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Roadmap to update the existing ecosystem typology for lakes

Cawthron Report 4088

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REVIEWED BY: Simon Stewart

APPROVED FOR RELEASE BY:
Roger Young

PROJECT NUMBER: 18837

ISSUE DATE: 6 September 2024

RECOMMENDED CITATION: Wood S, Schallenberg L. 2024. Roadmap to update the existing ecosystem typology for lakes. Nelson: Cawthron Institute. Cawthron Report 4088. Prepared for Ministry for the Environment

Roadmap to an updated ecosystem typology for lakes

Susie Wood, Lena Schallenberg

Ministry for the Environment

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Executive summary

This report focuses on lakes and is part of a wider project that aims to develop a unified and overarching ecosystem typology for Aotearoa New Zealand.

Although typologies are not commonly used in the lakes domain in Aotearoa New Zealand, a single typology is included in the Freshwater Ecosystems of New Zealand (FENZ) database; however, there is uncertainty as to how this typology was determined. Furthermore, the FENZ lake typology cannot be updated because key information is missing, including, for example, the thresholds that define large and small lakes.

We assessed whether the current FENZ lake typology aligns with the set of principles developed by end users and defined in Sprague and Wiser (2024). The findings were also discussed with a stakeholder group, and it was determined that the current typology would likely meet three of the seven principles.

The authors of this report and the stakeholder group also evaluated the alignment of the current FENZ lake typology with the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET) lakes classification. The current FENZ lake typology could be nested into the *F2 Lakes biome*, the *F3 Artificial wetlands biome*, and the *FM1 Semi-confined transitional waters biome* of the IUCN GETs. However, this approach would be imprecise and result in lakes being placed only in *F2.1 Large permanent freshwater lakes* (> 100 km^2) and *F2.2 Small permanent freshwater lakes* (generally less than 1 km^2 but can be up to 100 km^2). Additionally, because the FENZ lake typology does not include any information on whether the lake is natural or artificial, many lakes would be nested in the *F2 Lakes biome* instead of the *F3 Artificial wetlands biome*.

The stakeholder group and the report authors determined that the following six key steps should form the basis of a roadmap to amend or replace the existing FENZ lake topology:

1. Establish a working group.
2. Ensure all 'use cases' for a new lake typology have been identified.
3. Research options for lake typologies.
4. Determine and obtain the data required for creating a lake typology.
5. Develop and test a new national lake typology (including a regional case study).
6. Map the new typology and develop an approach for aligning this to the IUCN GETS framework.

Step 4 will likely be the most important and challenging phase. During a recent update of the FENZ lakes layer, over 2,000 new lake polygons were added. However, the metadata for these lakes has not been generated (i.e. lake depth, catchment area and land use). Any typology developed will likely require this knowledge; therefore, this significant – and likely very time-consuming – work should be given high priority, as it impacts the development of a typology as well as the ability of organisations such as StatsNZ and the Ministry for the Environment to model national-scale lake water quality.

1. Background

This report, which focuses on lakes, is part of a wider project that aims to develop a unified and overarching ecosystem typology (a method for grouping similar ecosystems) for Aotearoa New Zealand. To achieve this, existing environmental domain-specific typologies were reviewed to establish if they are fit for purpose. The typologies were assessed against a series of principles developed through previous engagement with end users and stakeholders (Collins 2024); hereafter referred to as 'the Principles'.

Lake typologies are not commonly used in Aotearoa New Zealand, although several approaches were reviewed and suggested by Snelder (2006, 2012) and Snelder et al. (2012). The Freshwater Ecosystems of New Zealand (FENZ) database (Leathwick et al. 2010) includes a single typology; however, the authors of this current report could not establish exactly how the FENZ lake typology was determined. To our knowledge, the Department of Conservation (DOC) is the only organisation to currently use the FENZ lake typology, which is included as part of their lake prioritisation process to ensure that lakes identified for investment are representative.

This report provides a summary of the outcomes from discussions with stakeholders from the Ministry for the Environment (MfE) and DOC. It also outlines the steps required to develop an Aotearoa New Zealand-focused ecosystem typology for lakes that is consistent with the Principles, including nesting the typology under the IUCN GET.

2. Methods

The sections below outline the steps that were undertaken to develop a roadmap to amend or replace the existing FENZ lake topology.

2.1 Stakeholder meeting

The authors of this report met with key stakeholders from MfE (Dr Kohji Muraoka) and DOC (Dr Craig Woodward) on 27 June 2024.

2.2 Assessment of how well the existing typology aligns with the Principles

The current FENZ lake topology includes seven categories based on temperature, depth and size (Table 1).

Table 1. Aotearoa New Zealand lake typology as given in Leathwick et al. (2010).

Typology type	Description
A	Warm, shallow, moderate-sized
B	Warm, moderately shallow, small
C	Warm, shallow, very small
D	Mild, deep, large
E	Mild, moderately deep and size
F	Mild, shallow, small
G	Cool, moderately shallow, small

In a series of workshops in 2023, stakeholders from DOC, regional councils, the Ministry for Primary Industries (MPI) and MfE identified and developed nine national principles and five additional requirements for a standardised typology (Collins 2024) – these Principles are defined in Sprague and Wiser (2024). As part of this research, we completed an initial assessment of the FENZ lake typology against the Principles and discussed our findings at the stakeholder meeting.

2.3 Assessment of how the existing typology maps to the IUCN GET

The **Lakes biome (F2)** sits within the core realm of **Freshwater** in the IUCN GET. This includes nine relevant ecosystem functional groups (Level three):

- F2.1 Large permanent freshwater lakes
- F2.2 Small permanent freshwater lakes
- F2.3 Seasonal freshwater lakes
- F2.4 Freeze-thaw freshwater lakes
- F2.5 Ephemeral freshwater lakes
- F2.6 Permanent salt and soda lakes
- F2.7 Ephemeral salt lakes
- F2.8 Artesian springs and oases
- F2.9 Geothermal pools and wetlands
- F2.10 Subglacial lakes.

Two other ecosystem functional groups relevant to lakes in Aotearoa New Zealand are included in the **F3 Artificial wetlands biome** within the core realm **Freshwater**:

- F3.1 Large reservoirs
- F3.2 Constructed lacustrine wetlands.

Additionally, within the **realm – Freshwater Marine** (FM) and the **biome – FM1 Semi-confined transitional waters** there is one relevant functional group (Level three):

- FM1.3 Intermittently closed and open lakes and lagoons.

We assessed whether the current FENZ lake typology could be nested in the IUCN GET, or whether lakes in Aotearoa New Zealand in general regardless of their current typology, could be nested in the IUCN GET typology.

2.4 Roadmap of steps to update the existing typology to align with the Principles and the IUCN GET

A roadmap was developed based on the gaps we identified during the assessment of the FENZ lake typology against the Principles and the IUCN GET *Lakes*, *Artificial wetlands* and *Semi-confined transitional waters* biomes. The roadmap was further refined following discussions with representatives from MfE and DOC.

3. Results

3.1 Stakeholder meeting

The key discussion points addressed at the stakeholder meeting are outlined below.

There is uncertainty surrounding how the current FENZ lake typology was determined. Leathwick et al. (2010) referred to Snelder (2006) for a description of an approach that appeared to be the FENZ typology:

> The primary classification was based on six variables that influence the mixing and stratification regimes of lakes and that determine the dominant form of primary production and, therefore the broad character of the biological structure when considering all New Zealand lakes. The chosen variables were depth and area and the climatic and morphological characteristics, which together determine physical mixing, i.e. solar radiation and air temperature stratification; and wind in mid-summer and fetch, which together determine the vigorousness and depth of mixing and thus the depth of the stratified layer. It was assumed that the latitudinal variation in the climatic variables ensures that the spatial variation in the seasonality of stratification and mixing is also represented. (Snelder 2006).

However, no thresholds for temperatures, sizes or depths are provided in Snelder (2006) or Leathwick et al. (2010). In correspondence with the authors of this report in June 2024, Ton Snelder suggested that the approach proposed in his 2006 report was not followed (or at least not as outlined in the report). Despite several attempts to contact individuals who were likely involved in the development of the FENZ lake typology, we could not determine the exact process behind its design. This lack of clarity means that it is difficult to apply the FENZ typology to lakes in Aotearoa New Zealand.

During a recent update of lake polygons in the FENZ database, 686 lake polygons were removed because of a lack of water present, or because they had an open water area of less than 1 ha; in addition, some 'lake' polygons were identified as other features such as wastewater treatment plants, rivers or estuaries. A total of 2,166 new lake polygons were also added to the FENZ lake database (Schallenberg et al. 2024). However, further information on the development of the FENZ lake typology is required to determine its ongoing relevance. Furthermore, our assessment established that there is insufficient data to place lakes into the current FENZ lake typology. For example, data on depth and temperature are lacking for the 2,166 new lakes added to the FENZ database in 2024. Schallenberg et al. (2024) also emphasised the need for further work to model or determine key data for new lakes and reassess existing data for pre-existing lakes. There was strong support for this action at the stakeholder meeting.

The stakeholders acknowledged that there is a significant lack of data for most lakes in Aotearoa New Zealand. Any typology that is developed and applied nationally would likely rely on modelled physical data. The group acknowledged some new data sources are being made available that might be useful;

these include a national-scale modelling project led by Waikato University (work in progress); a satellite imagery project that has identified a range of variables including lake colour (Lehmann et al. 2018) and the presence of cyanobacterial blooms (led by Waikato University); national-scale modelling of water quality (a variety of sources including MfE and the Lakes380 research programme [Abell et al. 2019, 2020; Snelder et al. 2022; Wood et al. 2023]); and climatic information and the Land Cover Database.[1] A geomorphic classification was assigned to all lakes (including the new lakes) as part of the recent FENZ lake polygon update, and it may also be useful to consider this attribute in the development of a new typology.

There was a strong emphasis on understanding the purpose of any new (or revised / updated) lake typology and how it would be used in an Aotearoa New Zealand management context. The participant from DOC noted that they used the current typology in their prioritisation process to help assess whether the lakes selected for investment are representative. There was discussion around this process and a consensus that the current typology does not ensure that representative lakes are selected.

3.2 Assessment of how well the existing typology aligns with the Principles

We assessed whether the current FENZ lake typology aligns with the Principles developed by end users and defined in Sprague and Wiser (2024; Table 2). The group determined that the current typology would likely meet three of the seven Principles. There was consensus that a new lake typology could be developed to meet most, if not all, of these requirements.

Table 2. Alignment of the FENZ lake typology as described in Leathwick et al. (2010) with the Principles as outlined by the Ministry for the Environment.

Principles or Requirements	Aligned (yes / no)
Hierarchical structure	Yes
Spatially explicit	Yes
Updateable	Yes
Compatible	No
Robust	No
Comprehensive	No
NZ Specific principles	No

1 https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

3.3 Alignment of the current FENZ lake typology with the IUCN GET lakes classification

The current FENZ lake typology could be nested into the following three biomes of the IUCN GET: *F2 Lakes, F3 Artificial wetlands* and *FM1 Semi-confined transitional waters*. However, this approach would be imprecise and result in lakes being placed only in *F2.1 Large permanent freshwater lakes* (greater than 100 km^2) and *F2.2 Small permanent freshwater lakes* (generally less than 1 km^2 but can be up to 100 km^2).[2] Because we could not determine the size threshold used in the FENZ lake typology, some additional assessment of size (area) data for each lake would be required.

The FENZ lake typology does not include any information on whether the lake is natural or artificial; therefore, many lakes would be nested in the *F2 Lakes* biome, rather than the correct biome of *F3 Artificial wetlands*

Discussions at the stakeholder meeting led to the assessment that based on existing metadata, most lakes could be placed into either the *F2 Lakes,* the *F3 Artificial wetlands* or the *FM1 Semi-confined transitional waters* biomes, without the need for a typology. For example, there is existing information on lake size and some knowledge on salinity and geothermal influence. However, some clear data limitations were noted:

1. Freeze-thaw lakes – There is currently no information on ice cover for lakes in Aotearoa New Zealand. The stakeholder group noted that this could likely be obtained from satellite imagery and would represent a valuable undertaking in terms of assessing the impact of climate change.
2. Ephemeral lakes – The recent update of the FENZ lake polygons (Schallenberg et al. 2024) included notes on whether a lake was likely ephemeral based on recent satellite imagery. However, this work did not capture all ephemeral lakes, and further assessment is required.
3. Salt lakes – Although there is some knowledge of salt lakes in Aotearoa New Zealand, this information is not officially recorded in the FENZ (or other) lake databases.
4. Geothermal pools and wetlands – Although there is some knowledge of geothermal lakes in Aotearoa New Zealand, this information is not officially recorded in the FENZ (or other) lake databases.
5. Artesian springs and oases – There is a possibility that some lakes in Aotearoa New Zealand fit within this category, for example, groundwater-fed dune lakes. Knowledge of such lakes is very limited, and this information is not included in any national databases or the current FENZ typology.

The discussion acknowledged the challenge associated with developing a lake typology that is fully nested within the IUCN GET ecosystem functional groups (i.e. the *F2 Lakes,* the *F3 Artificial wetlands*, and the *FM1 Semi-confined transitional waters* biomes) and that is also relevant and useful for the management of lakes in Aotearoa New Zealand.

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[2] Based on the updated lake polygons, nine lakes in Aotearoa New Zealand would be placed in *F2.1* and the remainder in *F2.2*, of which 5,137 lakes are smaller than 1 km^2.

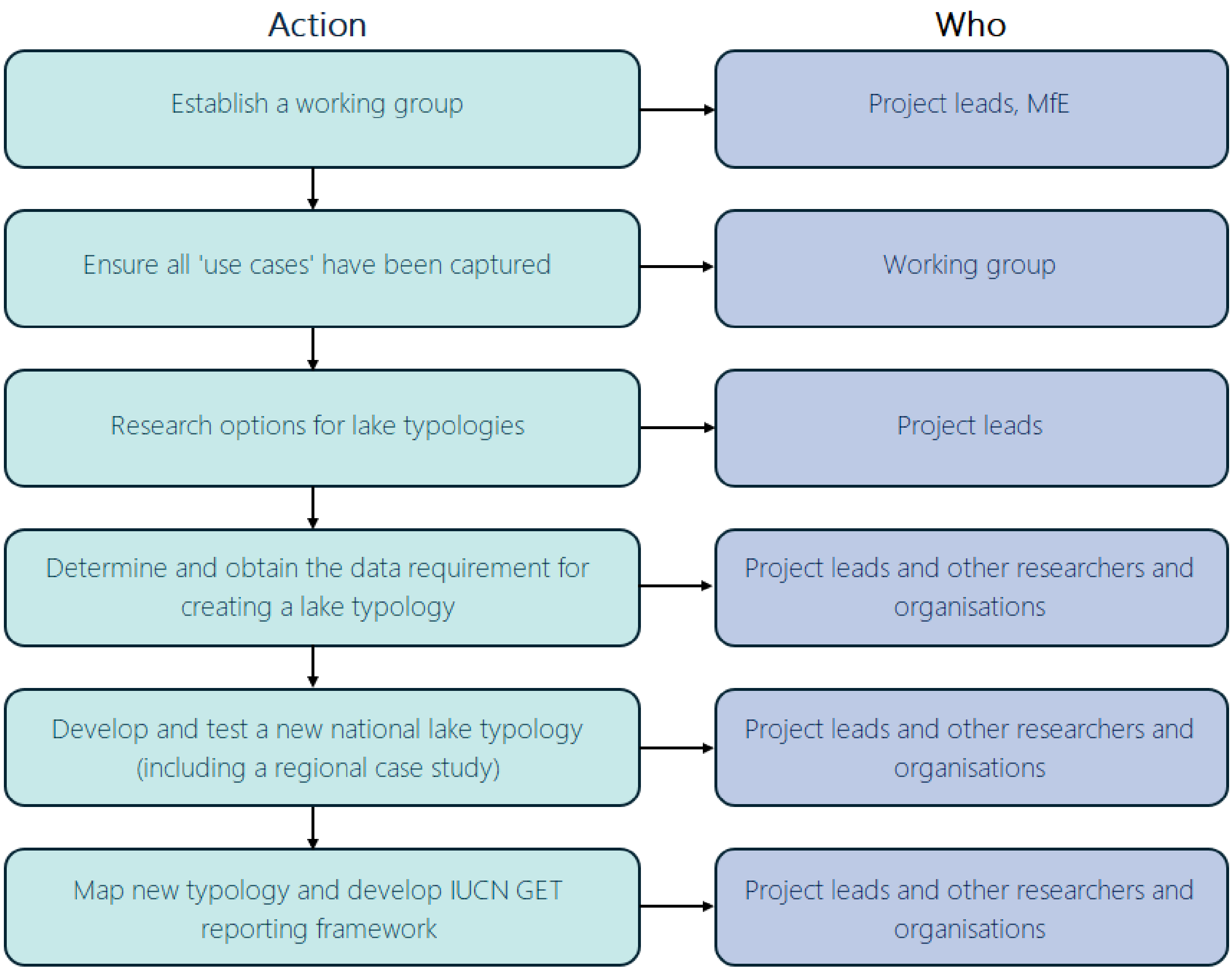
The importance of understanding and acknowledging the purpose of mapping / aligning lakes to both a lake typology and the IUCN GET was readdressed. It was acknowledged that while this approach could contribute to global reporting, such an exercise is unlikely to be useful for national or regional management or reporting.

There was uncertainty about whether a lake could be nested / aligned with two functional groups. For example, a lake might fit into both *F2.2 Small permanent freshwater lakes* and *F2.4 Freeze-thaw freshwater lakes*. The project leaders provided clarity by advising that if an ecosystem type is found to match two functional groups, then the proportion of fit is split between them. In the above example, the lake might fit 60% into the *F2.2 Small permanent freshwater lakes* and 40% into *F2.4 Freeze-thaw freshwater lakes*. This would likely be a relatively common scenario among lakes in Aotearoa New Zealand (i.e. most lakes would be split across functional groups).

4. Roadmap of steps to update the existing typology to align with the Principles

The stakeholder group and authors of this report determined that the following six key steps should form the basis of a roadmap to amend or replace the existing FENZ lake topology (Figure 1).

Figure 1. Steps required to develop a lake typology for Aotearoa New Zealand.



4.1 Establish a working group

Using a co-design process and seeking input from a range of lake experts and stakeholders will increase the robustness and relevance of a revised or new typology. It will also ensure that the typology is fit for purpose and enhance the likelihood of widespread uptake across a broad spectrum of potential end users.

A working group should include lake researchers from universities and research institutes, as well as consultants, Te Ao Māori experts, and freshwater scientists from regional and central government. Where possible, experts who were involved in the development / exploration of past lake typologies in Aotearoa New Zealand should be recruited for this working group and / or lead the research process. Key regional and central government organisations that should be involved include MfE, DOC and regional councils (this could be coordinated through the regional council lakes interest group). The inclusion of iwi in this group is particularly important, and this could involve liaising with iwi who are notably active in the lakes space, i.e. Te Arawa Lakes Trust, or seeking input from national groups such as the Freshwater Iwi Leaders Group.

Key actions:

- Discuss with MfE the types of expertise and representation that should be incorporated into the working group.
- Identify suitable members of the working group and send invitations.
- Establish the working group.

4.2 Ensure that all 'use cases' have been captured

Appendix 1 of Collins (2024) provides typology use cases submitted by MfE, DOC and regional councils. These examples provide a brief and generic overview of how the different agencies might make use of national-scale typologies. An initial task for the working group should be to refine this document and ensure that the key features and elements – as identified in Collins (2024) – are relevant to lakes and that no additional elements are missing. This work will impact decisions on the form and function of the typology, which is essential to ensuring that it is fit for purpose.

In the project brief, there is an emphasis on the typologies that fulfil the predefined Principles, with a presumed assumption that any typology that meets the Principles will be suitable for multiple unstated purposes. The Steering Group of the wider typology project 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.

In the context of the lakes domain, additional potential uses could include identifying lakes for protection or restoration (at regional or national scales), developing freshwater monitoring programmes and identifying the habitats of threatened species. **It is essential that all 'use cases' are identified**

before the development of the lake typology. This will ensure that key choices on typology form and function are justifiable and relevant.

Key actions:

- Run an in-person workshop with the working group (see Section 4.1) and representatives from MfE who are familiar with the overall aims of the typologies project. This will help ensure that all 'use cases' have been identified for the lakes domain.

4.3 Research the options for lake ecosystem typologies

The current lakes typology in Aotearoa New Zealand is not useable as there is no robust documentation on how it was developed.

Key actions:

- Actively acknowledge the considerable work that has previously been undertaken to explore the development of an Aotearoa New Zealand-specific lake typology (Snelder 2006, 2012; Snelder et al. 2012). This work should be revisited, as several different approaches were considered including multi-variant, bottom-up[3] and top-down[4] methodologies. Where possible, it would be valuable to engage with the authors of this previous work to develop a deeper understanding of their rationale and draw on their expertise and experience.
- Explore international approaches developed in the last decade to gain insights into whether they might apply to Aotearoa New Zealand.
- Present options for the lake typology to the working group. The working group should then assess and, if possible, agree that:
    - it is possible to develop a national lake typology (which is consistent with typologies from other domains) for multiple purposes
    - the benefits of using a unified typology (e.g. consistency across agencies) would outweigh the challenges associated with its development and adoption (e.g. development costs, possible loss of functionality for some purposes).

4.4 Determine and obtain the data required for creating a lake ecosystem typology

A key priority, before any new typology is developed, is to determine or model metadata for the lakes that have recently been added to the FENZ lake database (Schallenberg et al. 2024). This includes

[3] These methods use statistical methods such as clustering to group the classification locations into classes.
[4] This usually involves heuristic models that elucidate the assumed or known causes of differences between lakes.

parameters such as lake depth, catchment area and land use, catchment geology, and climatic conditions (Appendix 1). Any typology developed will likely require this knowledge.

The work that needs to be undertaken is significant and should be given high priority, as it not only impacts the development of a typology but also the ability of organisations such as StatsNZ and MfE to model national-scale lake water quality. Data for existing / original lakes in the FENZ database also need to be updated. For example, there is widespread acknowledgement that the lake depths in the database are inaccurate (e.g. Schallenberg et al. 2023).

Key actions:

Each of the tasks below will take considerable effort and likely need to be part of a multi-agency project.

- Review the international literature and evaluate different methods for estimating lake depth. Following this process, we recommend that lake depths be modelled or estimated for all lakes in the new database.
- Determine lake catchment size, land cover and altitude using GIS information. Recent work completed at the University of Waikato suggested that some of the catchment areas in the current FENZ database are inaccurate. We therefore advise that all catchment areas are evaluated.
- Ensure that all lake polygons from the updated FENZ lake database are integrated with future river databases, such as the national Digital River Network (Booker et al. 2024).
- Model / determine the other FENZ attributes for the newly added lakes (see Appendix 1).
- Update the FENZ database with information on ice cover and add data to identify ephemeral lakes, salt lakes, geothermal pools, wetlands, and artesian springs and oases.

4.5 Develop and test a new national lake ecosystem typology

In the unlikely scenario that the current FENZ lake typology cannot be updated, a new lake typology will need to be developed. When developing a new typology, the following points should be considered:

- The typology must align with the Principles.
- There needs to be a system for 'cross-walking' the typology to Level 3 of the IUCN GET.
- The typology must be fit for purpose(s).
- A case study in one region should be undertaken, ideally across multiple domains. This would allow the typology to be tested on a small sub-set of lakes to ensure that it can be used for the intended purposes. Using the same region to test all typologies would allow the researchers to investigate integration with other domains, such as rivers and groundwater.
- Identify if the data required are available at a national scale.

Key actions:

Based on the recommendations, the project team should:

- Undertake the analyses required to modify / create the lake ecosystem typology to meet the specifications.
- Liaise with the working group to ensure that the development of the typology aligns with the expectations of end users.
- Undertake a regional case study alongside the working group and other domain leaders to test the modified / new lake typology. A key focus of the case study should be to ensure the integration of the lake domain with other domains.
- Establish the preferred method for disseminating the typology to practitioners.

4.6 Map the new typology and develop the IUCN GET reporting framework

The lake typology will need to be mappable to support implementation and use. To facilitate international reporting, a new framework is required to cross-walk the lake typology to the IUCN GET Level 3. It will also be important to clarify the process for making decisions on the assignment of lakes (and the portion allocated) across multiple function groups.

Other considerations include:

- How will the typology be made available to end users?
- How will the typology be kept up to date? This is particularly important for the *F3 Artificial wetlands biome*. Our recent analysis (Schallenberg et al. 2024) showed that hundreds of artificial lakes have been constructed over the last decade.
- Who will host and update the lake database and associated typology?

Key actions:

- Determine a programme of action with the working group and MfE to seek answers to the above questions.
- Develop an approach for cross-walking the modified / new lake typology to IUCN GET Level 3.

4.7 Other considerations

Several other considerations were raised at the stakeholder meeting and while they do not fit directly into the roadmap, they are important to consider.

1. The stakeholder group acknowledged that currently there is unlikely to be sufficient biological data (e.g. biodiversity information) available to populate a lake typology; however, any new typology should have a flexible design so that new data can be included in the future. The group also recognised that new methodologies, such as environmental DNA, are changing the speed and scale at which biodiversity data can be generated.
2. The stakeholder group acknowledged that currently there is either no data or only very limited information available on the ecological value of artificial lakes, or how this varies among types of artificial lakes (i.e. a plastic-lined lake built as an irrigation reservoir versus a farm dam formed by blocking the natural flow of a stream – which may or may not have maintained some connectivity to the original stream). The group also recognised that addressing this knowledge gap will help guide important management considerations, such as whether artificial lakes should be prioritised for protection or restoration.

5. Acknowledgements

We thank Rowan Sprague and Susan Wiser for their excellent leadership and guidance throughout this project. Simon Stewart (Cawthron) is thanked for reviewing this report and Louisa Fisher (Cawthron) for scientific editing. We thank Kohji Muraoka (MfE) and Craig Woodward (DOC) for their valuable input into this report and the roadmap development.

Appendix 1. Metadata available for lakes in the original FENZ database

Lake classification	Description
LID	Unique lake identifier
Name	Name (where known)
Primary	Primary classification group (A to G)
Natural2	Natural classification level 2 (A.1 to G.3)
Natural3	Natural classification level 3 (A.1.1 to G.3.2)
Natural4	Natural classification level 4 (A.1.1.1 to G.3.2.1)
Natural5	Natural classification level 5 (A.1.1.1.1 to G.3.2.1.)
Current2	Current classification level 2 (A.1 to G.2)
Current3	Current classification level 3 (A.1.1 to G.2.1)
Current4	Current classification level 4 (A.1.1.1 to G.2.1.1)
Current5	Current classification level 4 (A.1.1.1.1 to G.2.1.1.1)
MaxDepth	Maximum lake depth (m)
LakeArea	Lake area (m^2)
DecTemp	Estimated December air temperature (degrees)
DecSolrad	Estimated December solar radiation ($MJ/m^2/day$)
Fetch	Maximum lake fetch (m)
SumWind	Estimated summer wind (m/sec)
CatBeech	Estimated catchment cover of forest dominated by *Nothofagus* species (percentage)
CatGlacial	Estimated catchment cover of glaciers (percentage)
CatHard	Average rock hardness in the upstream catchment (1 weak to 5 very strong)
CatPeat	Estimated catchment cover of peat soils (percentage)
CatPhos	Average phosphorus content of rocks in the upstream catchment (1 low to 5 high)
CatSlope	Average slope in the upstream catchment (degrees)
CatAnnTemp	Average annual air temperature in the upstream catchment (degrees)
DirectDistCoast	Shortest distance to the coast (km)
ResidenceTime	Estimated lake residence time (years)
Urban	Cover of built-up (urban) sites in the upstream catchment derived from LCDB2_1 (percentage)
Pasture	Cover of high-producing exotic grassland in the upstream catchment derived from LCDB2_40 (percentage)
WoniUnit	Woni biogeographic unit (29 total), as identified in Leathwick et al. (2007)
WoniProvince	Woni biogeographic Province (9 total), as identified in Leathwick et al. (2007)
RegionalCouncil	Regional council territory in which the lake occurs

LakeAreaHA	Lake area (ha)
LakePerim	Lake perimeter (m)
LakeVolume	Lake volume (m^3)
LakeElevation	Lake elevation (m)
MeanWind	Estimated mean annual wind speed (m/sec)
GeomorphicType	The geomorphic formation typology for the lake according to the classes aeolian (wind-formed, dune), dam, geothermal, glacial, landslide, peat, riverine, shoreline, tectonic and volcanic
Lake pressures and rankings	**Description**
LID	Unique lake identifier
Name	Name (where known)
Primary	Primary classification group (A to G)
Natural4	Natural classification level 4 (A.1.1.1 to G.3.2.1), reflecting the classification level at which the ranking analysis was conducted
WoniUnit	Woni biogeographic unit (29 total) in which the lake occurs, as described in Leathwick et al. (2007)
RegionalCouncil	Regional council territory in which the lake occurs
RegionalRank	Regional importance rank calculated using zonation with pressure constraints within each Woni biogeographic unit – low values indicate high ranks, i.e. 1 =first ranked, etc.
RegionalCumArea	As for RegionalRank, but values indicate the approximate cumulative area that would be protected, expressed as a proportion, if lakes are given protection in their ranked order
NationalRank	National importance rank calculated using zonation with pressure constraints – low values indicate high ranks, i.e. 1 = first ranked, etc.
NationalCumArea	As for NationalRank, but values indicate the approximate cumulative area that would be protected, expressed as a proportion, if lakes are given protection in their ranked order
NationalProtRank	As for NationalRank, but with all lakes already having 80% or more protection held back until all other lakes are removed. See accompanying documentation for details
NationalProtCumArea	As for NationalProtRank, but values indicate the approximate cumulative area that would be protected, expressed as a proportion, if lakes are given protection in their ranked order
NaturalCover	Indigenous vegetation cover removal in the upstream catchment (proportion), derived from satellite imagery. Values were traced downstream to calculate upstream catchment average for each segment, with the contributions weighted by their areas

LandusePressure	Nitrogen loading based on CLUES, a regionally based regression model. Values of N loading were summed for all inflowing tributaries and standardised (divided) to water residence time (lake volume/catchment flow)
Impervious	Pressure from impervious surfaces in the upstream catchment measured as a proportion of impervious cover (supplied by D. Brown, DOC) and standardised to the catchment area divided by the lake area to take into account lakes with small catchments
InvasivePlants	Pressure from invasive plants was calculated from the maximum AWRAM score of recorded invasive macrophytes from the NIWA LakeSpi database. Multiplied by the clarity proxy and then divided by the depth index (shallow 1, medium 2, deep 3).
InvasiveFish	Pressure of known invasive fish, calculated from invasive fish data from the New Zealand Freshwater Fisheries Database, and invasive fish scores by Wilding and Rowe (2008)
DamEffectUpstream	Upstream effect of dams/barriers on diadromous species – all segments affected by downstream dams and in which species richness of diadromous fish could be expected to exceed 0.5 species per electric-fishing sample area
DamEffectDownstream	Downstream effects of dams/barriers. Flow-weighted calculation of upstream dam effects and their progressive dilution downstream as flow increases with input from undammed tributaries. Dam locations were supplied by DOC
SumPressureEQ1a	Estimated pressure was calculated with invasive macrophyte and fish data excluded
SumPressureEQ1b	Estimated pressure was calculated using Equation 1 from de Winton et al. (2009), with invasive macrophyte and fish data included where present
SumPressureEQ2a	Estimated pressure was calculated using Equation 2 from de Winton et al. (2009), with invasive macrophyte and fish data excluded
SumPressureEQ2b	Estimated pressure was calculated using Equation 2 from de Winton et al. (2009), with invasive macrophyte and fish data included where present
LakeAreaHa	Lake area (ha)
catAreaHa	Lake catchment area (ha)
ResidenceTime	Estimated lake residence time (years)
NitrogenLoad	Total annual sum of nitrogen loading (kg/year) to the lake as predicted from the CLUES model (Woods et al. 2006), summed for all inflows to the lake
PredMacrophyteDepth	Predicted lower depth limit of macrophytes (m) in the lake modelled using various catchment attributes (see de Winton et al. 2009)
ActualMacrophyteDepth	Actual measured lower depth limits of macrophytes in the lake, where known, from the NIWA LakeSpi database
ClarityProxy	Light clarity proxy of the lake taken from either the predicted or known bottom depth limits of macrophytes (m)

Lake catchments	Description
LID	Unique lake identifier
Name	Name (where known)
Primary	Primary classification group for the lake (A to G)
LakeAreaHA	Lake area (ha)
lkElev	Lake elevation (m)
catArea	Total lake catchment area (m^2)
catPerim	Total lake catchment perimeter (m)
catSlope	Average slope in the upstream catchment (degrees)
catFlow	Mean annual flow (m^3/sec), derived from hydrological models, provided by Jochen Schmidt, NIWA, 2006.
catElev	Mean catchment elevation (m)
catAnnTemp	Average annual air temperature in the upstream catchment (degrees)
catDecSolRad	Estimated December solar radiation (MJ/m^2/day)
catJuneSolRad	Estimated June solar radiation (MJ/m^2/day)
catPhos	Average phosphorus content of surface rocks in the upstream catchment (1 low to 5 high) – see LENZ documentation for details
catCalc	Average calcium content of surface rocks in the upstream catchment (1 low to 4 high) – see LENZ documentation for details
catHard	Average rock hardness of surface rocks in the upstream catchment (1 weak to 5 very strong) – see LENZ documentation for details
catPsize	Average particle size of surface rocks in the upstream catchment (1 sand to 5 massive) – see LENZ documentation for details
catAlluv	Mean catchment proportional cover of alluvium – derived from LENZ (percentage)
catBeech	Estimated catchment cover of forest dominated by *Nothofagus* species (percentage)
catGlacial	Estimated catchment cover of glaciers (percentage)
catPeat	Estimated catchment cover of peat soils (percentage)
catImpervious	Area of anthropogenic impervious surface in the upstream catchment (proportion), computed using cover estimates from LCDBII by Derek Brown, DOC
catNatural	Area of indigenous vegetation in upstream catchment (proportion), computed using cover estimates from LCDBII
catPasture	Area of pasture in the upstream catchment (proportion), computed using cover estimates from LCDBII

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98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand | Ph. +64 3 548 2319

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