures performed better at discriminating taxonomic communities compared to top-down procedures, they concluded that the gains in performance were relatively small compared to the greater complexity of the methods. As such, it is justifiable to focus on optimising the performance and utility of a REC-type classification (top-down) as opposed to a FWENZ-type (bottom-up) on the basis that it is more consistent with MfE's parsimony principle. It is also our view that a top-down classification will generate more easily described and recognisable classes compared to bottom-up methods, which we envision will support wider adoption.

We acknowledge that it would be possible to regenerate a FWENZ-type classification such that it incorporates more/improved data, but this will not better fulfil the principles. For example, we could use the latest biological data to re-run the models and create an updated version of FWENZ. However, it is our understanding that the FWENZ method is most appropriate for application when all biological variables (species/taxa) can access all locations. The repercussions of incorporating species with restricted ranges into a modified FWENZ classification are unclear.

While the principles are logical, it is our view that it will be challenging to generate a national river ecosystem typology that will meet all the principles. Furthermore, there is an apparent assumption that if a typology meets the principles, then it will be fit for multiple purposes; we are not confident that this would be true for rivers due to the different needs of identified potential use cases. Establishing a clearly defined purpose(s)/use cases in collaboration with potential users is a critical step prior to making decisions on the most appropriate pathway towards a national river ecosystem typology. Of the REC and FWENZ, it is our view that REC is more likely to be suitable for adaptation to meet the requirements of a national river ecosystem typology. However, we also recommend assessing the utility of river typologies used elsewhere globally to determine whether they may be more fit-for-purpose than REC (or a modified version thereof) before concluding that modification of REC is the best pathway towards a fit-for-purpose national river ecosystem typology.

We point out that some purposes previously described in Collins (2024) and identified by stakeholders during our work related to the mapping of rivers rather than the labelling of river classes. The generation of a fit-for-purpose digital river network using the latest high-resolution topographical data is, therefore, a pressing task for mapping of any river classification, regardless of amendment or development of a REC-type, FWENZ-type, or any other classification.

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Appendix A Alignment with Principles

Table A-1: Evaluation of REC and FWENZ against the Principles.

Principles		REC	FWENZ
1. Hierarchical structure	1.1 Level type	Environmental.	Environmental.
	1.2 Nesting type	Yes. Perfectly nested because lower levels are the concatenation of higher levels and level being considered.	Yes. Perfectly nested.
2. Spatially explicit	2.1.1 Is typology mapped?	Yes. Can be mapped onto any functional routing digital river network provided that spatially-continuous (polygon or gridded) input data are available describing elevation, rainfall, potential evapotranspiration, coverage of snow and ice, lake areas, geology, and landcover. Was originally mapped onto Digital Network (DN) version 1. Booker (2023) report to MfE describes process for mapping onto any Digital network.	Yes, but only onto Digital Network (DN) version 1.
	2.1.2 Indicate extent, resolution, and accuracy.	Partially. Extent, resolution, and accuracy (in terms of segment/channel alignment) are dependent on both the digital network onto which the classes are mapped, and the input data layers (elevation, rainfall, potential evapotranspiration, coverage of snow and ice, lake areas, geology, and landcover) used to define classes. NIWA's DNs span versions 1 to 3, but all have complete national coverage except for some outlying islands (e.g., The Chatham Islands, Auckland Islands). A DN comprises many segments. Each segment represents the length of river between two confluences. The resolution of a DN is defined by the number of segments and the length of these segments. For example, v2.4 is defined by 593,548 segments with an average length of approximately 700 m.	Partially. Currently mapped to DN1 (c.567,000 reaches c.700 m long). Also see REC comments.

Principles		REC	FWENZ
	2.1.3 Also indicate how the ecosystem occurrence is represented (i.e., points, polygons, etc)	Lines.	Lines.
	2.1.4 If not mapped, are there data that could be used to produce maps?	Yes. Machinery (code and data) exists to automatically project the existing typology/classification onto any river network using the data and congruent thresholds used at the time (circa 1998–2000) that the classification was developed. Note that newer data (e.g., topography, landcover, geology) exist but previous thresholds defining classes may have to be amended.	NA.
	2.2 Extent (current, historical, potential)	Classification is environmental. Top 3 levels (climate, topography, geology) largely static (except maybe long term changes in climate) and so represent historical/current/potential. Level 4 is land use and so is temporally explicit if data were available (e.g., recent LCDB versions translated so that labels are compatible with LCDBv1). Current LU is LCDBv1, so at L4 represents historical as would be consistent with that LCDB version.	Classification is based on environmental variables (e.g., slope, average summer air temperature) with classes trained to best discriminate patterns in observed biological data (fish and invertebrates) after they have been predicted across the entire digital river network.
	2.3 Are the methods used to map the typology sufficiently well described that they could be reproduced by a third party?	Yes. Rules-based model described clearly defined in reports and papers (e.g., Snelder and Biggs 2002). Has been reproduced to map onto any digital network. Some lack of clarity about which data would have been used to produce the original classification.	Partially. The general methodology is well described in reports and papers (e.g., Leathwick et al. 2011). However, some technical details are not prescriptive enough for results to be reproduced by a third party. Note, method is explicitly stochastic because randomly selected subsets of observed data are sampled and then used to fit models, before averaging over all fitted models. Therefore results will not be able to be reproduced precisely by a third party.
	2.4 Other comments	NA.	NA.

Principles		REC	FWENZ
3.1. Accommodates increased knowledge and change over time: Updateable	3.1.1 Spatial boundaries on maps can change over time?	Yes. If underlying environmental data change (e.g., rainfall), the class to which a river segment is assigned could change/be updated because the classification is rules based. Topography may change due to improved data (LiDAR) but should not cause widespread changes in mapped classes.	Partially. If underlying environmental data change (e.g., rainfall), the class to which a river segment is assigned could change/be updated. If the biological data input to GDM model fitting are updated, then the GDM could be re-fitted, but this would result in a fundamentally different classification and the meaning of each class would have to be re-interpreted.
	3.1.2 Temporal changes can be made to mapped unit attributes?	Partially. L4 of the classification incorporates land use. Hence the classification could be updated over time to reflect temporal changes in land use at L4–L6. Upper levels are unlikely to change substantially over time at short time scales. No measure of condition included at any level, so cannot reflect changes in quality of the class.	Partially. No measure of condition included at any level, so cannot reflect changes in quality of the class.
3.2. Accommodates increased knowledge and change over time: Flexible/adaptable	3.2.1 New ecosystem types can be added	Partially. Classification is abiotic. Could theoretically 'slice the pie' in a different way by changing the classification rules which would create different classes or move the spatial boundaries of existing classes. Will not reflect new biological data.	Not easily/No.
	3.2.2 Ecosystems can be split or combined	Yes, split and combined for all numerically-driven classes. Categories can be combined for all categorical-driven variables. Categories can be split for categorical-driven variables until the point when all categories in the base data are represented in the classification.	Not easily/No. Only by going up and down the levels of the hierarchy.
	3.2.3 Methods can be changed to better define ecosystem types	Yes. Could change the rules based on new knowledge, or change order of drivers, or change drivers.	Yes. Could use different statistical models.

Principles		REC	FWENZ
3.3. Accommodates increased knowledge and change over time: Temporally explicit	3.3.1 Time span of underlying data and when typology created documented. Changes have been date-stamped	No. Original is Snelder and Biggs (2002). Original underlying data somewhat documented in paper. Not specifically time stamped.	No. Original is Leathwick et al. (2008a). Original data somewhat documented in papers/reports. Not specifically time stamped. Not aware that it has been updated since original.
	3.3.2 If maps have been created, is the time period of application documented? Have any changes been date-stamped?	No.	No.
4.1. Compatibility across domains and typologies: Compatible	4.1.1 Rationale behind typology structure clear?	Yes. Explained in Snelder and Biggs (2002) and Snelder et al. (2005).	Yes. Explained in Leathwick et al. (2008a) and associated references e.g., Leathwick et al. (2011).
	4.1.2 Does it build on/acknowledge other typologies? Are relationships to units in other typologies explained?	No.	No.

Principles		REC	FWENZ
	4.1.3 Could the typology be cross-walked to other typologies in the domain	Partially. Classes of REC have specifically-described and objective definitions. Cross-walking is straightforward for stream order, which is a metric of stream size that is also mentioned under definitions of IUCN GET types for rivers. Cross-walking is possible for "topography" (Lowland, Hill, Mountain, Glacial-mountain, Lake-fed) if these labels exist in the other typology and have the same meaning.	Partially. Classes of FWENZ do not have specifically-described definitions because they emanate from a model fitting process, but numerical attributes (e.g., spread of altitude, etc) have been inspected to subjectively derive meaningful labels (e.g., Mid-elevation streams with dry climates). Cross-walking is therefore possible if these labels can be compared with those present in the typology being cross-walked to. Note; Leathwick et al. (2008a) report Figure 1 describes size using "large" and "small" "streams" and "rivers".
	4.1.4 Other comments	REC is a hierarchical classification.	FWENZ is a hierarchical classification.
4.2. Compatibility across domains and typologies: Consistent use of species concepts	4.2.1 Describe whether and how taxonomic changes can be accommodated	No concept of taxonomy is included in the classification.	Partially. Generalised dissimilarity modelling (GDM) used to create classification that defines an optimal set of transformations of candidate environmental predictors to maximise explanation of species turnover in site-based biological data. Biological data consisted of 30 fish species (some with very few presences, and several with restricted ranges), and 86 invert taxa. Taxonomic changes can be accommodated because the method uses a data-driven approach.
	4.2.2 Biotic names follow a reference taxonomy (e.g., NZOR). Please provide name of reference taxonomy	NA.	NZFFD codes for fish. Unknown for invert taxa?
4.3. Compatibility across domains and typologies: Nesting under IUCN GET	Yes, No, Partial	Partial.	Partial.

Principles		REC	FWENZ
5.1. Robust: Parsimony and utility	5.1.1 Detailed descriptions of units exist?	Yes. Units (classes, types) are mathematically defined.	Partially. Qualitative descriptions of classes (L1 and L2) have been presented in reports and papers.
	5.1.2 Clearly applicable diagnostic criteria to allow identification of units	Yes.	No.
	5.1.3 Do ecosystem names facilitate identification in the field?	No; not in the field.	No.
	5.1.4 Are the number of units manageable? Please specify the number of units at each level.	Yes. REC is a hierarchical classification. Number of classes increases with number of levels. Level 1 = 6. Level 2 = 30 (6×5), Level 3 = 210 (6×5×7), Level 4 = 1,680 (6×5×7×8), Level 5 = 5,040 (6×5×7×8×3), Level 6 = 15,120 (6×5×7×8×3×3). Although not all possible classes exist when mapped onto NZ. For example, only 2,793 combinations of classes exist at REC Level 6 when mapped onto DNv2.4.	Partially. FWENZ is a hierarchical classification. Level 1 = 20, Level 2 = 100. These are groupings of an initial 400 initial groups.
5.2. Robust: Transparent and reproducible	5.2.1 Method to produce typology documented and independently reproducible	Yes. Documented and reproducible (but need original data).	Yes, methodology documented, but several technical details are not prescriptively described which means that the final results may not be reproducible even if original data were available.
	5.2.2 If 5.2.1 is 'No', is the method defensible?	Yes. Well cited journal paper.	Yes. Well cited journal paper.

Principles		REC	FWENZ
	5.2.3 Was typology data derived, data underpinned, or expert-derived/qualitative	Data-derived with expert-derived thresholds to define classes.	Data-driven with expert-derived methodological choices.
6. Comprehensive	6.1 Does it accommodate transformed ecosystems including engineered, passed tipping point, successional, novel	Possibly, if "urban" and "pastoral" landcover classes are interpreted as transformed ecosystems. But does not, for example, distinguish systems modified by hydropower development nor delineate artificial watercourses e.g., canals, drains.	No. Intentionally designed to not include transformed ecosystems.
	6.2 Does it accommodate ecotones?	Partially. Somewhat recognises that classes have an order (e.g., dry-wet-extremely wet).	Partially.
	6.3 Does it distinguish biotic (e.g., species) assemblages that are uncommon?	No.	Not specifically.
	6.4 Is there any other form of ecosystem variation that is missing from the typology?	Yes. REC is a landscape-scale classification, therefore local environmental variables that are important drivers of ecology such as meso-habitat types (e.g., pool, riffle) and river planform types (meandering, braided) are not considered. It also does not explicitly include any biotic variables (e.g., species information).	Difficult to comment on since non-descriptive classes are derived from data-driven methods.
7. NZ-specific	7.1 Reflects NZ ecological diversity and processes (if NO explain why)	Partially. Reflect NZ landscape types (mountain, hill, lowland) but not explicitly ecological diversity and processes.	Partially. Explicitly incorporates ecological diversity, but has strong possibility for bias due to non-uniform spread of observed sites.

Principles		REC	FWENZ
	7.2 Does the typology use terminology and concepts familiar to NZ ecologists and conservation practitioners?	Yes.	Partially.