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Review of 'lakes' in the Freshwater Ecosystems of New Zealand database

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Review of 'lakes' in the Freshwater Ecosystems of New Zealand database

Lena Schallenberg, Georgia Thomson-Laing, Konstanze Steiner, Kirill Shchapov, Hannah Hampton, Katie Brasell, John Pearman, Susie Wood

Prepared for Ministry for the Environment

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Executive summary

The Freshwater Ecosystems of New Zealand (FENZ) database was published in 2009 through the Department of Conservation. This was a culmination of work by government and research organisations detailing the geographical locations, classifications, physical and biological attributes, and human pressures on freshwater ecosystems in Aotearoa New Zealand. The spatial locations of lakes were largely identified using data from the topographic map series and imposing a lower size limit of 1 ha of open water. Given the challenges associated with assigning lakes at a national scale, as well as the changes in the landscape since the FENZ database was developed, it is likely that some lakes were either misidentified or subsequently drained or modified. Equally likely is that a number of lakes were missed or have been constructed since the development of FENZ. The database has not been updated in the last 15 years, yet is being increasingly used to make national-scale predictions of lake water quality and to assist regional councils in prioritising lake restoration and protection.

Cawthron Institute was commissioned by the Ministry for the Environment to: (1) facilitate two online workshops with lake experts, a Te Ao Māori expert and lake / freshwater scientists from regional and central government to discuss the size and type of waterbody that should be included in the lakes layer of FENZ, and (2) review the current lakes layer of FENZ and identify waterbodies that should be removed or added.

The main recommendation from the two workshops was that lentic waterbodies with open water greater than *or equal to* 1 ha in surface area should be included in the lakes layer of FENZ, except for wastewater ponds. The workshop participants emphasised that the use of surface area was a choice of convenience, and that this does not reflect the scientific definition of a lake and / or the definition of lake that is used in policy documents.

Using the criteria identified during the workshops, we combined lentic shapefiles from three sources (the original FENZ database, the 1:50,000 topographic map series and the Land Cover Database version 5.0) and reviewed these manually in ArcGIS. After selecting the most accurate polygons or creating new ones, the resulting 'FENZ lake update 2024' database was created, containing 5,301 waterbodies.

A large number (*n* = 686) of waterbodies in the original FENZ database were removed. This was done for a number of reasons, including a lack of water present, an open water area < 1 ha and 'lake' polygons being other features such as wastewater treatment plants, rivers or estuaries. Many of the new lakes that were added (*n* = 1,690) were human-made. Of note were the large number of new artificial lakes in Canterbury (*n* = 538).

The geomorphic classifications of lakes in the original FENZ database and newly added lakes were reviewed. A high portion (approximately 47%) of lakes in the 'FENZ lake update 2024' database contained the geomorphic class 'Artificial'. The only metadata that were added for the new lakes were geographic location, region, geomorphic class and area (ha), which was obtained from the polygons.

We recommend that the following actions are taken to enable the database to be used for purposes such as national-scale predictions of water quality and regional planning:

- Review and evaluate different methods for estimating lake depth and apply this to all lakes in the 'FENZ lake update 2024', adding 'estimated lake depth' as an attribute.
- Determine lake catchment size, land cover and altitude for the 'FENZ lake update 2024'.
- Model or determine the other FENZ attributes for the newly added lakes and add these as attributes.
- Enable the database to be regularly updated as new lake information becomes available.
- Ensure that polygons from the updated lake database are integrated with current or future river databases.

1. Introduction

The Freshwater Ecosystems of New Zealand (FENZ) project mapped rivers, lakes and wetlands, and was published in 2009 through the Department of Conservation (DOC; Leathwick et al. 2010). This was a culmination of work by government and research organisations detailing the geographical locations, classifications, physical and biological attributes, and human pressures on freshwater ecosystems in Aotearoa New Zealand. The spatial locations of lakes were largely identified using data from the 1:50,000 topographic map series and imposing a lower size limit of 1 ha of open water.

Given the challenges associated with assigning lakes at a national scale, as well as the changes in the landscape since the FENZ database was developed, it is likely that some lakes were either misidentified or subsequently drained or modified. Equally likely is that a number of lakes were missed or have been constructed since the development of FENZ. In addition, a lack of available high-resolution satellite imagery when FENZ was originally developed limited detailed assessments of waterbodies and in-depth evaluations of their geomorphic class.

Recent studies have shown that in some regions more than 20% of waterbodies in FENZ have less than 1 ha of open water and do not fit the FENZ criteria for a lake. There are also many waterbodies greater than 1 ha in area that are not included in FENZ, and there are obvious errors in the assignment of geomorphic class (Wood et al. 2022a, 2022b; Schallenberg et al. 2023a, 2023b; Steiner and Wood 2023). There are inconsistencies with the types of waterbodies included in FENZ. For example, wastewater treatment ponds are often (but not always) included in the lakes layer. Similarly, waterbodies that might be better defined as wetlands are included in the lakes layer. These inconsistencies and errors make it very difficult to effectively assess and manage lakes at regional and national scales. Having inaccurate fundamental information risks jeopardising the design and implementation of monitoring networks. It also creates challenges when undertaking regional and national-scale prediction of lake water quality – for example, the data presented in reports such as 'Our Freshwater' (MfE and Stats NZ 2020; Snelder et al. 2022).

The Ministry for the Environment (MfE) commissioned Cawthron Institute (Cawthron) to update the FENZ lakes database. The work involved nine key objectives:

1. Organise and facilitate at least two online workshops with lake experts, Te Ao Māori experts and lake / freshwater scientists from regional and central government to discuss the size and type of waterbody that should be included in the lakes layer of FENZ.
2. Review the current lakes layer of the FENZ database and evaluate which waterbodies currently in the database should remain.
3. Use satellite imagery and GIS to identify waterbodies that are not currently in FENZ. Register new lakes with new IDs and shapefiles.
4. Where possible, include corresponding catchment and other data (e.g. depth, area, volume) for newly added lakes.
5. Include data on actual lake depth where available (only for existing lakes in FENZ). Consider options for how the modelling / estimations of lake depth could be improved.

6. Include land-use (LCDB5) and catchment characteristic data for each lake (excluding the new lakes).
7. Include additional information if it is available or beneficial for existing lakes in FENZ, e.g. modelled trophic level index.
8. Provide a report documenting the updates made and the rationale for these. This will include outcomes regarding how lakes and geomorphic classes are defined in FENZ (from the workshops in Task 1).
9. Provide the data in a format suitable for publication on the MfE Data Service.

As part of this contract, Cawthron will supply the above data to MfE. It is the responsibility of MfE to liaise with DOC regarding updating the FENZ database and to make decisions on when and how these new data are made publicly available.

2. Summary of expert workshops

Two online workshops were held with lake experts, a Te Ao Māori expert and lake / freshwater scientists from regional and central government (Table 1). Two Workshop 1 sessions were held on 28 November and 13 December 2023 (participants were required to attend only one of these dates), and the Workshop 2 session was held on 24 January 2024. Slides presented at both workshops are provided in Appendix 1.

Table 1. List of Workshop 1 and Workshop 2 participants.

Name	Organisation
Ebi Hussain	Auckland Council
Paul Scholes	Bay of Plenty Regional Council
Susie Wood	Cawthron
Konstanze Steiner	Cawthron
Katie Brasell	Cawthron
John Pearman	Cawthron
Lena Schallenberg	Cawthron
Georgia Thomson-Laing	Cawthron
Simon Stewart	Cawthron
Hugh Robertson	Department of Conservation
Dave West	Department of Conservation
Craig Woodward	Department of Conservation
Tina Bayer	Environment Canterbury
Marcus Vandergoes	GNS Science
Mereana Wilson-Rooy	GNS Science
Dave Kelly	Hydrosphere Research
Kohji Muraoka	Ministry for the Environment
Graeme Clarke	Ministry for the Environment
Hugo Borges	Otago Regional Council
Markus Dengg	Otago Regional Council
Marc Schallenberg	University of Otago
Deniz Özkundakci	University of Waikato
David Lowe	University of Waikato
Mat Allan	Waikato Regional Council

2.1 Workshop 1

At Workshop 1, participants were introduced to the aims of the project and were provided with examples of waterbodies whose inclusion in the FENZ database as a lake might be contentious. The purpose of Workshop 1 was to provide participants with an overview of the types of challenges the project team were navigating and to allow them time to consider viable solutions, which would then be discussed further in Workshop 2.

An important point of clarification at this workshop was that the aim of this project **was not** to establish a definition of a 'lake'. Rather, the aim of these workshops was to **identify which waterbodies should be included in the 'lakes' layer in FENZ**. We did, however, note that there is considerable scientific literature discussing the definition of a lake and that there has been extensive debate on this topic (e.g. Richardson et al. 2022).

An important consideration when making decisions about which waterbodies to include in the lakes layer of FENZ was that there is very limited information for most lakes. All participants acknowledged that there are many attributes or features that should be included when identifying whether a waterbody is a lake – for example, water depth, residence time, biodiversity, etc. This information is available for only a very small number of waterbodies in Aotearoa New Zealand. The only reliable information available for this project at a national scale was lake area, altitude and surrounding land-use and geology data obtained from satellite imagery and other mapping tools such as topographical and geological maps.

Based on the assumption that only lake area, altitude and surrounding land-use and geology data would be used to identify the waterbodies, Workshop 1 focused on the following points.

1. Participants were presented with examples of waterbodies that were currently in the FENZ lake layer but that the project team thought should be excluded. These included dry land that was covered in vegetation and was clearly wrongly assigned during the initial FENZ development, dried lakes that regularly experience periods with low or no water, waterbodies that are permanently open to the ocean and might be better classified as estuaries, and waterbodies that were clearly rivers / streams or channels.
2. Participants were asked to consider whether using an area greater than 1 ha of open water was a sensible size for the inclusion of a waterbody in the lake layer of FENZ. Examples of culturally significant lakes that were smaller than 1 ha were given, as were examples of a larger waterbody that had reduced in size, resulting in several smaller waterbodies that no longer met the 1 ha cut-off. Two reasons for the original criterion of an area greater than 1 ha in FENZ were provided: (1) it results in the inclusion of lakes that collectively account for more than 98% of lentic surface area, as defined by the complete Land Information New Zealand (LINZ) database, which encompasses all lentic waterbodies greater than 50 m in diameter (approximately 60,000 waterbodies); (2) it was assumed that physical processes that generally define lakes (e.g. stratification, open water mixing) are more likely to occur in larger waterbodies, and a 100 m length (a hectare being 100 m × 100 m) seemed like a reasonable cut-off (waterbodies smaller than this tend to be dominated by benthic processes). An important management consideration

was noted – if the area was reduced below 1 ha, regional councils / lake managers would potentially have hundreds more lakes to manage under the National Policy Statement – Freshwater Management (NPS-FM), which is unlikely to be viable due to limited resources.

3. Participants were provided with examples of ephemeral lakes where our inspection of images over a period of about 5 years showed times when the waterbody contained water with an area greater than 1 ha and others when it was completely dry. The participants were asked if these should be included in the database. The issue of whether to include paleolakes was raised by participants. A paleolake is a former lake that no longer exists because it has been infilled or drained by natural processes.
4. Participants were asked to consider the inclusion of artificial waterbodies. Examples were given of farm dams, water storage reservoirs, constructed irrigation ponds, wastewater treatment ponds and waterbodies associated with mining.
5. Participants were shown examples of wetlands that contain multiple areas of open water greater than 1 ha, but where it was difficult to define the boundary between waterbodies and where the flow and presence of water are likely to be very dynamic. Two particularly challenging examples were provided: Sinclair Wetlands and Taieri Scroll Plain (both in Otago). These larger wetland complexes contain many waterbodies that vary in size and morphology depending on climatic conditions and the flow of the main rivers / streams within them.

There was considerable discussion about the above points during Workshop 1. Participants were asked to take time to consider these scenarios prior to Workshop 2.

Participants noted that before making any decisions related to the above points there needed to be clarity as to the key purposes and uses of the lakes layer in the FENZ database (see Section 2.2).

There was considerable uncertainty about the geomorphic classes used in the current FENZ database and no robust definitions were provided in the FENZ user guide. Professors David Lowe and John Green (University of Waikato) have recently produced a detailed definition of 10 geomorphic classes (Table 2; Lowe and Green 2024), and this was presented to workshop participants. They were asked to consider whether these would be appropriate to use as geomorphic classes for the FENZ lake database. Professor Lowe noted that lakes can also have multiple origins, forming hybrid lakes with more than one geomorphic classification (e.g. riverine-phytogenic).

Table 2. Classification of the origins of lakes in Aotearoa New Zealand according to Lowe and Green (2024).*

Lake class or type	Mode of formation
Artificial (A)	Human activity, forming reservoirs or recreational lakes by dam or weir construction, by excavation (including enlarging or modifying pre-existing natural lakes or waterways), by maintaining open water in peatlands or wetlands, or by flooding of open-cast mines
Barrier bar (B)	Longshore current or wave action, and other coastal processes, forming barrier bars, chenier ridges, or spits or tombolos on coasts or lake shorelines, typically enclosing inlets, embayments, old river courses or estuaries
Aeolian / Wind (W)	Wind-blowing of sand, chiefly on coasts, to dam valleys or generate depressions between dunes or dune belts, or by the excavation of cover beds and / or regolith from hollows by wind erosion (deflation basins)
Glacial (G)	Glacial activity, including glacial scouring or frost riving, forming rock depressions (e.g. cirque and fjord lakes); deposition of tills, forming moraines; deposition of fluvioglacial sediments; or collapse of deposits as a result of melting of large blocks of *in situ* ice (kettle lakes) or permafrost thawing (thermokarst lakes)
Landslide (L)	Blockage of valleys by landslide debris, including debris avalanche deposits, lahars, rockslides, mudflows, screes and colluvium; potentially includes subsidence in unconsolidated materials, forming sinkholes
Phytogenic (P)	By substantial peat accumulation, causing damming; by subsidence in peat; by peat fires forming 'burn pools'; or by upwelling of minerogenic or geothermal groundwater under peat, resulting in permanent pools or lakes
Riverine (R)	River action, including blockage of tributary drainage by deposition of fluvial sediment (alluvium); by aggrading rivers, forming blocked-valley (lateral) lakes; by the isolation of meander loops or abandoned channels, forming cut-off lakes (including oxbows, scroll lakes and concave bench lakes); and by alluvial-fan deposition; also plunge-pool lakes
Solution (S)	Dissolution of carbonate rocks (mainly limestone, marble, calcareous sandstone), forming bowl-shaped corrosion hollows (solution dolines); land collapse into underlying caves, forming depressions (collapse dolines); or the formation of blind valleys, including poljes (long blind valleys with flat floors and vertical walls); all characteristic of karst terrains
Tectonic (T)	Faulting, folding or associated activity that creates depressions, including formation of sag ponds or basins alongside faults and fissures at the land surface that result from earthquake shaking
Volcanic (V)	Volcanic activity, including caldera collapse because of magma withdrawal in large-volume eruptions; smaller explosive eruptions, forming craters (ground craters, including maars, and also volcano craters) and blocking valleys or impounding embayments by lava, pyroclastic flow (density current) deposits, debris avalanche and laharic deposits, or hydrothermal deposits

* Modified from Lowe and Green (1987, 1992), Timms (1992) and Williams (2001), and Håkanson (1981).

2.2 Workshop 2

During Workshop 1, the participants indicated a need to identify the purpose and uses of the lakes layer in FENZ.

There was agreement that a key purpose of the lakes layer in FENZ was to have a nationally standardised record of 'lakes' in Aotearoa New Zealand that could be used for understanding regional- and national-scale patterns in lake water quality and ecology and to assist in informing management at these scales. Some of the key uses identified (in no particular order) were:

1. To enable national-scale modelling of lake water quality.
2. To enable national-scale modelling of pressures and biological predictions. For example, the current FENZ has been used to make predictions on the likely current and future distribution of non-native species.
3. To help inform and improve lake management nationally.
4. To assist regional managers in identifying and prioritising lakes for protection or restoration and fulfilling obligations under the NPS-FM.
5. To allow assessments of changes in water storage through semi-regular updates to the database – for example, the number and distribution of constructed lakes.
6. To enable researchers to undertake regional- or national-scale assessments.

Table 3 provides a list of the key recommendations from participants to address the challenges identified during Workshop 1.

Table 3. Key recommendations for the challenges identified.

Recommendation	Outcome
Use of only surface area (of open water) to identify waterbodies for inclusion as lakes in the FENZ layer	There was general consensus that this was the only practical solution for this project. However, the participants asked that it was made clear that this is a choice of convenience, and that it does not necessarily reflect the scientific definition of a lake. A recommendation was made that future work should identify and add other important attributes (i.e. lake depth) to the database, which may result in some waterbodies being removed.
Greater than or equal to 1 ha of open water be used as the area to define inclusion of a waterbody in the lakes layer	There was general agreement that this was a practical solution and likely the only feasible one, especially in the absence of the use of other attributes (i.e. depth). Note the subtle change from the current use of greater than 1 ha of open water, to **greater than or equal to** 1 ha. Suggestions for future work included: (1) identifying culturally / socially / ecologically important lakes that are smaller than 1 ha and considering adding these to the lakes layer, and (2) reviewing the full LINZ lentic layer.

Recommendation	Outcome
A suite of different recommendations were made regarding waterbodies for removal / exclusion / inclusion	**Dried** – remove from lakes layer if no water visible within last ~5 years. Include a descriptor that documents the reason for removal, as these data may be valuable (e.g. to assess the effects of climate change). Lakes that have dried / shrunk and that are not currently in FENZ should not be added. **Ephemeral –** maintain in lakes layer. Include a descriptor to note this. **Paleo-lakes** – identifying these lakes is beyond the scope of this project. **Rivers / streams** – remove these waterbodies from the lakes layer. **Estuaries** – remove waterbodies where there is no evidence of the complete closure / isolation of the outflow from the ocean during the last ~5 years. Participants acknowledged that this might be challenging due to limited imagery and that the definition of 'enclosed inlets' might need to be improved.
Artificial lakes	The recommendation was that all wastewater ponds should be removed, but that all other artificial lakes should remain in the FENZ layer. Where possible, the main use of the artificial lake was to be noted. There was concern about the inclusion of completely constructed waterbodies, i.e. lined ponds. The decision was that these would remain in the lakes layer but that a descriptor would be added to identify them. After working through several regions and trialling a range of descriptors, the project team decided on the use of the following: **Dam (D)** – this encompasses the vast majority of artificial lakes and includes everything from farm dams and ornamental lakes to large hydroelectrical lakes. The dams were usually built within an existing watercourse (typically a river valley of an existing lake basin). The team felt that further refinement of this category was not possible from aerial imagery only. **Constructed (C)** – these lakes generally have very small catchments, are constructed outside of a natural watercourse and rely on managed (e.g. pumped or directed) inputs. They are often lined and usually very symmetrical, and lack most / any natural features (Figure 1A, 1B). **Mine (M)** – these are lakes that are clearly associated with recent or active mining or quarrying (Figure 1C, 1D).
Lakes in wetland	The recommendation was that all waterbodies in wetlands equal to or greater than 1 ha of open water should be added to or maintained in the lakes layer. A descriptor should be added to note that they are part of a wetland complex. An exception was made during the project when working on the Taieri Scroll Plain region in Otago. Waterbodies in the Taieri Scroll Plain that were within the active river channel or that showed some connection to the current main river channel were removed.
Use of the geomorphic classes presented in Table 2	There was agreement with this by participants. The project team emphasised that accurate assignment of geomorphic classes based solely on aerial imagery is very challenging and that refinements will be required. In many instances this will require site visits and further exploration of geological and other mapping and historical resources.

There was a strong suggestion that the database be maintained as a 'living database' that can be updated as site visits or other ground-truthing is undertaken.

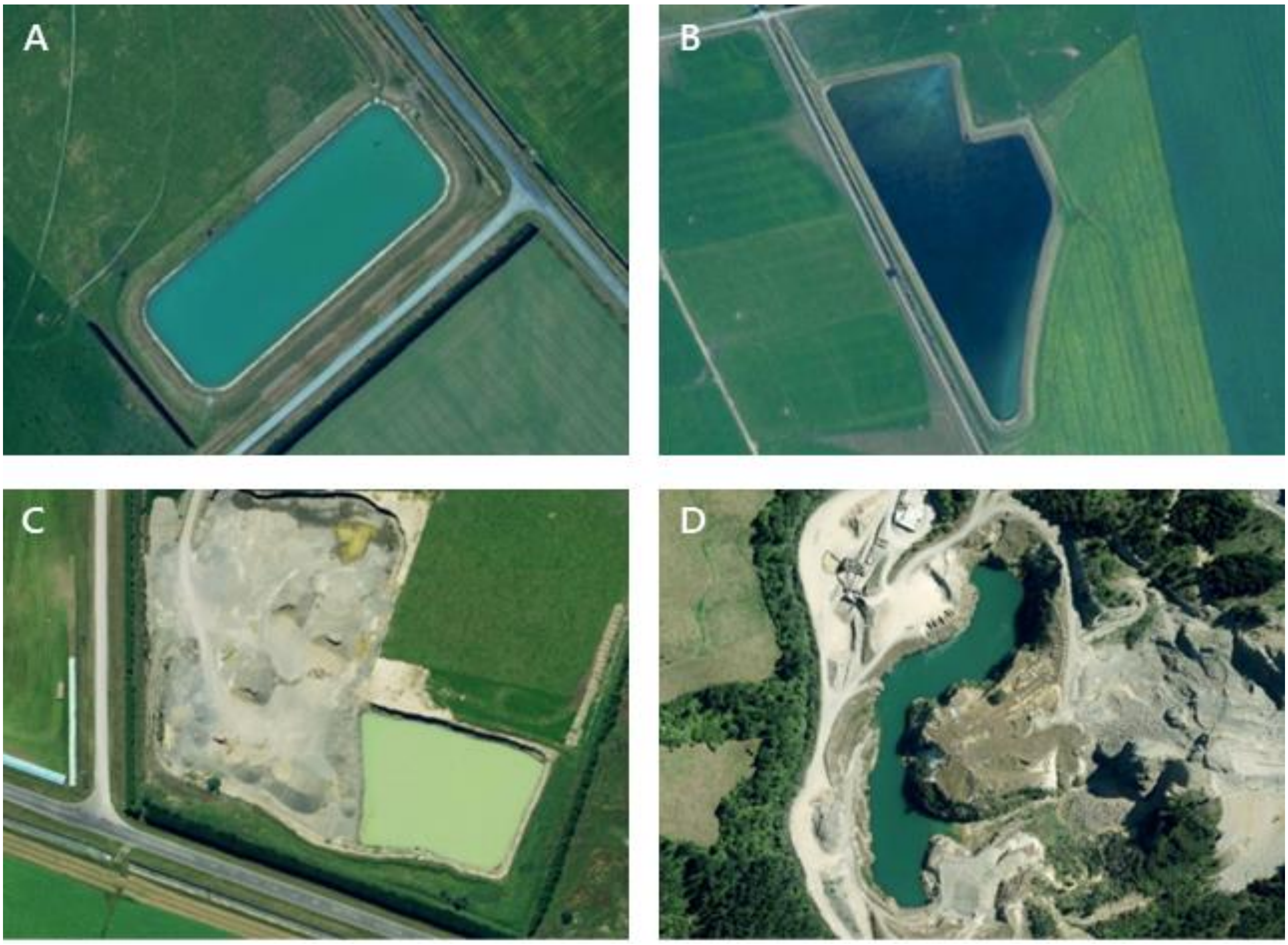


Figure 1. Examples of artificial lakes, classified as: (A, B) Constructed, and (C, D) Mine.

3. Methods

3.1 Review of lakes in FENZ and addition of new waterbodies

To undertake the review of waterbodies in the current FENZ lakes database (evaluate whether these should remain and identify new waterbodies for inclusion), the following steps were taken:

1. Lentic shapefiles for Aotearoa New Zealand were acquired from three sources (Table 4).

Table 4. Shapefiles that include lentic waterbodies and the number of waterbodies found in each.

Name	Date last updated	Date downloaded	Download source	Lake (or polygon) ID	Number of lake polygons	Number of lake polygons ≥ 1 ha
Freshwater Ecosystems of New Zealand (FENZ) – lake classification layer	2009	Supplied by DOC (date unknown)	Department of Conservation	LID	3,821 (> 1 ha)	
NZ Lake Polygons (Topo, 1:50k)	19 December 2023	28 February 2024	Land Information New Zealand (LINZ) Data Service	t50_fid	60,207	4,694
LCDB v5.0	11 November 2021	28 February 2024	Land Research Information Systems (LRIS) Portal – Manaaki Whenua – Landcare Research	LCDB_UID	11,577*	5,473

* 'Name_2018' = 'Lakes or Ponds'

2. The Aotearoa New Zealand regional boundary shapefile 'Regional Council 2022 (generalised)' was sourced from the Statistics New Zealand website (last updated 7 December 2021) and accessed on 11 March 2024 to provide updated regional boundaries.

3. The shapefiles from the three sources were joined, creating a new database for use in this project: 'FENZ lake update 2024'. Some waterbody polygons were found across multiple layers. For example, the polygon for a lake might have been present in the FENZ and NZ Lake Polygons shapefiles but was lacking from the LCDB shapefile, and all possible combinations of this. One polygon was kept per lake when multiple polygons occurred at the same location. The most accurate polygon from the three databases was selected. A filter was applied and only waterbodies greater than or equal to 1 ha were maintained. These steps resulted in a total of 6,931 potential lake polygons for review. Many of these had multiple IDs originating from the different layers, e.g. a FENZ LID and a NZ Lake Polygons t50_fid.
4. The waterbodies were allocated to a region if the centre of the lake polygon fell within that region.
5. All 6,931 lakes were then manually checked in ArcGIS using the latest satellite imagery basemaps and historical imagery from the past 5 years.

Manual assessment of waterbodies

1. **Removal of lakes**. When waterbodies were deemed not to fit the required criteria for inclusion in the updated lakes layer, they were removed from the 'FENZ lake update' database. The rationale for this was noted (Table 5, Figure 2).

Table 5. Reasons why waterbodies did not fit the criteria for inclusion in the FENZ lakes layer.

Reason (abbreviation)	Description
River / stream / channel (R)	Flowing water or clearly part of a river / stream / channel
Wetland (W)	Waterbody part of a wetland and area of open water is not greater than or equal to 1 ha
Dried (D)	No open water visible in imagery from approximately the last 5 years, but clear evidence that a lake / waterbody was once present
Too small (TS)	The area of open water is less than 1 ha in imagery from approximately the last 5 years and generally the open water is much smaller than the size of the original polygon
Estuary (E)	Waterbody continually (or usually) open to ocean
Wastewater pond (WP)	Waterbody a wastewater / oxidation / treatment pond
Not a lake (NAL)	No evidence that there was previously a waterbody here, e.g. polygon covers an area of grass or forest
Other (O)	Other not specified above (including salt ponds, fish farms, other treatment ponds)

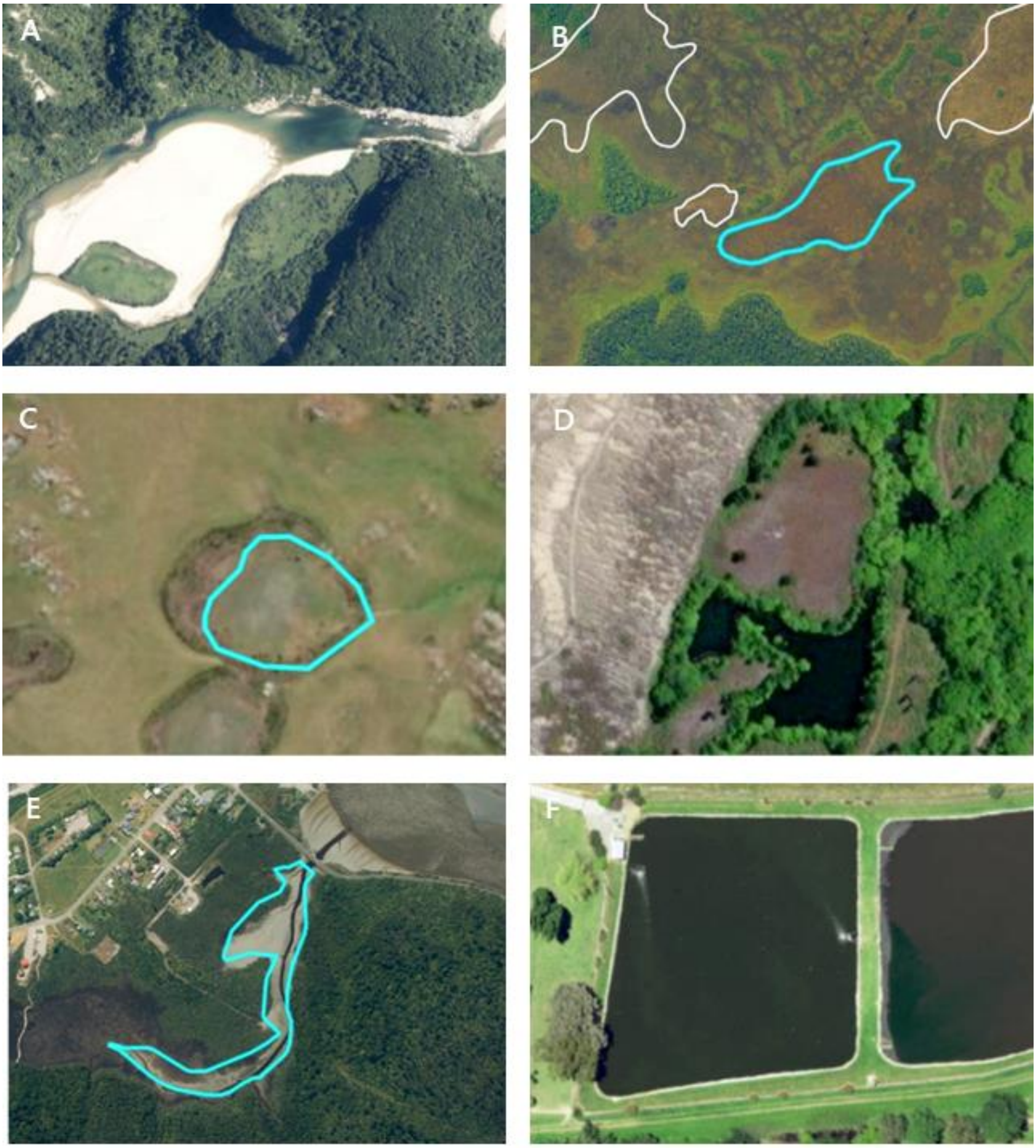


Figure 2. Examples of removed lakes. (A) River / stream / channel. (B) Wetland. (C) Dried. (D) Too small. (E) Estuary. (F) Wastewater pond.

Figure 2 (cont.). (G) Not a lake.

2. **Merging or splitting of lake polygons.** In some instances, the polygon needed to be merged or split to match the current area of the waterbody. This was done in ArcGIS and the affected polygon IDs were recorded. If a visible hydrological connection was seen between waterbodies, they were counted as one lake. However, if a lake had been artificially separated (e.g. earth excavated and moved to form a road between), or no visible connection was seen, lakes were classified as separate.
3. **Noting wetland / ephemeral lakes**. We noted when included lakes (≥ 1 ha) were part of an obvious wetland and if they were ephemeral.
4. **Assessments of polygons**. The polygons were assessed to ensure that they matched the area of open water. If lakes were included in more than one of the source databases, the polygon from the database (i.e. FENZ, Topo, LCDB) that best matched the open water area was selected. When polygons from all layers were deemed to be less than approximately 20% accurate, a new polygon was drawn.
5. **Addition of lakes not in databases**. During our manual assessment, waterbodies that were not in any of the databases (Table 4) were sometimes observed. The geographic location of these was recorded and new polygons were drawn in ArcGIS.
6. **Construction of new databases**. The information described above was used to make the following databases and associated shapefiles:
   a) 'FENZ lake update 2024' – includes all waterbodies that met the criteria for inclusion in the updated lakes layer.
   b) 'Removed waterbodies – FENZ lake update 2024' – includes all waterbodies that were removed from the combined database and the rationale for this.

Geomorphic classes

Geomorphic classes were assigned to the lakes based on the classes and descriptions provided in Table 2. Additional resources were used, including Lowe and Green (1987, 1992), resources provided by Professor Lowe, topographical and geological maps, and historical information sourced from internet searches.

Despite using these resources, it was extremely challenging to assign geomorphic classes in many instances. Given the national scale of this project and the large number of lakes, an in-depth assessment for all lakes was not possible. The current classifications should be considered preliminary, and site visits in concert with in-depth investigations are required when a robust geomorphic classification is required. Where there was a high level of uncertainty about the geomorphic classification, it is given in brackets – e.g. (R) or (G).

Lowland lakes in highly modified catchments were often extremely hard to assign to a geomorphic class. Most of these lakes have had considerable modification – i.e. they have been drained, or the lake level has been raised. For dammed waterbodies, it was often impossible to determine whether a natural waterbody greater than or equal to 1 ha was present prior to damming.

As noted in Section 2.2, further descriptors were provided for Artificial lakes: Dam (D), Constructed (C) and Mine (M). See Figure 1 for examples of C and M lakes.

Assignment of LakeID number

All waterbodies in the 'FENZ lake update 2024' that were not previously in FENZ were assigned a new LakeID (LID). This was done sequentially, starting at 54,743 (the last number in the current FENZ lakes database).

Caveats

Lake polygons

The polygons were redrawn only if they were deemed to be > 20% inaccurate. Almost all polygons contain some degree of error. However, changes in lake levels and wetland vegetation – which can occur on an annual basis – add further challenges to defining accurate polygons. If an accurate and up-to-date lake area is essential, we recommend re-creating the lake polygons.

Ephemeral lakes

These have been left in the lake layer database. Ephemeral lakes include lakes in very dry regions of the country, and alpine lakes where snowmelt or gravel / glacier movement may result in the lakes containing no water for significant periods of the year. Lake managers will need to use their discretion when considering whether these are included in regional planning. It is likely that different management strategies will be needed for these lakes.

Inclusion based on surface area only

As noted in Table 3, there is considerable uncertainty when determining whether a waterbody of greater than or equal to 1 ha of open water should be included in the lakes layer based solely on satellite imagery and surface area. We strongly recommend that the database is updated as additional information becomes available through site visits or other sources.

Potential for error or lack of inclusion of a waterbody in the database

The evaluation of waterbodies in this project was conducted by a team of researchers. There will be some differences in their interpretation of whether a waterbody should be included as a lake and which geomorphic class it belongs to. Additionally, a systematic search across the whole of Aotearoa New Zealand waterbodies not in the three databases used in this project was not undertaken. Therefore, it is likely that some waterbodies that should be included will have been missed. We anticipate that this is a very small number of waterbodies. This adds further weight for the call that this be a 'living database' that can be updated as further information becomes available.

3.2 Additional information for new lakes

Due to the large number of new lakes, the only information that could be included in the database in addition to the polygons was geographic location, region, geomorphic class and area (ha) – all obtained from the polygons. In Section 5 we provide recommendations for additional environmental / catchment information that should be assessed / modelled for the newly added lakes.

3.3 Inclusion of actual lake depths and options for improved modelling of depth

It is widely acknowledged that the modelled lake depth data in FENZ are inaccurate (e.g. Schallenberg et al. 2023a). In this project we have maintained these data for lakes included in the original FENZ database. We have also added a new attribute, called measured maximum lake depth, for lakes where the actual depth has been measured. Measured depth data were obtained from Lowe and Green (1987; n = 114) and the Lakes380 programme[1] (n = 280).

Several approaches to predict lake depth using landscape and lake features have been developed. For example, Heathcote et al. (2015) used landscape features and geological information to model bathometry features in lakes in Quebec (Canada), and Oliver et al. (2016) used lake surface area and the slope of the land close to a lake to predict lake depth in 17 regions in the USA.

Similar approaches have been tested by Associate Professor Deniz Özkundakci and his team at the University of Waikato. Preliminary testing indicates that this approach will not work for many of the lakes in Aotearoa New Zealand where the formation process is decoupled from landscape features (e.g.

1 www.lakes380.com

volcanic lakes, dune lakes). We recommend further assessment of these and other approaches to predict depth as a second stage of this project.

3.4 Addition of catchment land-use data (existing lakes only)

As part of the Lakes380 project, land use in the catchment of all lakes in the original FENZ lake database was determined using data from Land Cover Database version 5.0 (2020). This information has been added to the updated database for lakes where the catchment area had been defined.

Other information (e.g. depth, volume, pressures) that was in the FENZ lakes database has been carried over to the new database for lakes in the original FENZ database.

Estimating / modelling this information for new waterbodies added to the 'FENZ lake update 2024' was beyond the scope of this project.

3.5 Addition of other modelled data available for original FENZ lakes

Between 2020 and 2023, three nationwide spatial lake water quality modelling projects were undertaken by (1) MfE, (2) the Lakes380 programme, and (3) Abell et al. (2019, 2020). This information was included where suitable and available for lakes in the original FENZ dataset. Further information and the data included in the 'FENZ lake update 2024' are provided below.

Ministry for the Environment national lake water quality modelling

In 2022, MfE commissioned a study that aimed to estimate chlorophyll-*a* (chl-*a*), total nitrogen (TN), total phosphorus (TP), ammoniacal nitrogen (NH_4-N), Secchi depth, *Escherichia coli* (*E. coli*) and trophic level index (TLI3 and TLI4) for all lakes in Aotearoa New Zealand using data from the period 2016–20 (Snelder et al. 2022). This study used monitoring data provided by regional councils. Random forest models were created using measured and modelled lake and catchment characteristics to estimate the attribute state for all lakes in the FENZ database. The models varied in their performance depending on the attribute modelled (Table 6).

Table 6. Performance and ratings of the water quality models, modified from Snelder et al. (2022) and with performance ratings based on Moriasi et al. (2015). *N* = number of lakes, R^2 = coefficient of determination of observation versus predictions, NSE = Nash–Sutcliffe efficiency, PBIAS = percent bias, RMSD = root mean square deviation (units are the $\log_{10}$ transformed original units). The data were downloaded from https://www.stats.govt.nz/indicators/modelled-lake-water-quality

Attribute	*N*	R^2	NSE	PBIAS	RMSD	Rating
Total nitrogen (median, mg/m³)	124	0.78	0.77	3.66	0.23	Very good
Total phosphorus (median, mg/m³)	124	0.62	0.62	0.44	0.35	Good
NH_4-N (adj. median, mg/L)	80	0.31	0.31	0.74	0.35	Unsatisfactory
NH_4-N (adj. maximum, mg/L)	80	0.29	0.29	0.71	0.55	Unsatisfactory
NH_4-N (maximum, mg/L)	97	0.51	0.51	0.76	0.34	Satisfactory
Chlorophyll-*a* (median, mg/m³)	124	0.45	0.45	-0.82	0.41	Satisfactory
Chlorophyll-*a* (maximum, mg/m³)	124	0.58	0.57	-0.42	0.45	Satisfactory
TLI3	124	0.65	0.65	0.01	0.83	Good
TLI4	75	0.66	0.66	0.46	0.75	Good
Secchi depth (median, m)	75	0.64	0.61	-0.08	0.31	Good
***E. coli* (median, MPN/100ml)**	55	0.65	0.64	-0.21	0.34	Good
***E. coli* (Q95, MPN/100ml)**	55	0.38	0.38	0.09	0.53	Satisfactory
***E. coli* (G260, % exceedance)**	55	0.31	0.29	7.52	0.07	Unsatisfactory
***E. coli* (G540, % exceedance)**	55	0.30	0.30	3.50	0.04	Unsatisfactory

Of note was the unsatisfactory performance of the median and annual maximum NH_4-N models and G260 and G540 *E. coli* models. In the 'FENZ lake update 2024' we included data from models rated as satisfactory or higher. For more information on these models and data, see Snelder et al. (2022).

Lakes380 national lake water quality modelling

The Lakes380 team collected lake surface sediment samples from 256 naturally occurring lakes in Aotearoa New Zealand, 96 of which had robust monitoring data. Lakes were carefully selected to be highly representative of all lakes in the country (by region and lake type) and to cross multiple environmental gradients (Wood et al. 2023). Sediment bacterial communities from the 96 lakes with monitoring data were characterised using 16S rRNA metabarcoding, from which key indicator bacteria associated with different lake TLIs and attribute concentrations were identified. These were used to develop a Surface Bacteria Trophic Index (SBTI; Pearman et al. 2022). The team then used selected lake characteristics obtained from the FENZ database, land-use characteristics from the catchments of each lake (Land Cover Database version 5.0) and machine learning to predict the SBTI for all lakes in Aotearoa New Zealand (Wood et al. 2023). The Lakes380 team tested six different machine learning approaches (random forest, linear model, support vector machine, boosted regression tree, neural networks and extreme boosting). Extreme boosting was selected because it had the highest mean R^2, the lowest root mean squared deviation (RMSE) and the lowest mean absolute error (MAE) of the evaluated approaches

(Table 7). The SBTI for all lakes in the original FENZ database is included in the 'FENZ lake update 2024'. For more information on this data, see Pearman et al. (2022) and Wood et al. (2023).

Table 7. Model statistics and performance rating of Sediment Bacterial Trophic Index (SBTI) using extreme boosted regression models. Model performance ratings are based on Moriasi et al. (2015). RMSE = root mean squared error, R^2 = coefficient of determination, NSE = Nash–Sutcliffe efficiency, PBIAS = percent bias.

	SBTI
RMSE	0.7
R^2	0.82
NSE	0.81
PBIAS	-1.3
Model performance	**Very good**

Empirical nutrient mass loading models

Abell et al. (2019) estimated TN, TP, chl-*a*, Secchi disc depth and TLI for 1,038 lakes in Aotearoa New Zealand using empirical nutrient mass loading models. First, they estimated concentrations of inflow TN and TP using the CLUES model (Elliott et al. 2016) for 1,200 lakes. They then used the nutrient inflow estimates to parameterise in-lake TN and TP models, along with lake residence time and lake maximum depth taken from the FENZ database. Next, measured nutrient concentrations (2000–14) from 76 to 84 lakes were used as training sets to develop models for in-lake average TN and TP concentrations. The models were then extrapolated to 1,033 (TN) and 1,038 (TP) lakes that had mapped inflows.

Abell et al. 2020 used the modelled TN and TP concentrations as parameters to model current average in-lake chl-*a* concentrations in 1,031 lakes. They used chl-*a* estimates along with lake fetch, wind speed and lake maximum depth to model average Secchi disc depth across the same lakes. Model performance statistics are presented in Table 8Table . Unfortunately, model statistics required to evaluate model performance as specified in Moriasi et al. (2015) were not provided by Abell et al. (2019) or Abell et al. (2020). These data, along with their confidence intervals, have been included in the 'FENZ lake update 2024' database.

Table 8. Model performance for the total phosphorus (TP), total nitrogen (TN), chlorophyll-*a* (Chla) and Secchi models used in Abell et al. (2019) and Abell et al. (2020) to model 1,033 Aotearoa New Zealand lakes. SEE = standard error of the estimate, ESS = error sum of squares, CF = correction factor, p = number of parameters, AIC = Akaike information criterion, RMSE = root mean squared error.

Model name	SEE	ESS	CF	R^2	p	AIC	RMSE
log_{10}TP	0.33	8.99	1.34	0.69	3	58.63	–
log_{10}TN	0.24	4.09	1.16	0.78	3	1.64	0.2
log_{10}Chla	0.21	2.99	1.12	0.89	3	-18.12	0.21
$Secchi^{0.5}$	0.32	4.93	–	0.89	4	34.5	1.68

4. Results

Following manual inspection of the lakes in ArcGIS, 5,301 waterbodies were maintained (Figure 3). Of these, 3,117 were in the original FENZ database, 1,124 were in the Topo layer, 1,698 were in the LCDB and 51 were not in any of these databases. In total, 2,183 new lakes were added to the database that were not present in the original database.

The percentage of lakes removed from the original FENZ database ranged from 5% in Southland to 57% in Gisborne (Table 9). The region with the greatest number of lakes added was Canterbury, with 631 additional lakes (Table 9). The region with the most lakes in the 'FENZ lake update 2024' database was Southland (n = 1,131), and that with the least was Nelson (n = 1). A full breakdown of the lakes in each region, including the number of lakes in the original FENZ database and those now removed, is provided in Table 9 and maps for each region are provided in Appendix 2.

The surface area of lakes ≥ 1 ha in Aotearoa New Zealand using the original FENZ database was approximately 373,585 ha of open water. The removal of 686 FENZ lakes and addition of 2,183 new lakes (Table 9) has increased the total surface area of lakes to approximately 404,203 ha, an increase of 30,617 ha. However, we note that calculations based on polygon area are unlikely to be highly accurate given that polygons were included in the database with an accuracy of ≥ 80% (see Section 3.1).

A total of 64 ephemeral lakes were added to the 'FENZ lake update 2024' and 237 lakes were recorded as being part of wetlands.

During this update, 37 lakes in the Chatham Islands were manually added and assigned to the Canterbury Region, as these did not appear in any of the three databases consulted. Of these, 26 are named lakes, and these names have been brought forward into the new 'FENZ Lake Update 2024'

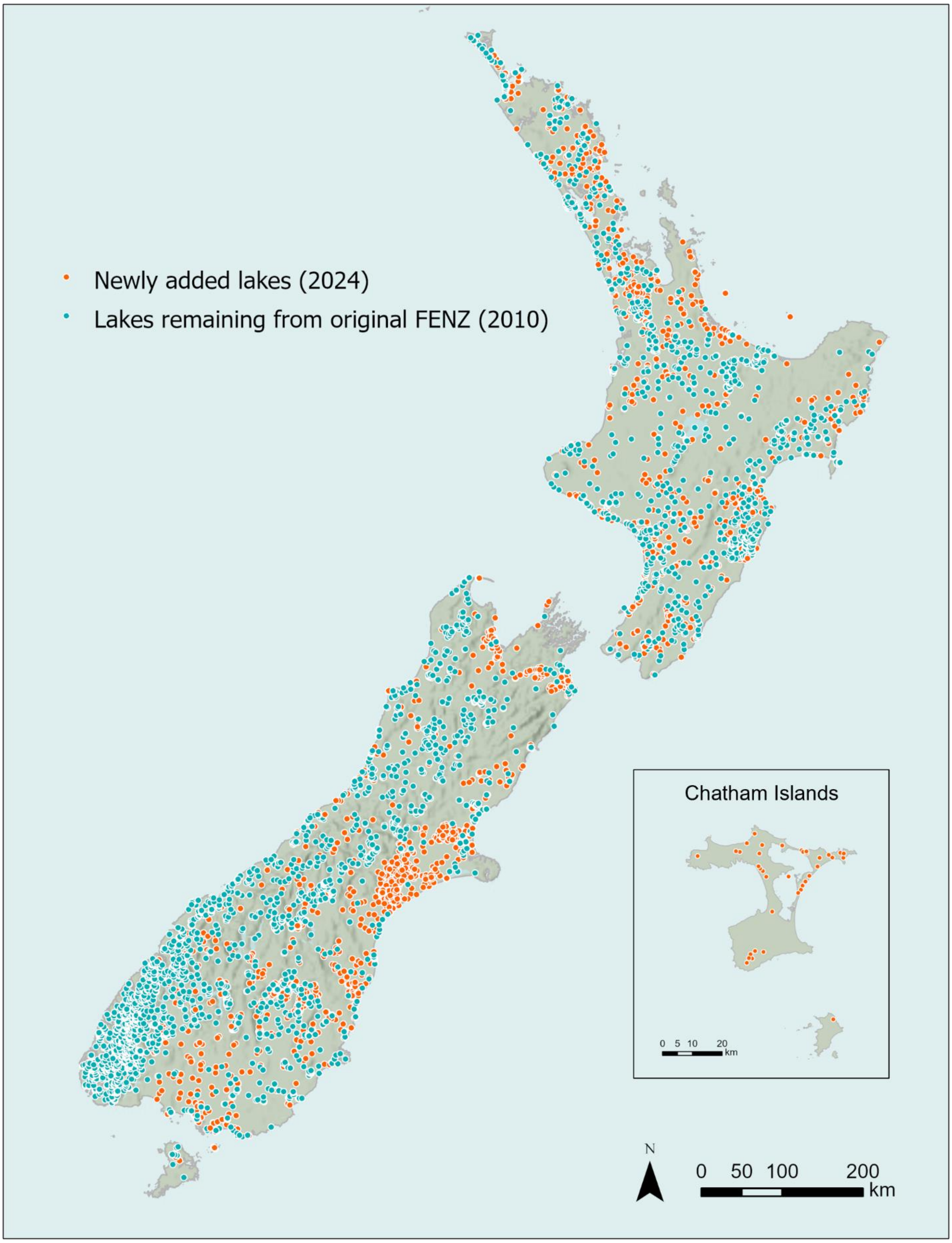


Figure 3. Map of Aotearoa New Zealand showing locations of lakes in the 'FENZ lake update 2024' database (*n* = 5,301 lakes). Lakes remaining from the original FENZ database are shown in blue, and new lakes added to the database are shown in orange.

Table 9. Number of lakes ≥ 1 ha in the original FENZ lakes layer, number and percentage of lakes removed and remaining from the original FENZ database, and total number of lakes added and removed from Topo and LCDB and in the 'FENZ lake update 2024' database. Many of the lakes in the original FENZ database were not in the correct region, which is why the 'lakes remaining' value is sometimes higher than the 'lakes in original FENZ' value.

Region	Lakes originally in FENZ	Lakes removed from original FENZ	% original FENZ lakes removed	Lakes remaining from original FENZ	Lakes added from other sources	Removed lakes (all updated lakes)	Total lakes in 'FENZ lake update 2024'
Canterbury	464	80	17	365	631	196	997
Auckland	75	24	32	58	50	75	108
Bay of Plenty	100	18	18	80	47	35	127
Gisborne	30	17	57	40	45	29	85
Hawke's Bay	285	32	11	230	137	68	367
Manawatū-Whanganui	226	66	29	166	116	152	282
Marlborough	50	11	22	46	93	55	139
Nelson*	0	–	–	0	1	8	1
Northland	263	89	34	168	141	167	309
Otago	380	86	23	294	324	182	618
Southland	991	52	5	939	192	139	1,131
Taranaki	90	21	23	63	31	50	94
Tasman	57	15	26	83	55	53	138
Waikato	243	56	23	181	184	185	365
Wellington	109	24	22	80	56	48	136
West Coast	457	95	21	324	80	159	404
TOTAL	**3,820**	**686**	**18**	**3,117**	**2,183**	**1,601**	**5,301**

* There were no lakes in the Nelson Region in the original FENZ database.

Of the 5,301 lakes included in the 'FENZ lake update 2024', 2,829 (53%) were assessed as naturally occurring and 2,473 (47%) as artificial. Included among the artificial category, however, are 201 lakes that were formed naturally and have since been modified. For example, Lakes Tekapo and Pukaki, which were formed by glaciers but have since been dammed and their water level raised for hydroelectric power generation, are classified as hybrid lakes (Glacial-Artificial [GA]). Of the 2,183 newly added lakes, 1,690 of these were artificial in origin.

The most abundant geomorphic class was Artificial (2,473 lakes), followed by Glacial (1,595); in contrast, only nine lakes were in the Tectonic geomorphic class (Table 10). The most abundant type of Artificial lake was 'Dam', which includes a wide diversity of man-made lakes, from small farm dams to large lakes dammed for hydroelectrical power (Table 10). A total of 340 lakes were classified as hybrids – i.e. they were formed by two or three different processes.

Table 10. Number of lakes in each geomorphic class, including types of Artificial lakes. Note that lakes can be categorised in more than one geomorphic class, and thus the total number of lakes in this table is greater than the total number of lakes (*n* = 5,301).

Geomorphic class	No. of lakes
Contains Artificial	2,473
Artificial type – Constructed	633
Artificial type – Dam	1,699
Artificial type – Mine	136
Contains Barrier bar	118
Contains Wind / Aeolian	396
Contains Glacial	1,595
Contains Landslide	137
Contains Phytogenic	141
Contains Riverine	657
Contains Solution	31
Contains Tectonic	9
Contains Volcanic	89

A breakdown of the geomorphic classes by region is provided in Table 11. Of note was the high number of Artificial lakes in Canterbury and Otago, and particularly the number of constructed Artificial lakes in Canterbury. Maps of the distribution of geomorphic types throughout Aotearoa New Zealand are provided in Appendix 3. For ease of use, a 'quick user guide' for those wanting to explore the database is provided in Appendix 4.

Table 11. Number of lakes in each geomorphic class and type of Artificial lakes by region. Note that lakes can be categorised in more than one geomorphic class, and thus the total number of lakes in this table is greater than the total number of lakes (*n* = 5,301).

	Contains Artificial	Artificial type			Contains Barrier bar	Contains Wind	Contains Glacial	Contains Landslide	Contains Phytogenic	Contains Riverine	Contains Solution	Contains Tectonic	Contains Volcanic
		Constructed	Dam	Mine									
Auckland	76	1	69	6	3	29	0	0	0	4	0	0	1
Bay of Plenty	37	0	34	3	7	4	0	0	1	36	0	0	53
Canterbury	639	424	200	14	33	21	280	12	29	53	0	0	0
Gisborne	58	1	56	1	0	2	0	11	3	9	2	0	1
Hawke's Bay	268	12	253	3	19	3	0	33	6	54	10	0	0
Manawatū-Whanganui	149	4	136	9	1	71	0	7	1	48	0	0	7
Marlborough	103	43	60	0	9	3	24	4	0	13	0	0	0
Nelson	1	0	1	0	0	0	0	0	0	0	0	0	0
Northland	146	9	131	4	2	144	0	0	7	22	2	0	7
Otago	415	109	290	16	2	16	128	5	20	68	0	0	0
Southland	127	10	101	16	6	28	848	17	41	121	0	0	0
Taranaki	50	7	41	2	0	19	0	16	1	13	0	0	1
Tasman	50	6	41	3	1	7	52	13	4	10	2	0	0
Waikato	203	5	168	29	13	12	0	5	27	116	15	0	19
Wellington	92	3	86	3	9	11	0	0	1	38	0	1	0
West Coast	59	0	32	27	13	26	263	14	0	52	0	2	0

5. Discussion and recommendations

Obtaining accurate information on Aotearoa New Zealand lakes is of increasing importance, given the need to halt freshwater degradation (MfE 2020), accurately model climate change adaptation and manage freshwater resources. To help enable this, the original FENZ lakes database was updated to accurately reflect our changing freshwater landscape. Two workshops held with lake experts, a Te Ao Māori expert and lake / freshwater scientists from regional and central government led to the recommendation that lentic waterbodies greater than or equal to 1 ha in surface area should be included in the updated FENZ lakes layer. The main exception to this was the exclusion of wastewater ponds, which were not included in the updated layer. In addition, the workshop participants emphasised that the use of surface area was a choice of convenience, and does not reflect the scientific definition of a lake. A further recommendation was that future work should identify and add other important attributes (i.e. lake depth, residence time) to the database.

Using the criteria identified during the workshops, we combined lentic polygons from three sources and reviewed these manually in ArcGIS. This resulted in a new database, the 'FENZ lake update 2024', which contained 5,301 waterbodies.

A large number of waterbodies (n = 686) from the original FENZ database were removed for a range of reasons, including open water areas comprising < 1 ha and some 'lakes' being river reaches or open estuaries (Table 5). Of note was the large number of new man-made lakes, especially in regions such as Canterbury. Many of these were in the category Artificial – Constructed, they often appeared to be lined or have concrete sides, and they had few, if any, natural features. These lakes have been identified in the database to enable lake managers to use their discretion around whether to include them in management plans.

The geomorphic classification of lakes in the original FENZ database and newly added lakes was reviewed. A number of lakes were identified as hybrid lakes, i.e. lakes that have been formed by more than one process. There were no hybrid lakes in the original FENZ database. Of interest was the high portion (approximately 47%) of 'Artificial' lakes in the 'FENZ lake update 2024'. It was extremely challenging to assign geomorphic classes using the information available and due to the large scale of the project. The current classifications need to be considered preliminary, and site visits in concert with in-depth investigations are required when a robust geomorphic classification is required.

The only metadata that have been included for newly added lakes are geographic location, region (according to 'Regional Council 2022 (generalised)' regional boundary data), geomorphic class and area (ha), which was obtained from the polygons. We also noted whether the lakes were part of a wetland or were ephemeral.

While this update has improved our knowledge of lake numbers, distribution and geomorphic type in Aotearoa New Zealand, there are limitations and caveats with this analysis. These include polygon accuracy, for which we attempted to maintain an accuracy of > 80%, difficulties in confidently classifying lake geomorphic type, and the inclusion of lakes deemed ephemeral. We have noted these lakes in the database and advise lake managers use their discretion when considering whether these are included for regional planning. We recommend that the following actions are taken to enable the database to be used for purposes such as national-scale predictions of water quality and regional planning (see Section 2.2 for key uses of FENZ):

- Review the international literature and evaluate different methods for estimating lake depth. Following this process, we recommend that lake depths are modelled or estimated for all lakes in the new database. This work is essential given that the current lake water quality models are sensitive to depth – for example, it was the ninth most important predictor in TLI3 models used in Wood et al. (2023) and Snelder et al. (2022).
- Enable the database to be regularly updated as new lake information becomes available.
- Determine lake catchment size, land cover and altitude. This can be done using GIS. Recent work at the University of Waikato suggests that some of the catchment areas in the current FENZ database are inaccurate. We advise that all catchment areas are evaluated.
- Ensure that polygons from the updated lake database are integrated with future river databases, such as national digital river networks (Booker et al. 2024).
- Model / determine the other attributes for the newly added lakes (see Appendix 5).

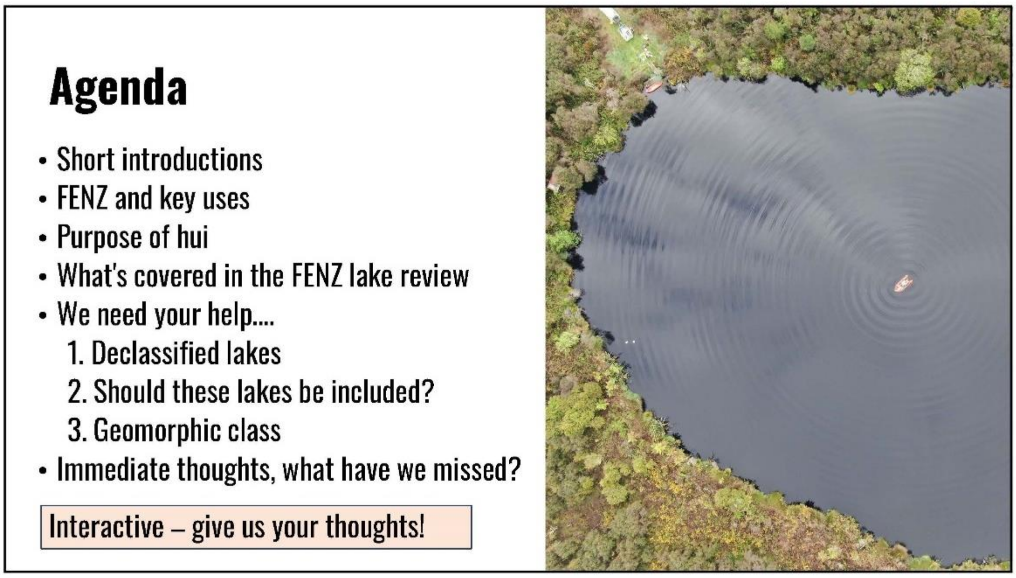
Part of this contract is supplying an ArcGIS shapefile with the lake polygons and associated metadata. It is the responsibility of MfE to liaise with DOC regarding the actual updating of the FENZ database and to make decisions on when and how these new data are made publicly available .

6. Appendices

Appendix 1. Slides from Workshops 1 and 2

A1.1 Workshop 1

1



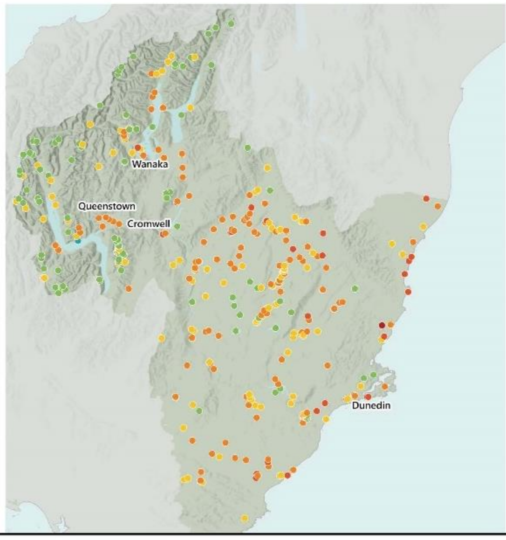
2

Freshwater Ecosystem New Zealand database

- Developed in ~2010
- Geospatial layers -environ/biol patterns

- Lake = open water > 1 ha = 3821 (3596) lakes

Key applications:
- MfE – national scale assessments
- Regional Councils – NPS-FM implementation
- Researchers



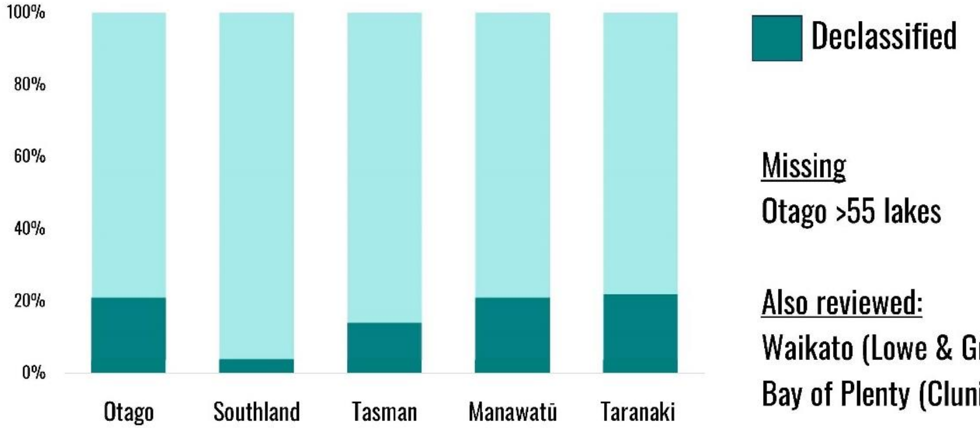
3

....but there are some challenges

Should these waterbodies be included as “lakes” in the FENZ database?

4

Regions reviewed to date



Missing
Otago >55 lakes

Also reviewed:
Waikato (Lowe & Green)
Bay of Plenty (Clunies-Ross)

5

What's covered in the review

- Expert workshops (today and Jan/Feb)
- Declassify lakes
- Register new lakes (IDs/shape files)
- Geomorphic class
- Update current database
    - Actual depths
    - Latest catchment land use
    - Measured and modelled data

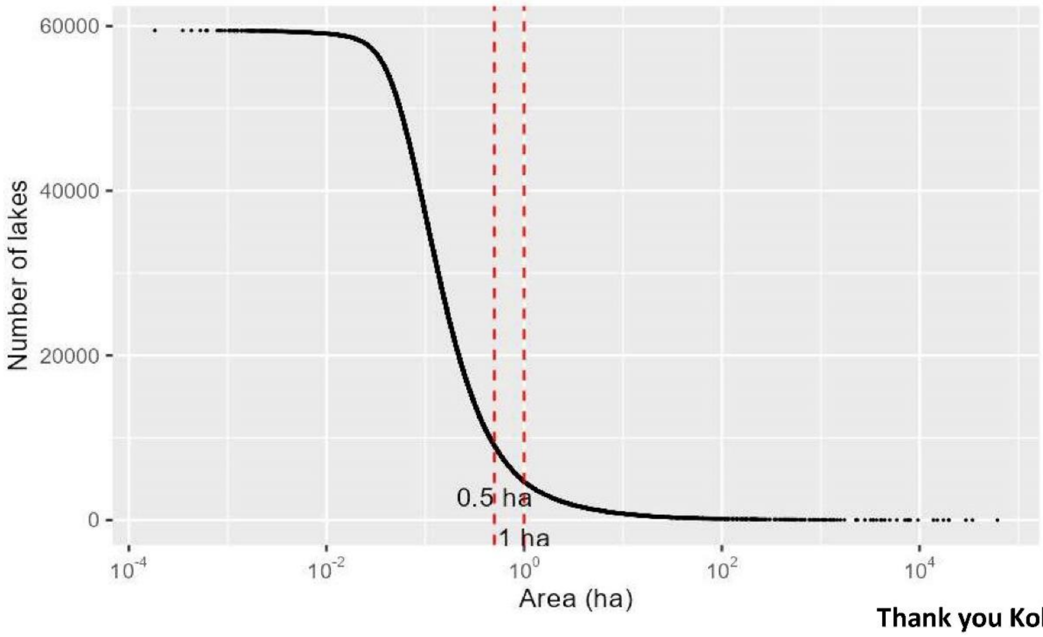
6

Why are we here today?

What waterbodies should be included as "lakes" in the FENZ database

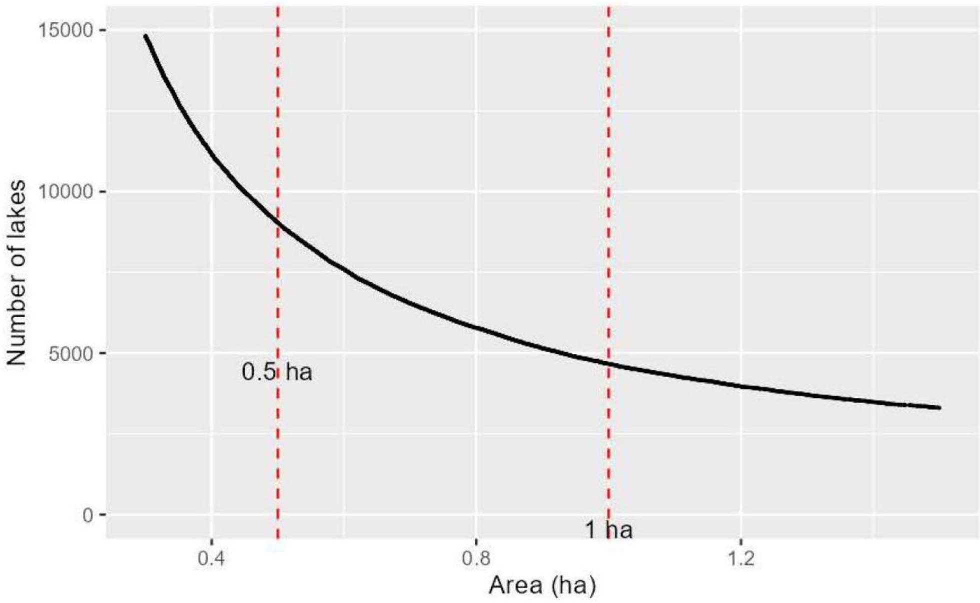
How many lakes are there in Aotearoa New Zealand?

7



Thank you Kohji!

8



9

Part 1 - declassified lakes

As we go through the next slides please consider if there are any that you think need further discussion (hui 2)

10

Declassified lakes – Field or grassland

11

Declassified lakes – Dried (in all available images)

12


Declassified lakes – Estuaries
36046 = Catlins lake

13


Declassified lakes – Rivers, channels, streams
44657

14

Declassified lakes – Riverbeds

15

Were there any declassified waterbodies you think we need to reconsider?

- Fields/grassland
- Dry
- Estuaries
- River, channel, streams
- Riverbeds

16

Part 2 – we're not sure about these "lakes"….

We will discuss these further in the second hui. Please note any initial thoughts.

17

Is 1 ha a sensible cut off?

18

Is 1 ha a sensible cut off? …culturally significant waterbodies

Rototai - 0.57 ha

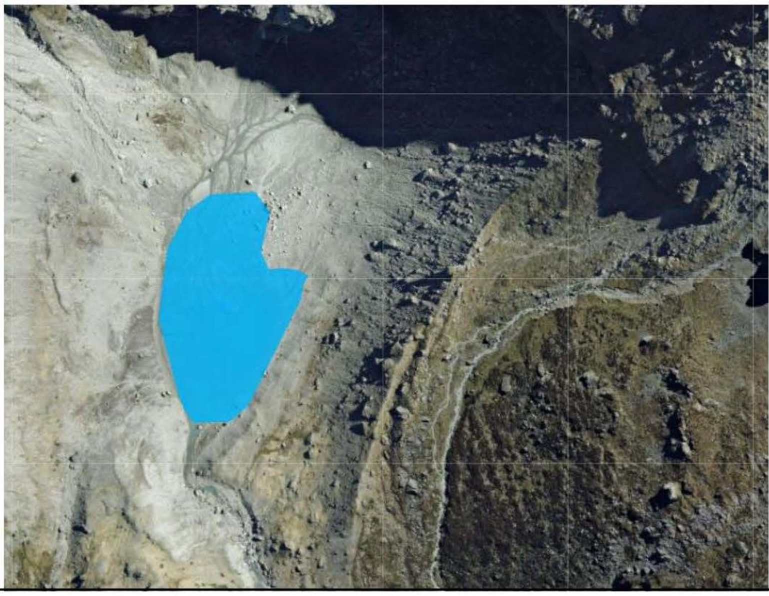
Killarney – 0.87 ha

19

When one becomes many…..

20

Ephemeral lakes

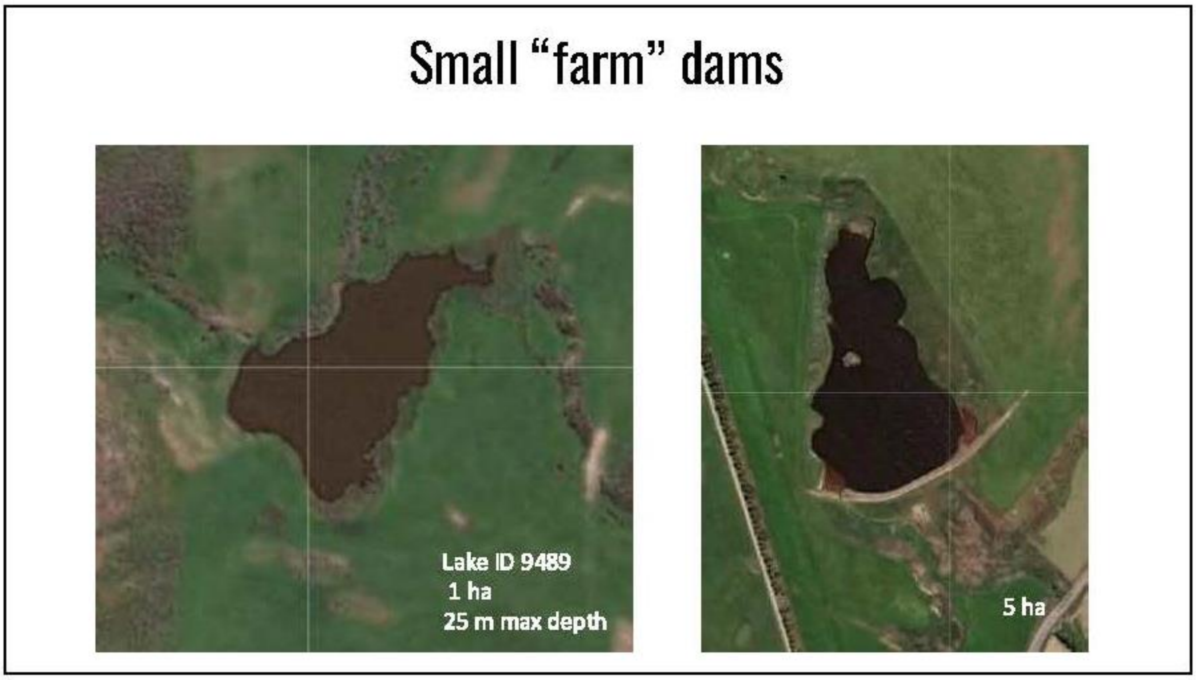


21

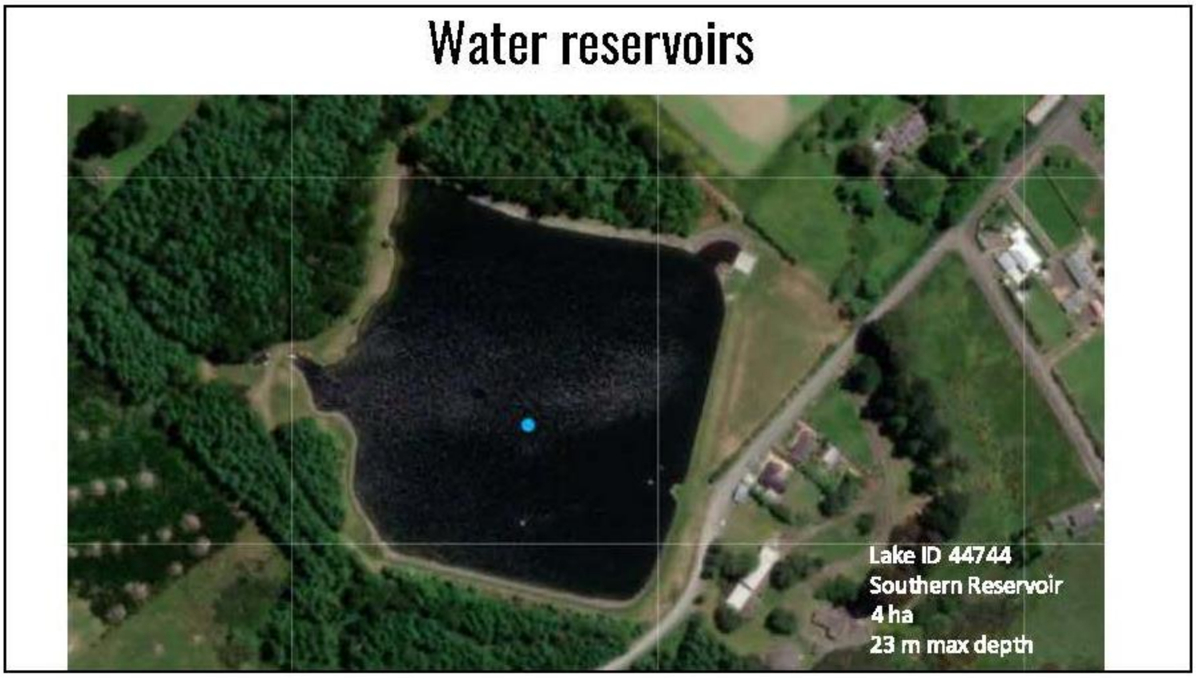
Part 2 – man-made lakes/artificial

We will discuss these further in the second hui. Please note any initial thoughts.

22


Small "farm" dams
Lake ID 9489
1 ha
25 m max depth
5 ha

23


Water reservoirs
Lake ID 44744
Southern Reservoir
4 ha
23 m max depth

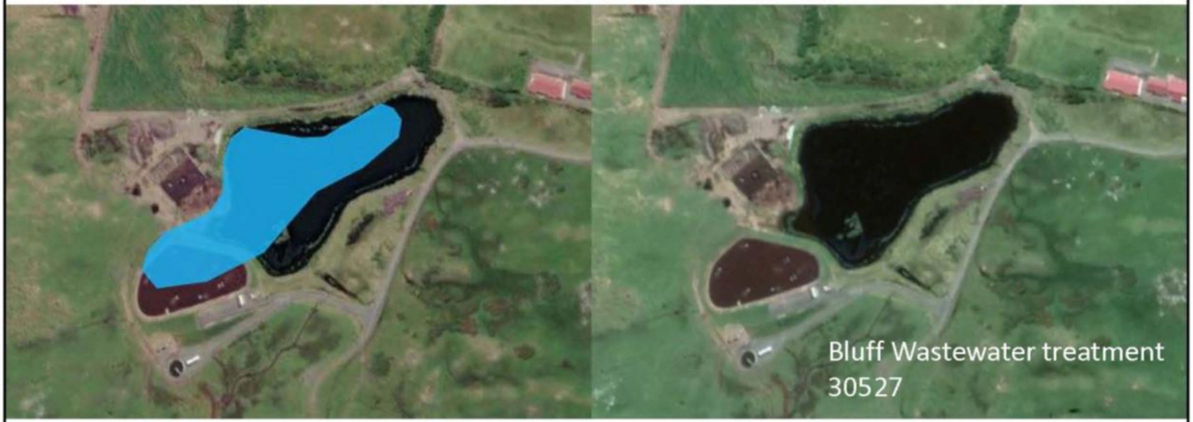
24

Water storage

25

26

Wastewater treatment ponds

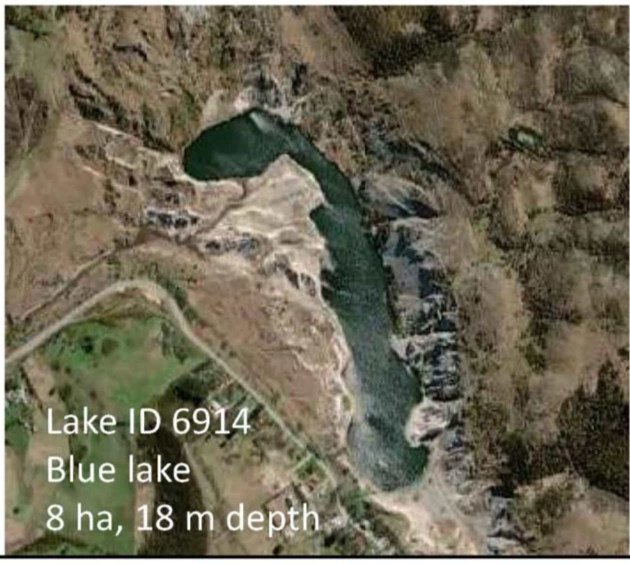


27

Waterbodies associated with mining

28

Waterbodies associated with mining



29

Are there any man-made lakes you think shouldn't be included?

- Small dams
- Water reservoirs
- Wastewater treatment
- Associated with mines
- Others?

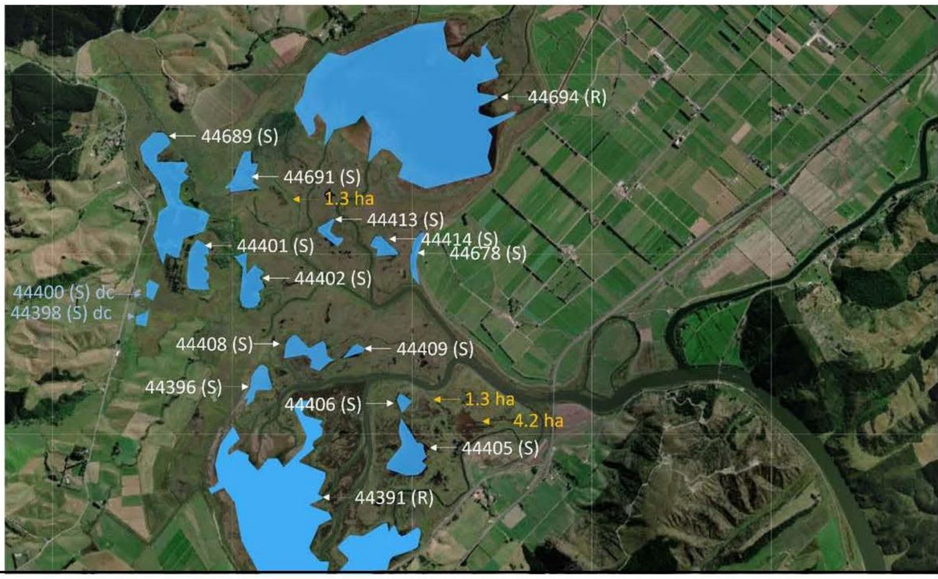
30

Part 2 – lakes - wetlands

We will discuss these further in the second hui. Please note any initial thoughts.

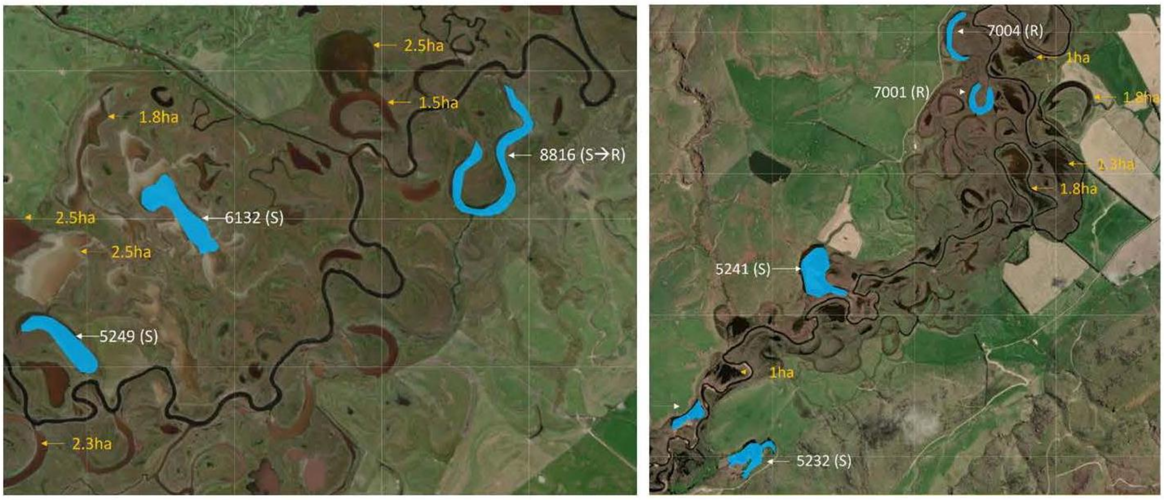
31

Wetlands and lakes – Sinclair wetlands



32

Wetlands and lakes – Taieri Scroll



33

Wetlands and lakes – Lake Tuakitoto

34

Part 3 - Geomorphic class

Lake class or type[2]	Mode of formation
Artificial (A)	Human activity forming reservoirs or recreational lakes by dam or weir construction, by excavation (including enlarging or modifying pre-existing natural lakes or waterways), by maintaining open water in peatlands or wetlands, or by flooding of open-cast mines
Barrier-bar (B)	Longshore current or wave action, and other coastal processes, forming barrier-bars, chenier ridges, or spits or tombolos on coasts or lake shorelines, typically enclosing inlets, embayments, old river courses, or estuaries
Dune (D)	Wind-blowing of sand, chiefly on coasts, to dam valleys or generate depressions between dunes or dune belts, or by the excavation of (sand-rich) hollows by wind erosion (deflation basins)
Glacial (G)	Glacial activity including glacial scouring or frost riving forming rock depressions (e.g., cirque and fjord lakes), deposition of tills (forming moraines), deposition of fluvioglacial sediments, or collapse of deposits as a result of melting of large blocks of *in situ* ice (kettle lakes) or permafrost thawing (thermokarst lakes)
Landslide (L)	Blockage of valleys by landslide debris including debris avalanche deposits, lahars, rockslides, mudflows, screes, and colluvium; potentially includes subsidence in unconsolidated materials forming sinkholes
Phytogenic (P)	By substantial peat accumulation causing damming, by subsidence in peat, by peat fires forming 'burn pools', or by upwelling of minerogenic or geothermal groundwater under peat resulting in permanent pools or lakes
Riverine (R)	River action including blockage of tributary drainage by deposition of fluvial sediment (alluvium) by aggrading rivers forming blocked-valley (lateral) lakes, by the isolation of meander loops or abandoned channels forming cut-off lakes (including oxbows, scroll lakes, and concave bench lakes), and by alluvial-fan deposition; also plunge-pool lakes
Solution (S)	Dissolution of carbonate rocks (mainly limestone, marble, calcareous sandstone) to form bowl-shaped corrosion hollows (solution dolines), the formation of depressions via land collapse into underlying caves (collapse dolines), or the formation of blind valleys including poljes (long blind valleys with flat floors, vertical walls), all characteristic of karst terrains
Tectonic (T)	Faulting or folding or associated activity that creates depressions, including formation of sag ponds or basins alongside faults and fissures at the land surface that result from earthquake shaking
Volcanic (V)	Volcanic activity including caldera collapse because of magma withdrawal in large-volume eruptions, smaller explosive eruptions forming craters (ground craters including maars, and also volcano craters), and blocking of valleys, or impounding embayments, by lava, pyroclastic flow (density current) deposits, debris avalanche and laharic deposits, or hydrothermal deposits

Lowe & Green (2024) – Origins & ages of Waikato lakes

35

Swamp/wetland or riverine or glacial

36

Salt lakes

37

Initial thoughts, questions, what have we missed?

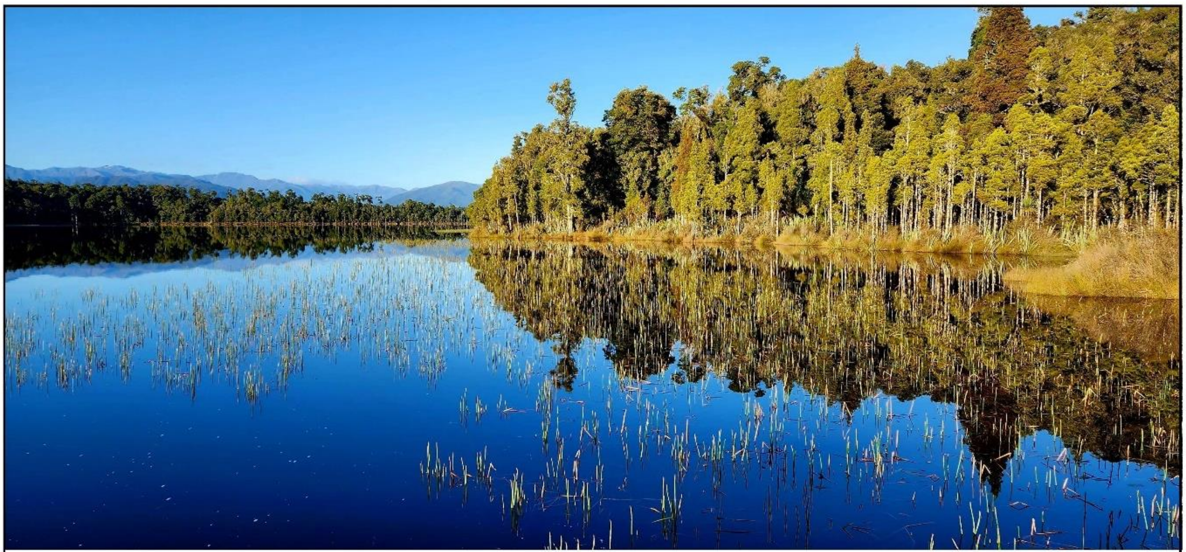
38

Things to think about for the next hui....

- Do you agree with the declassified lakes?
- Lakes with uncertain classification?
- Size for inclusion in FENZ?
- Lakes in wetlands?
- What criteria are important? size, depth, cultural value..
- Geomorphic classification

39

A1.2 Workshop 2



Lakes for inclusion in the FENZ database, Hui 2, 24 Jan 2024

1

Introduction

- Great suggestions/ideas hui 1
- Thank you!
- Outcomes of today need to be practical and within scope

- Purpose of current project
- Use of FENZ (lakes section)

- Small breakout groups
  1. Recommendation (strong objections)
  2. Ideas for future work

2

What we are <u>not</u> doing

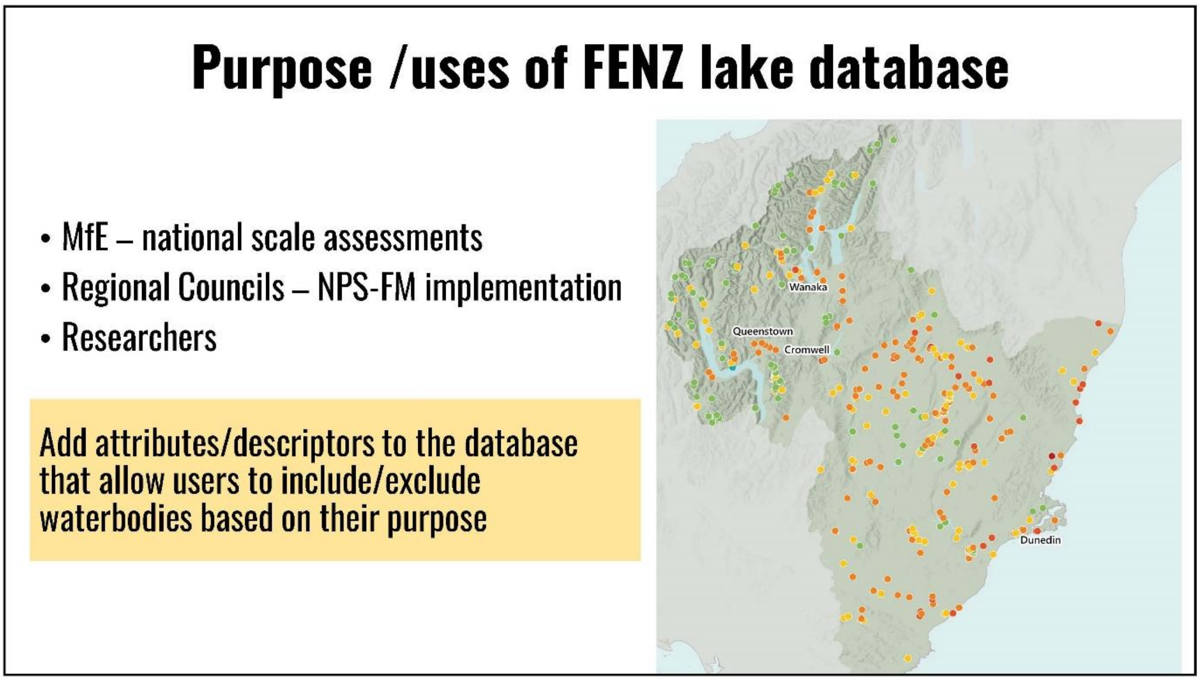
- Coming up with a definition for "what is a lake"
- Refining/removing the FENZ lentic layers (i.e., still waterbodies > 50 m, ~60,000 waterbodies)

3

Aim of this project

- Identify waterbodies for inclusion in FENZ lake database
- Currently many waterbodies missed or included that do not meet this criteria

4


Purpose /uses of FENZ lake database
• MfE – national scale assessments
• Regional Councils – NPS-FM implementation
• Researchers
Add attributes/descriptors to the database that allow users to include/exclude waterbodies based on their purpose
Wanaka
Queenstown
Cromwell
Dunedin

5


Breakout groups

6

Session 1 – using only area, area?, reduced area

7

Use of area only = not valid to identify waterbodies for inclusion based on area only

Recommendation = Area is the only reliable attribute currently available at national scale.

Future work

- Make this a living/updateable document
- Lake managers can add other attributes (depth, residence time etc.) as identified
- (Discuss)

8

What area (ha) should be used to guide inclusion as a "lake"

Recommendation = Continue with the use of ≥1 ha of open water

- This area accounts for ~97% of area of all lentic waters in Aotearoa
- Allows some continuity in reporting
- The FENZ lentic layer will still remain (~60,000 waterbodies) – note: we are not updating this
- Scale of waterbody area and fetch - physical processes that define lakes (stratification, open water mixing). Thought that a 100 m length (a hectare being 100x100 m) seemed like a reasonable cutoff
- Waterbody that is only 50 m in length = edge/bottom benthic processes are more likely to dominate these systems with very little open water influences
- Management consideration – if reduced, suddenly 100's more lakes to manage under NPS-FM

9

What area (ha) should be used to guide inclusion as a "lake"

Future work (beyond current scope)

- Identify culturally/socially/ecologically significant waterbodies – add to database
- Update the lentic waterbody layer (waterbodies larger than 50 m)
- (Discuss)

10

Should lakes that have reduced in size remain in database?

11

Should lakes that have reduced in size (completely dried) remain in database?

Recommendation = yes. A new 'attribute/descriptive' column will be added which describes size reduction and why (wetland encroachment, dried etc)
= no to adding any additional 'paleo lakes'

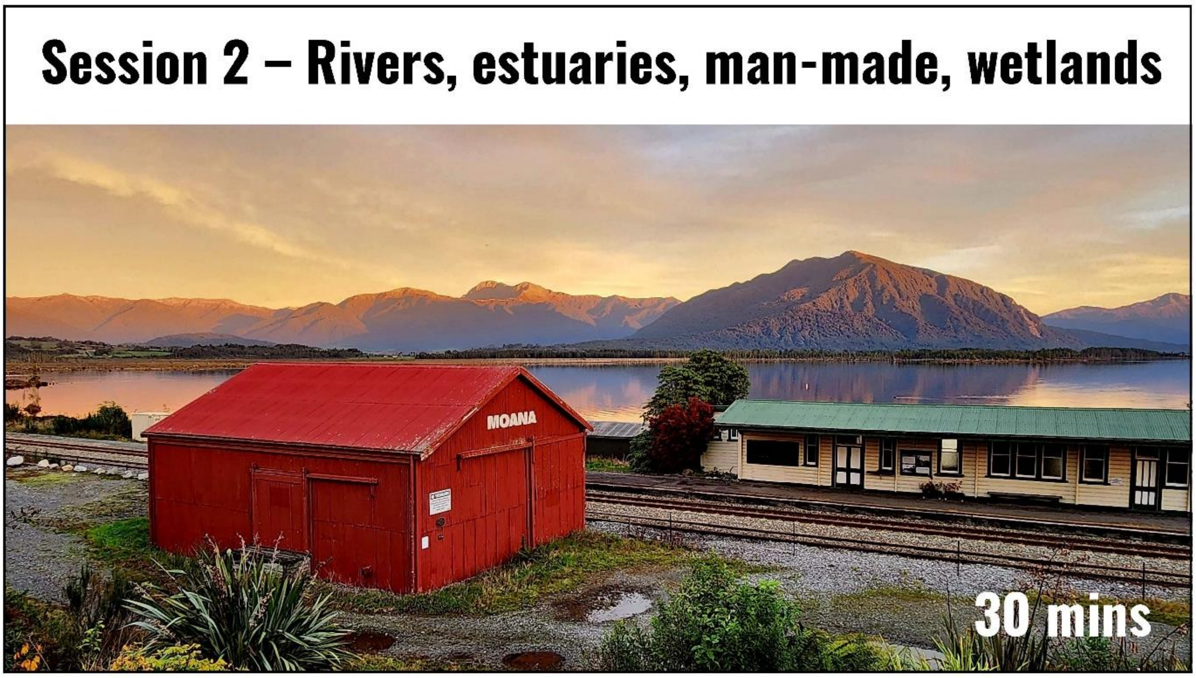
Future work (beyond current scope)

- Undertake a review to explore location/size of 'paleo' lakes
- (Discuss)

12


Report back –
Session 1

13


Session 2 – Rivers, estuaries, man-made, wetlands
MOANA
30 mins

14

Inclusion of rivers (and streams)

Note: currently no large rivers are included, its mostly streams/channels

15

Inclusion of rivers (and streams)

Recommendation = Do not include these, in general most do not function as lakes. These generally have their own specific management plans.

Future work (beyond current scope)

- (Discuss)

16

Estuaries – should these be included, what rules do we apply?

Barrier bar = Longshore current or wave action, and other coastal processes. Forming barrier-bars, chenier ridges, or spits or tombolos (isthmus) on coasts or lake shorelines, typically enclosing inlets, embayment's, old river courses, or estuaries.

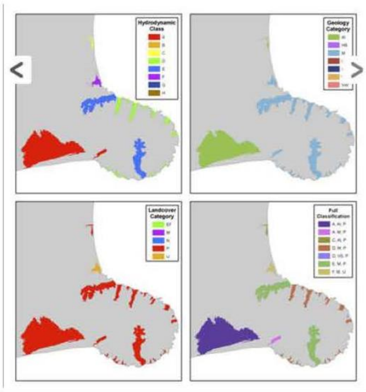
17

Estuaries – should these be included, what rules do we apply?

Recommendation = Include 'estuaries' when there is evidence that the waterbody is at times isolated from sea (if in doubt include).
= Compare with Estuary Environment Classification (~300 estuaries in Aotearoa), add attribute/descriptor if also in here.

Future work (beyond current scope)

- (Discuss)



18

Man-made lakes – should all these be included?

Farm dams, hydro-lakes, wastewater ponds, irrigation, mines…

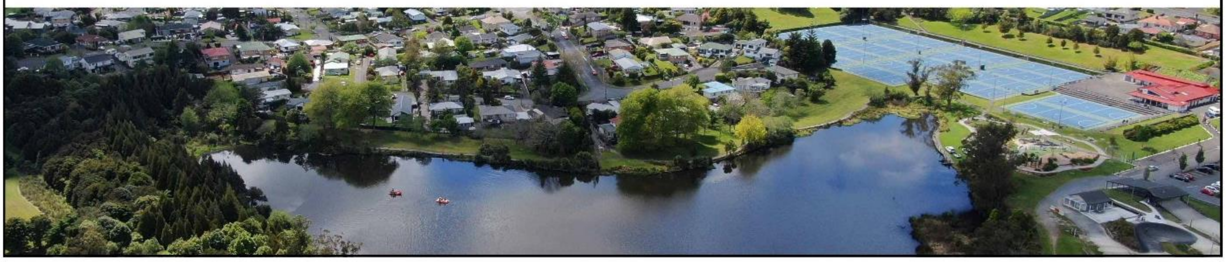
19

Man-made lakes – should all these be included?

Recommendation = Remove wastewater ponds?
= All other man-made lakes remain. Where possible add attribute/descriptor to describe main use or how formed

Future work

- Living document that can be updated to better reflect uses
- (Discuss)



20

Wetlands – should waterbodies within wetlands be included?

RMA definition of a wetland = Wetland includes permanently or intermittently wet areas, shallow water, and land water margins that support a natural ecosystem of plants and animals that are adapted to wet conditions.

.

21

Wetlands – should waterbodies with wetlands be included?

Recommendation = Include all waterbodies with open water ≥1 ha within wetlands
= Add attribute/descriptor to record that it is within wetland complex

Future work

- (Discuss)

22

23

Geomorphic class

24

Geomorphic class – use below classifications

Lake class or type	Mode of formation
Artificial (A)	Human activity forming reservoirs or recreational lakes by dam or weir construction, by excavation (including enlarging or modifying pre-existing natural lakes or waterways), by maintaining open water in peatlands or wetlands, or by flooding of open-cast mines
Barrier-bar (B)	Longshore current or wave action, and other coastal processes, forming barrier-bars, chenier ridges, or spits or tombolos on coasts or lake shorelines, typically enclosing inlets, embayments, old river courses, or estuaries
Aeolian (W)	Wind-blowing of sand, chiefly on coasts, to dam valleys or generate depressions between dunes or dune belts, or by the excavation of cover beds and/or regolith from hollows by wind erosion (deflation basins)
Glacial (G)	Glacial activity including glacial scouring or frost riving forming rock depressions (e.g., cirque and fjord lakes), deposition of tills (forming moraines), deposition of fluvioglacial sediments, or collapse of deposits as a result of melting of large blocks of *in situ* ice (kettle lakes) or permafrost thawing (thermokarst lakes)
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Lowe & Green (2024) – Origins & ages of Waikato lakes

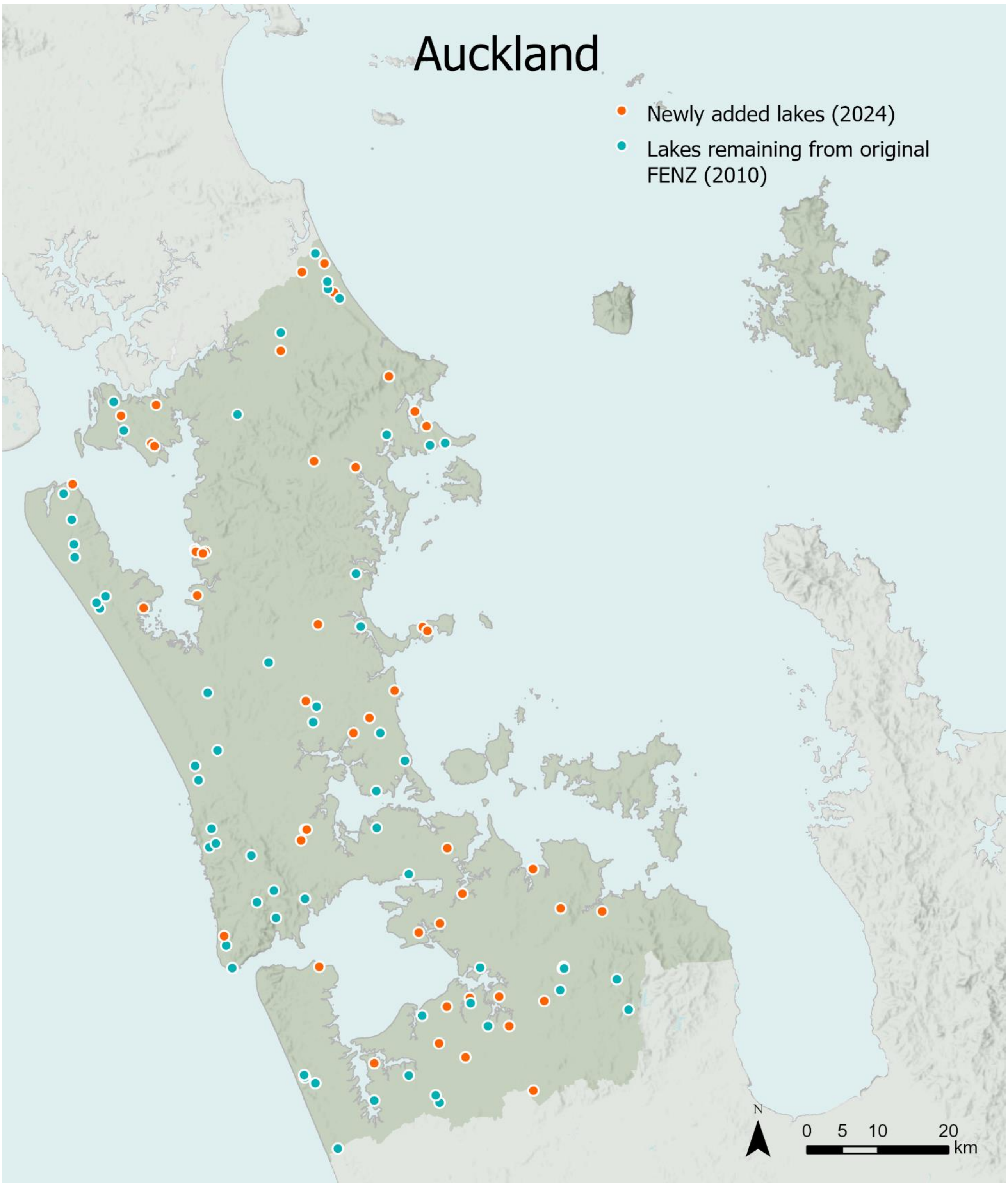
25

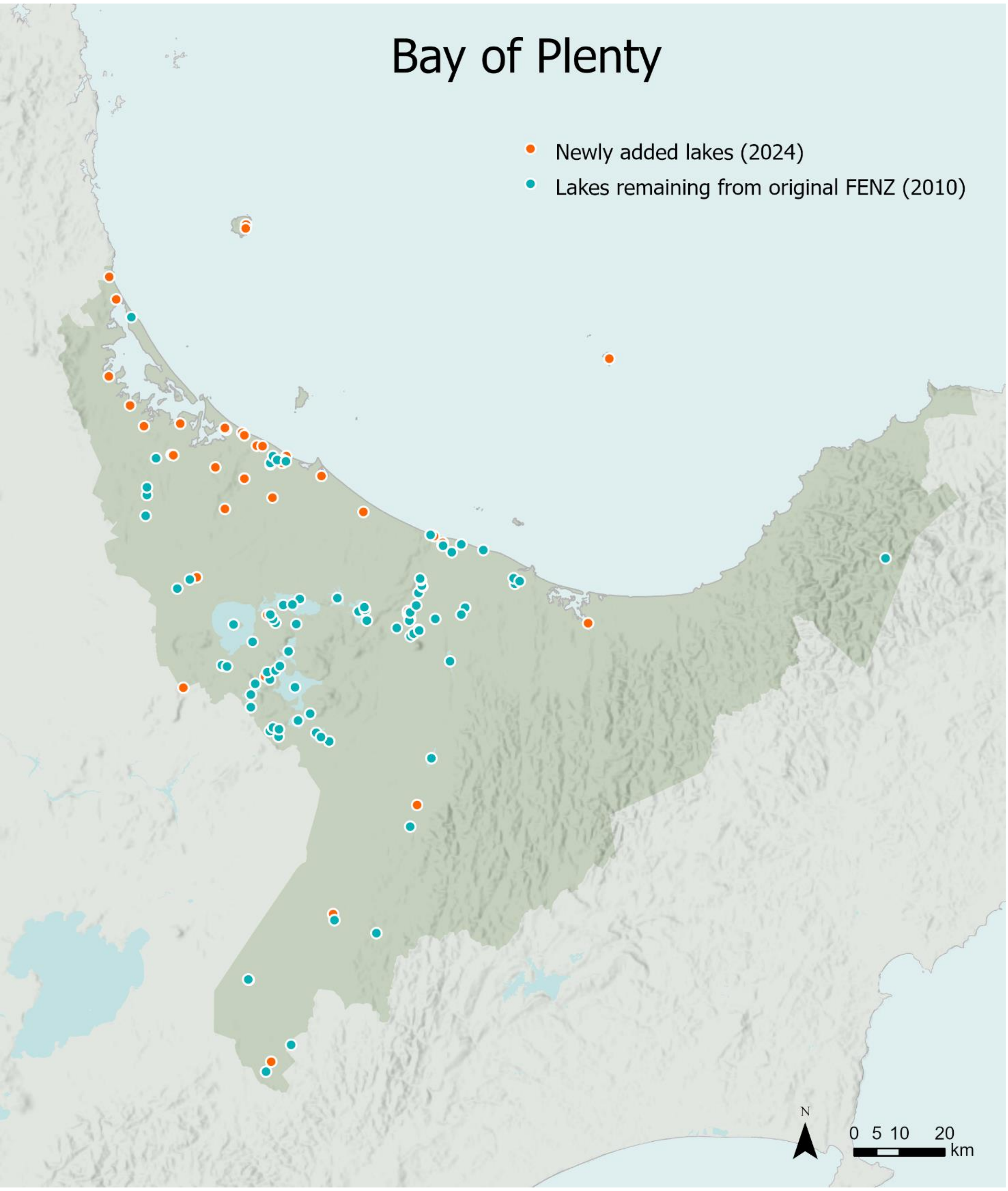
Next steps….

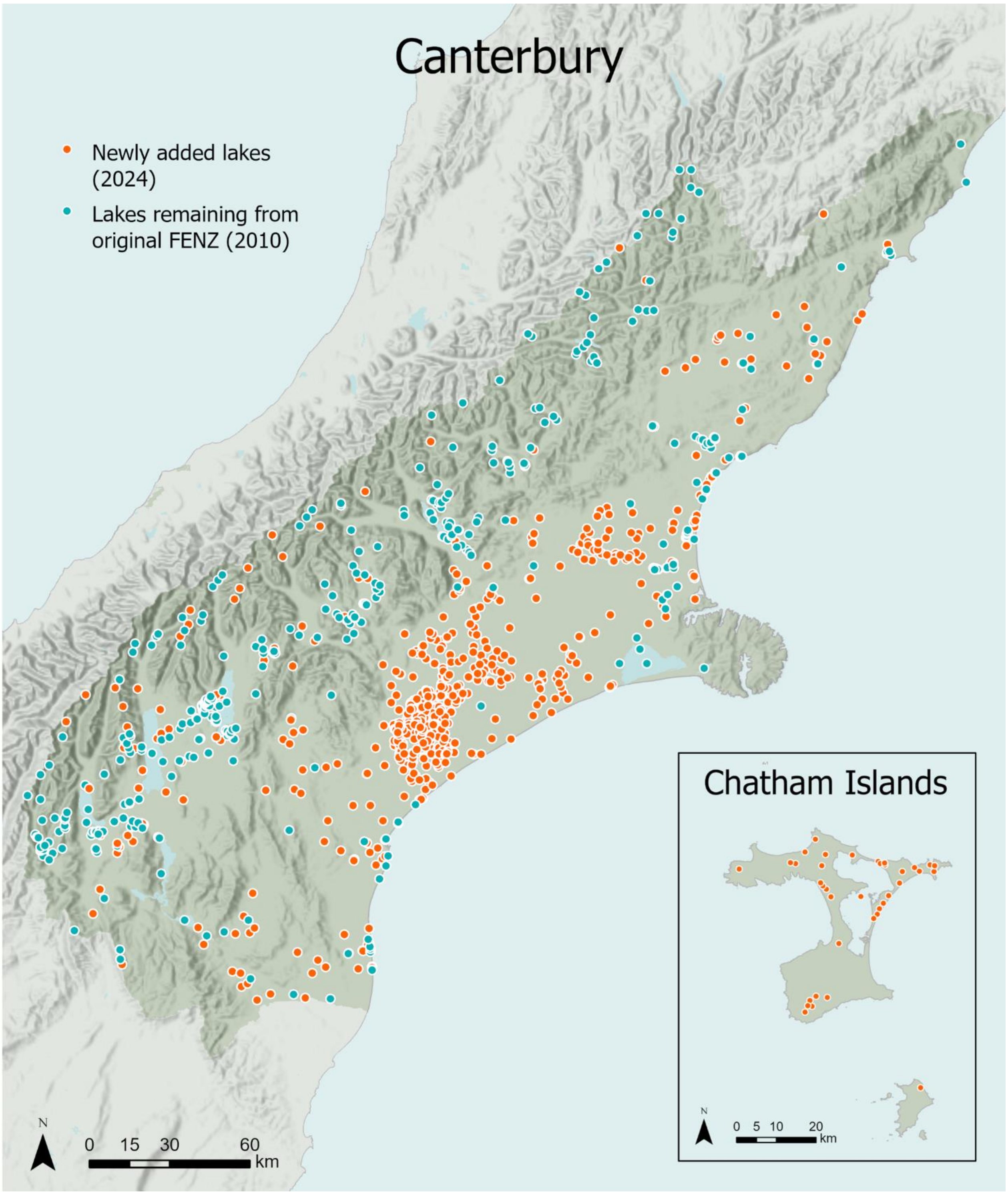
- Circulate summary of todays discussions and outcomes
- Opportunity for additional feedback (12 February)
- Team starts updating database (Stage 1 = 30 June 2024)
  - Declassify lakes
  - Register new lakes (IDs/shape files)
  - Geomorphic class
  - Update current database
- Hopefully Stage 2 where additional information is added for "new" lakes

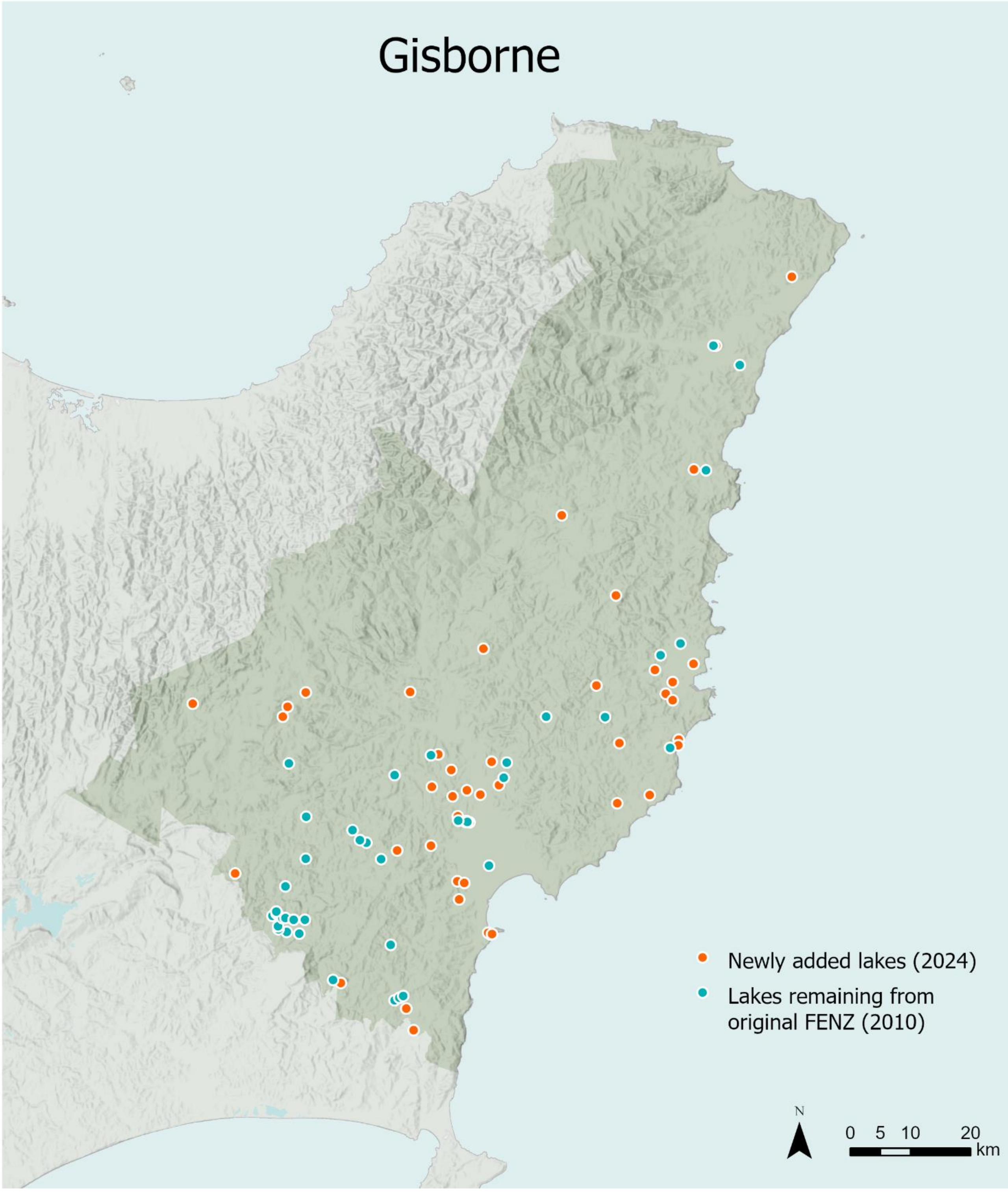
26

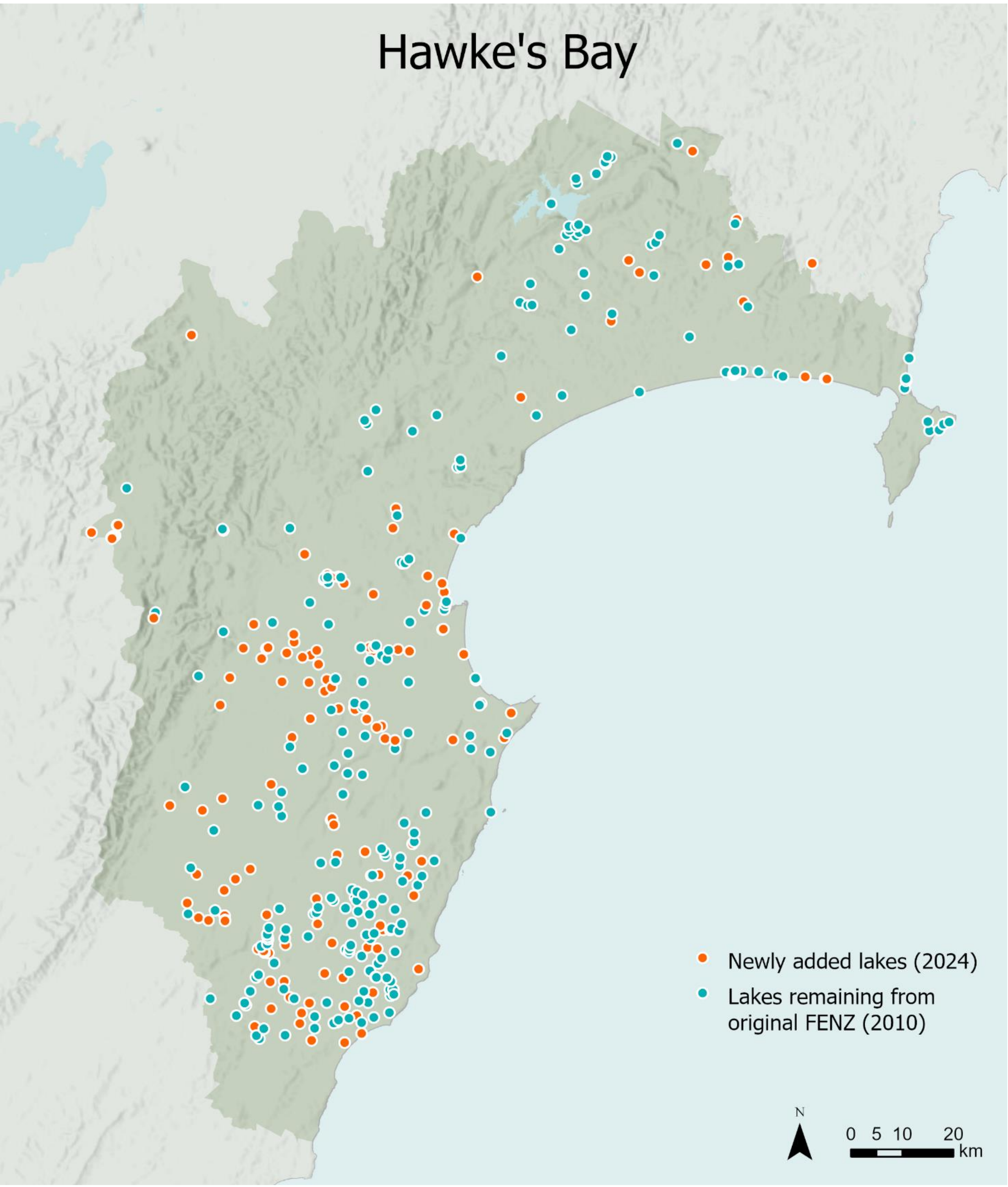
Appendix 2. Regional maps of updated FENZ lakes

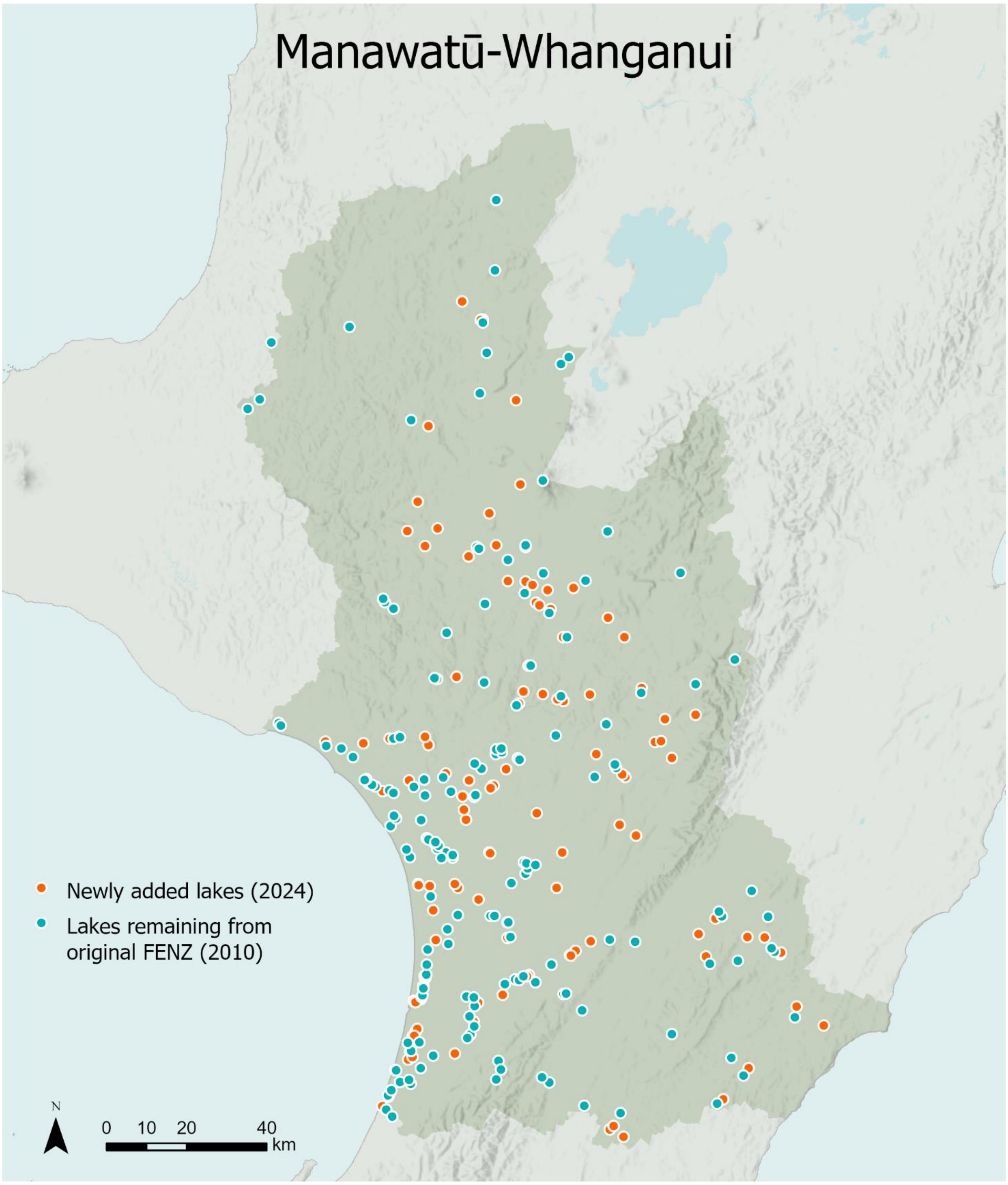


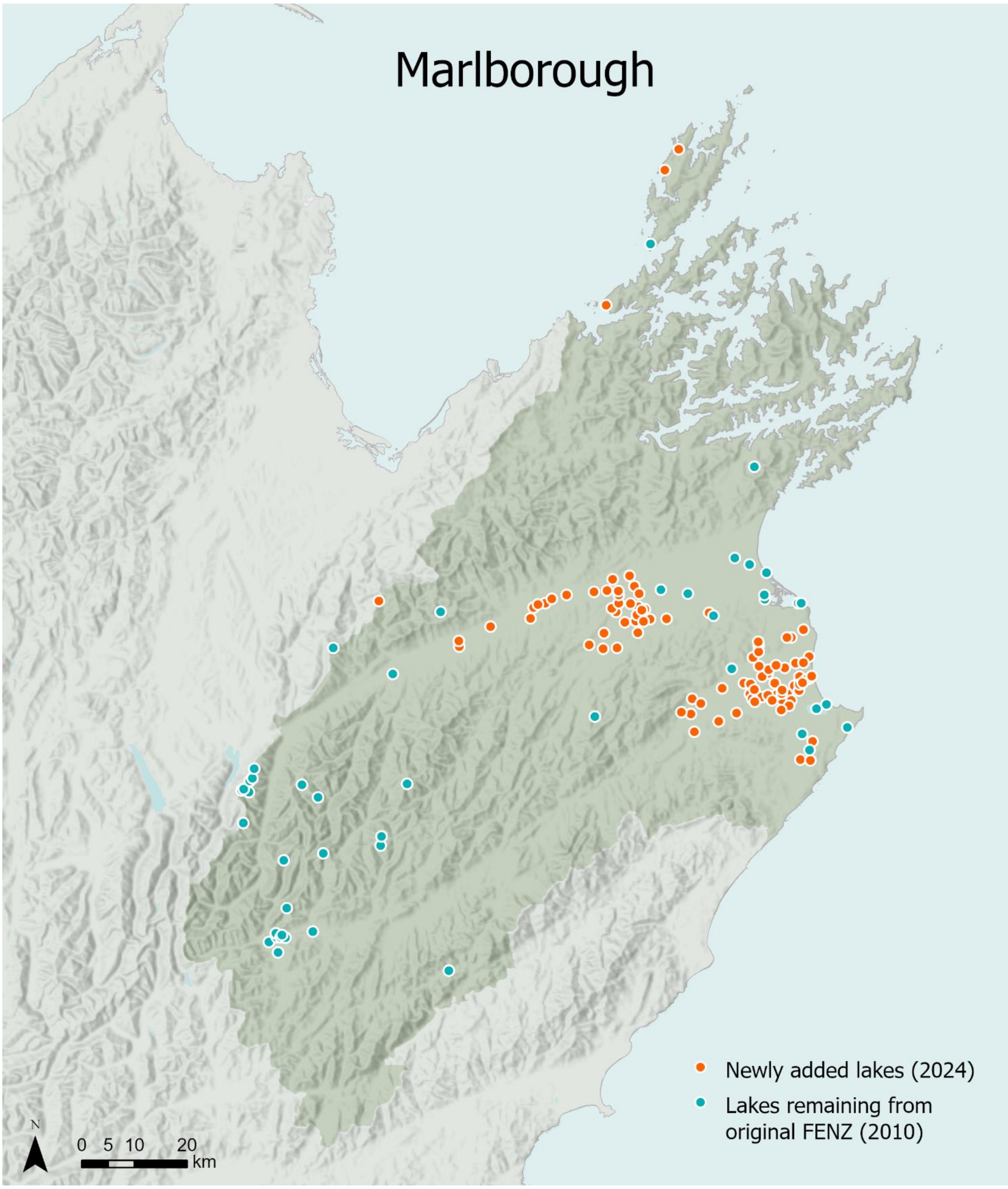

Bay of Plenty
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

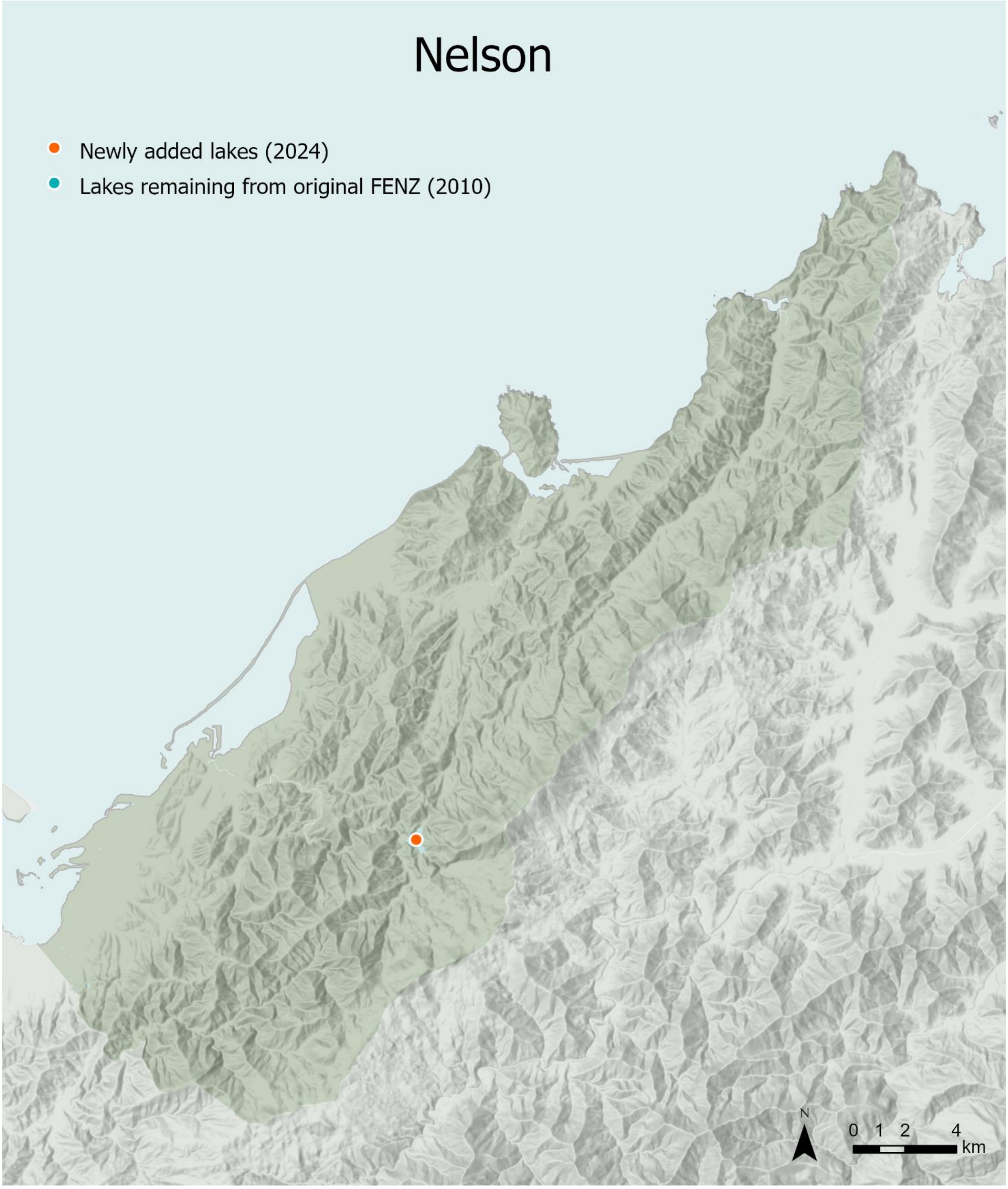

Canterbury
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
Chatham Islands
N
0 15 30 60
km
N
0 5 10 20
km

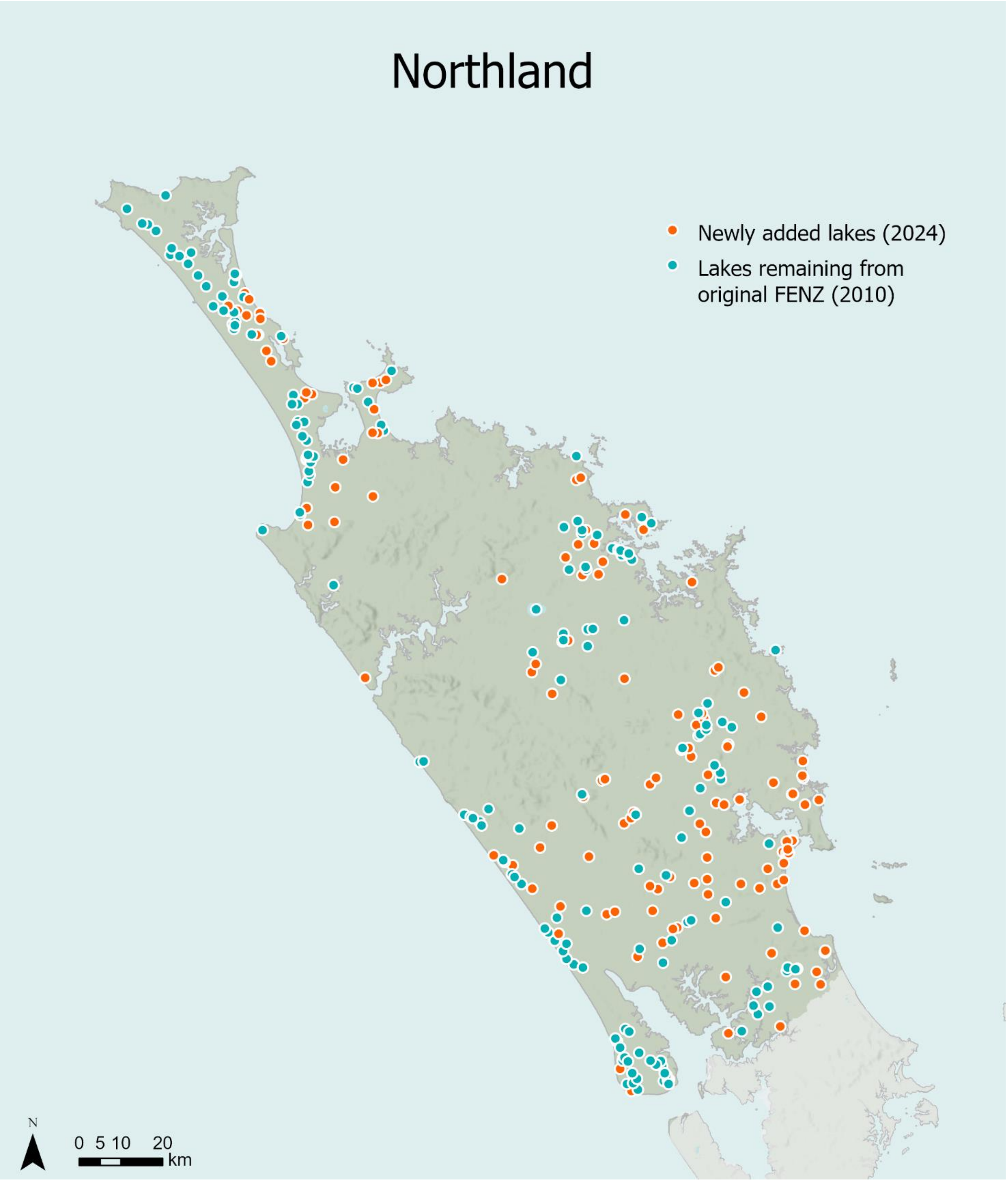

Gisborne
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

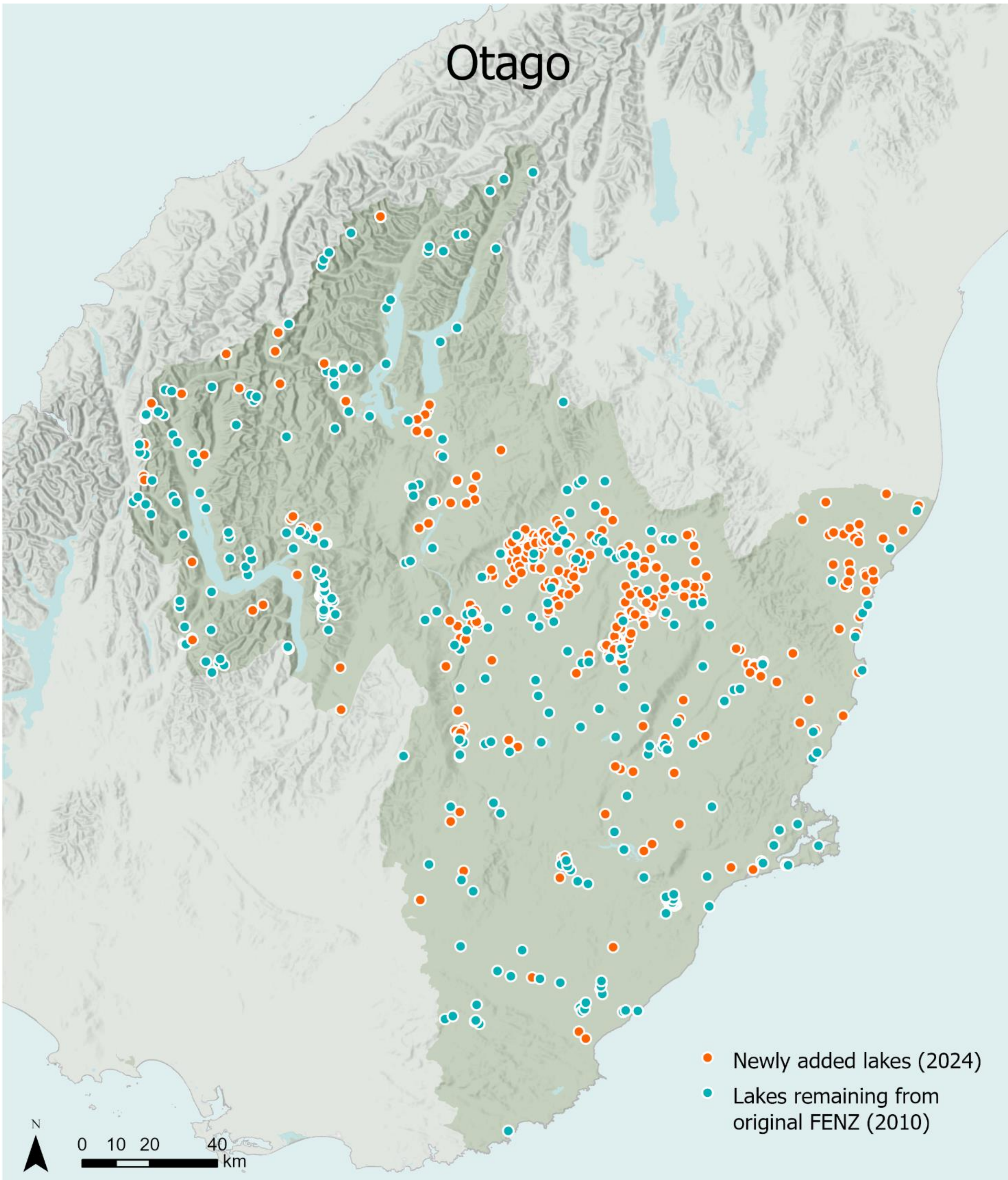

Hawke's Bay
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

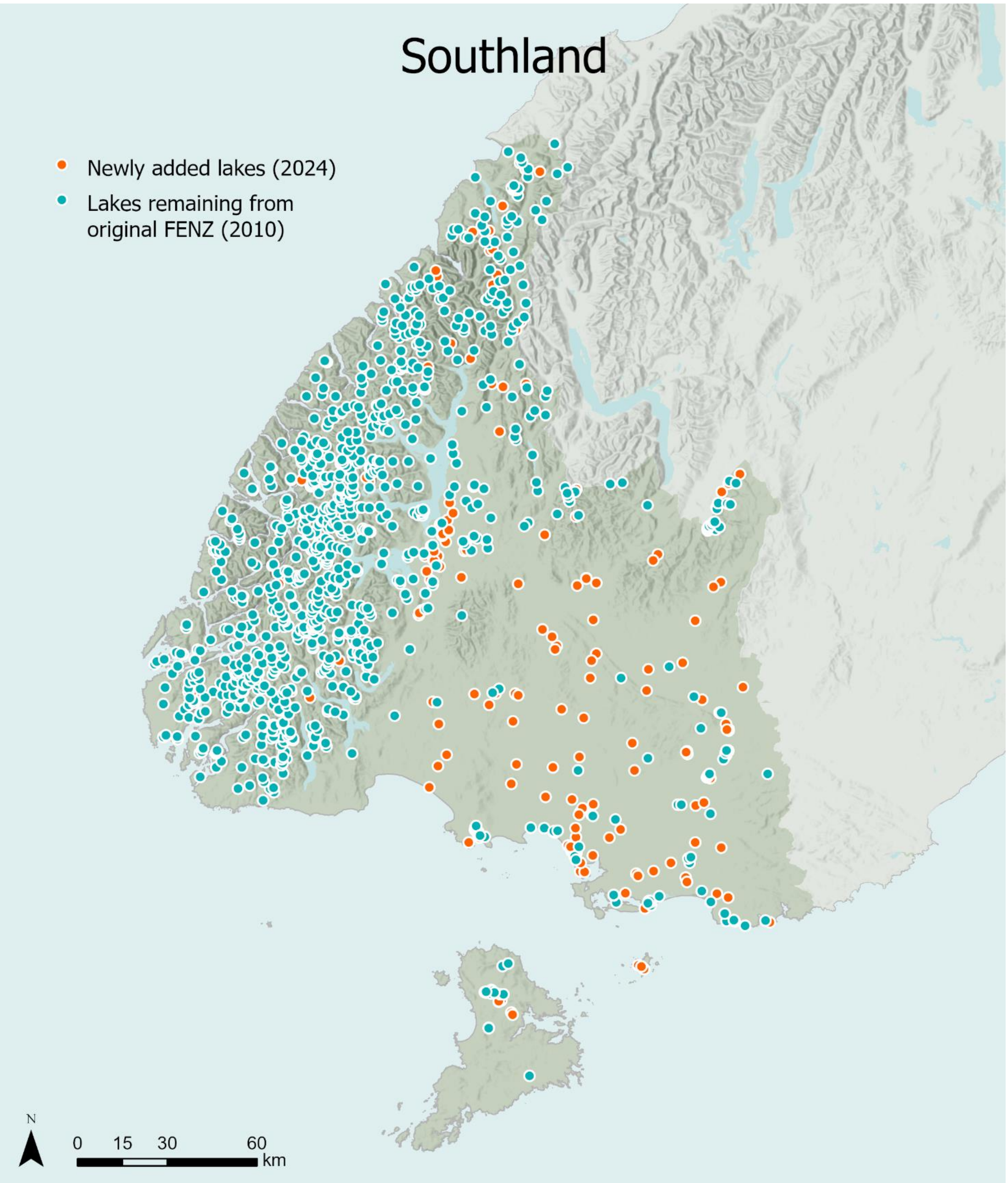

Manawatū-Whanganui
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 10 20 40
km

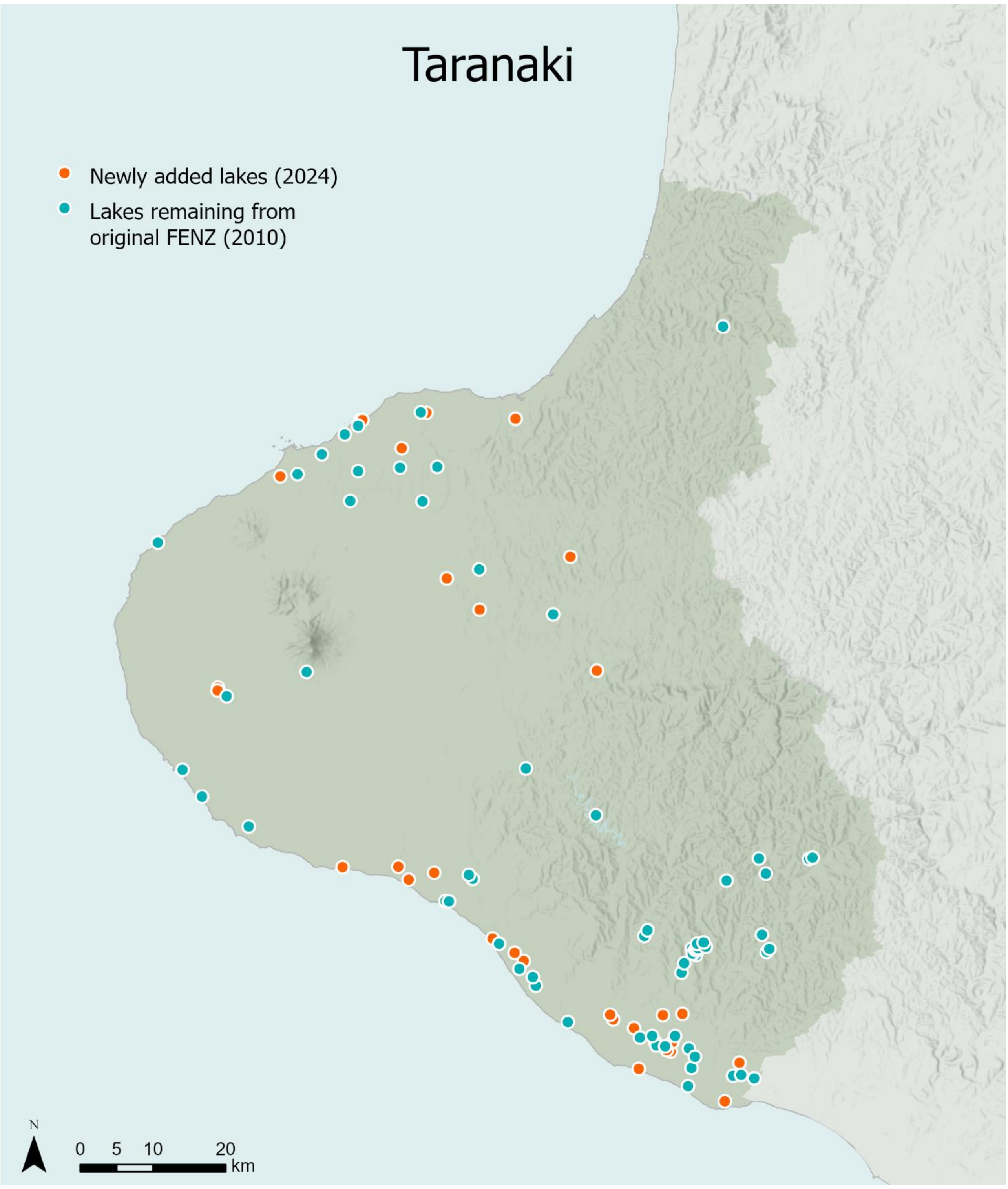

Marlborough
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

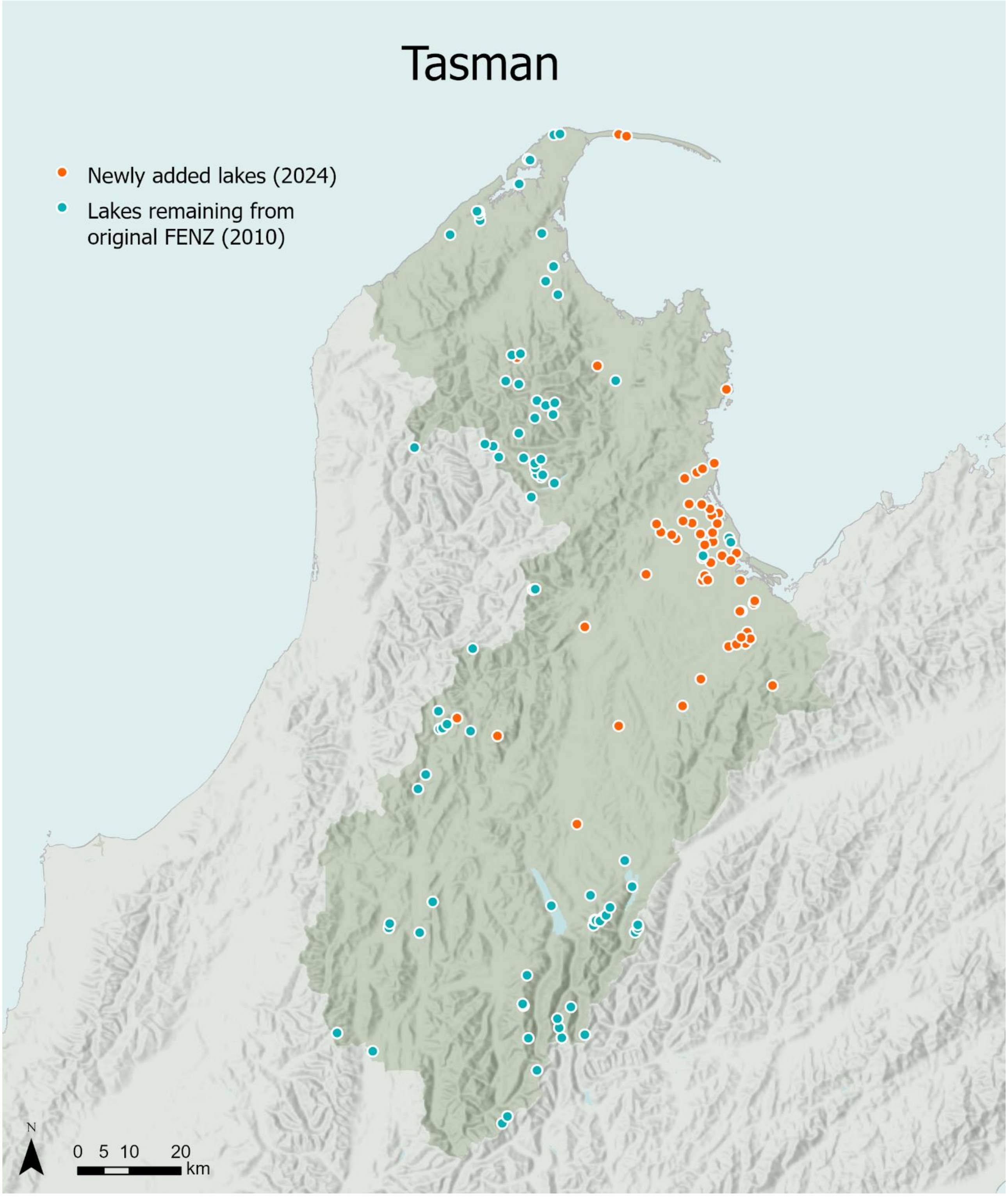

Nelson
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 1 2 4
km

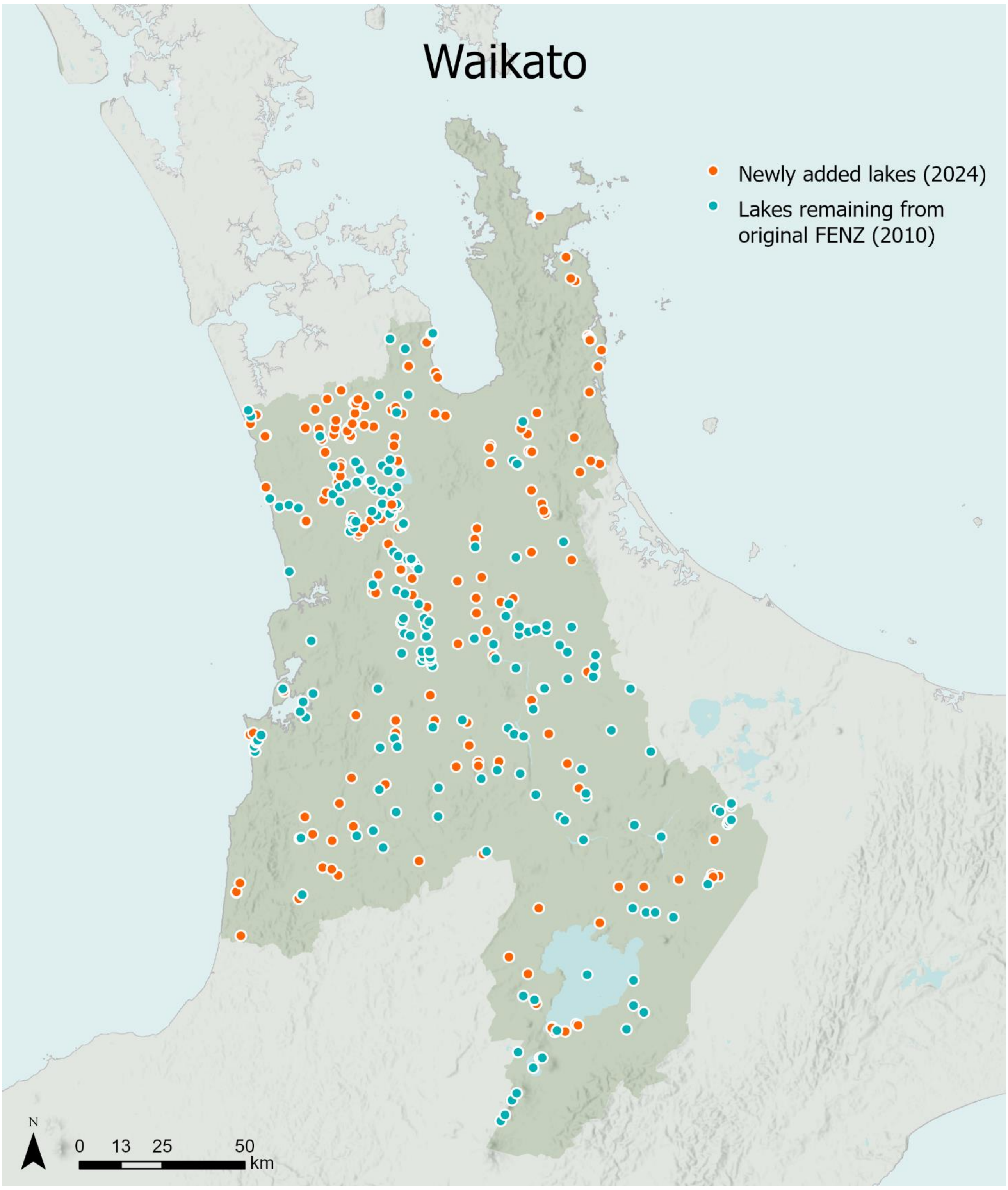

Northland
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

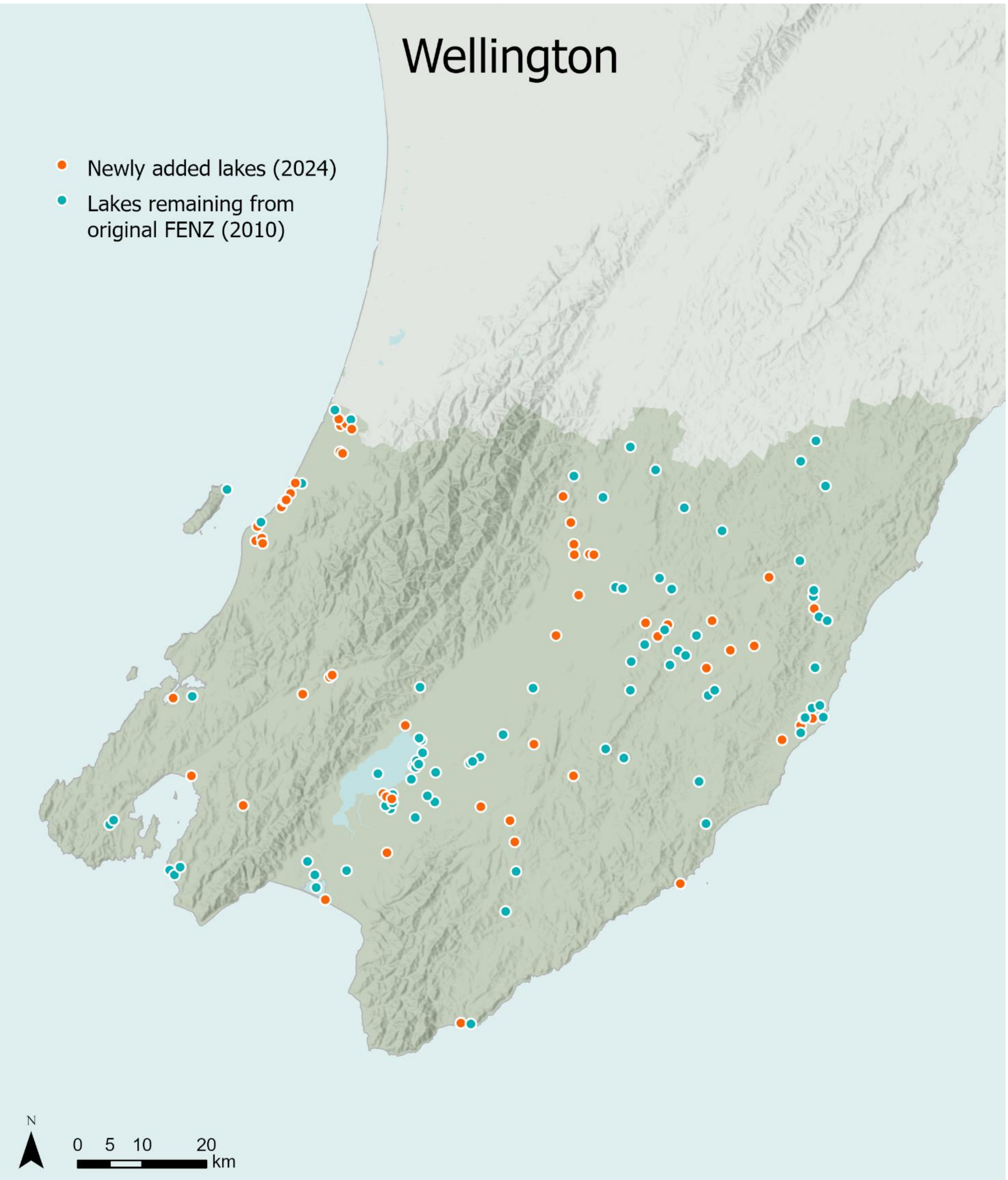

Otago
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 10 20 40
km

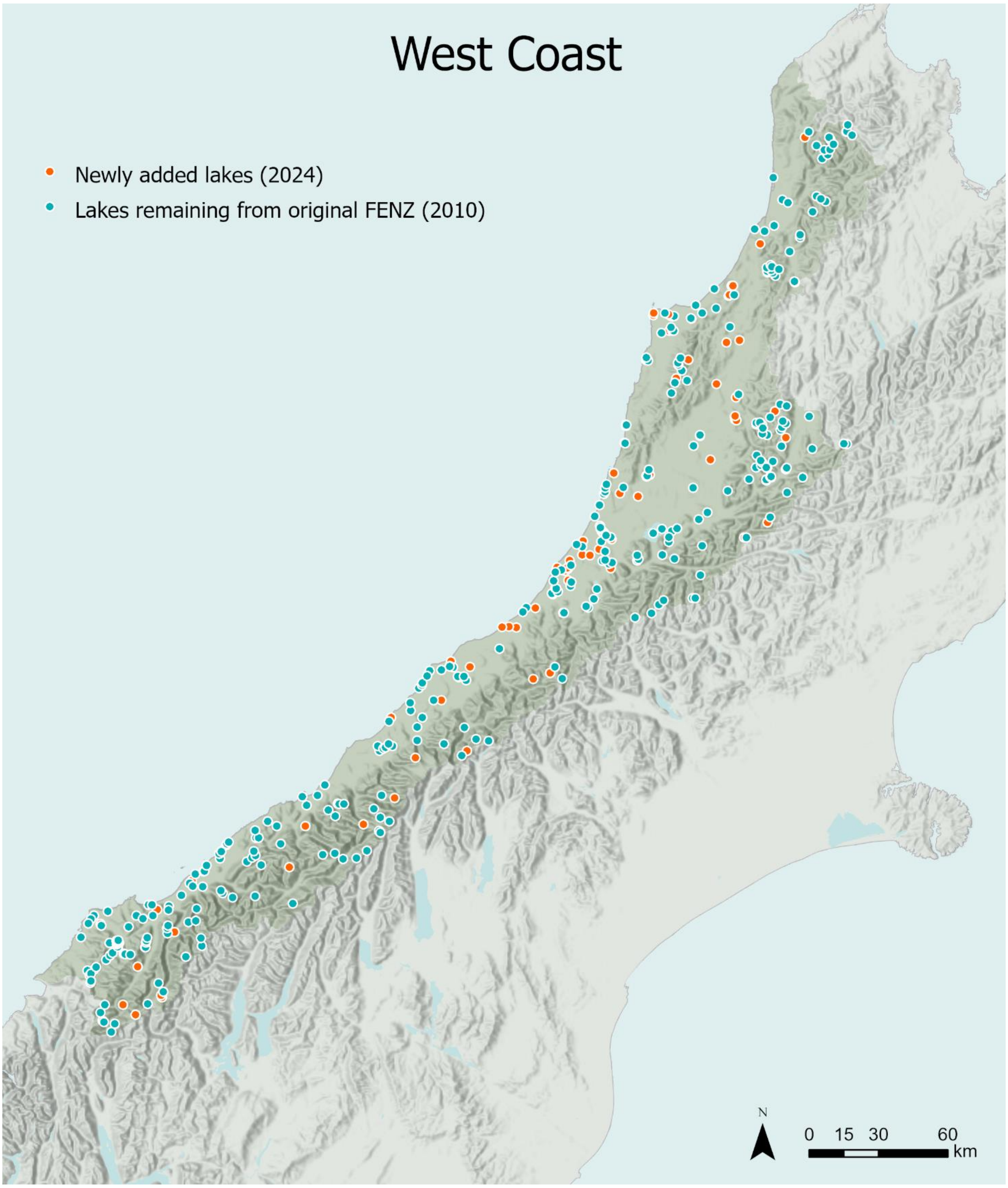

Southland
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0
15
30
60
km


Taranaki
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20 km

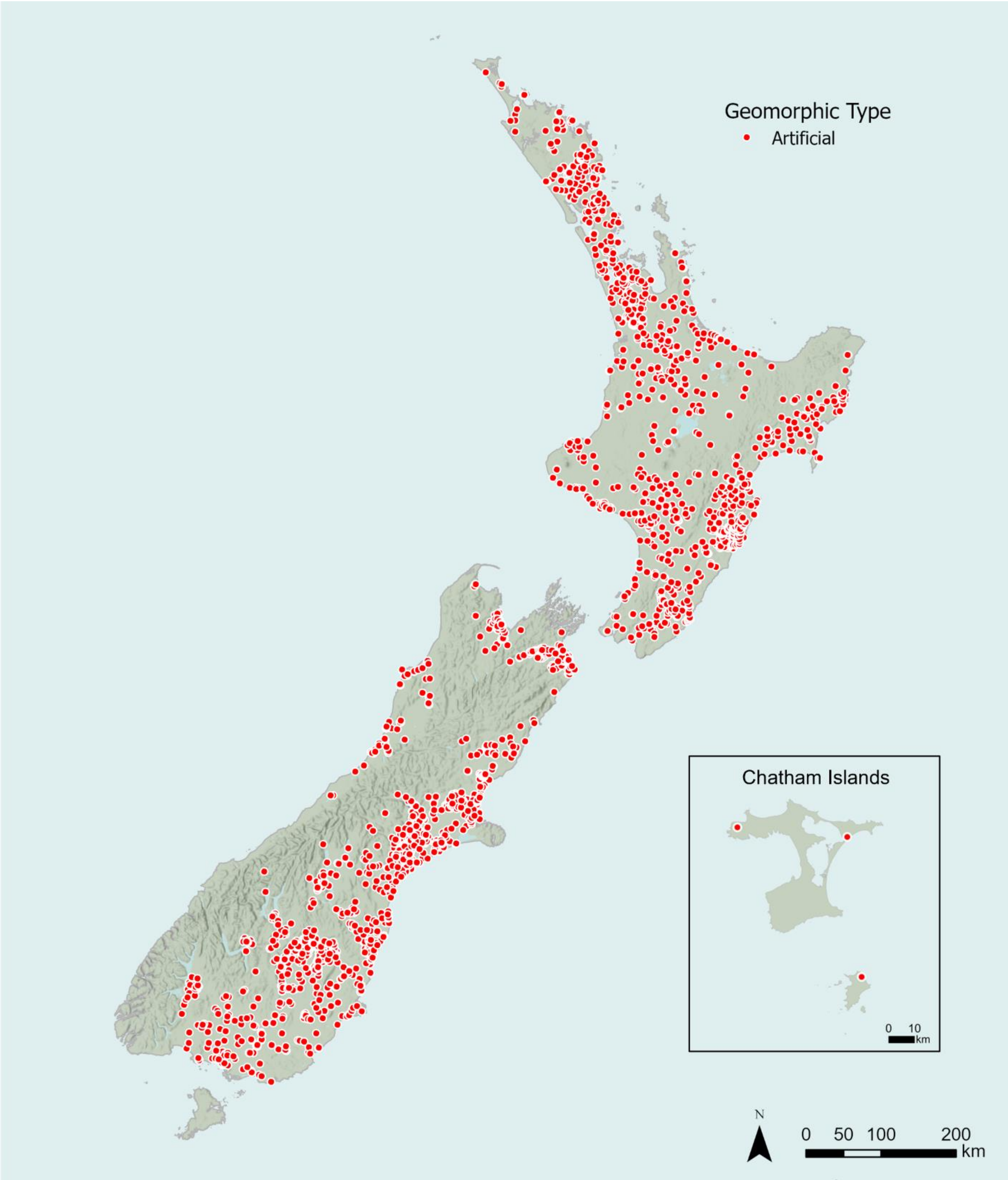

Tasman
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

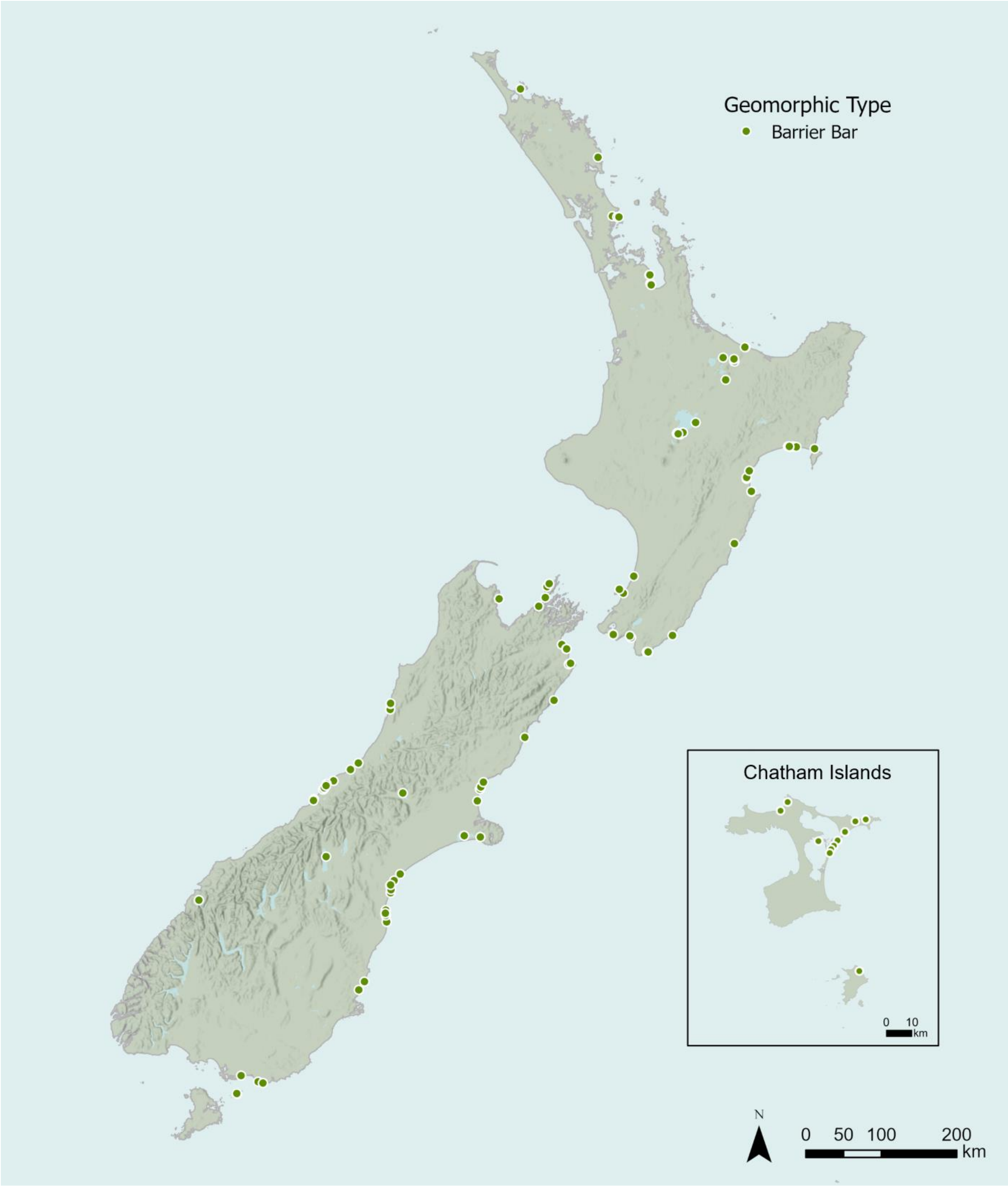

Waikato
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 13 25 50
km

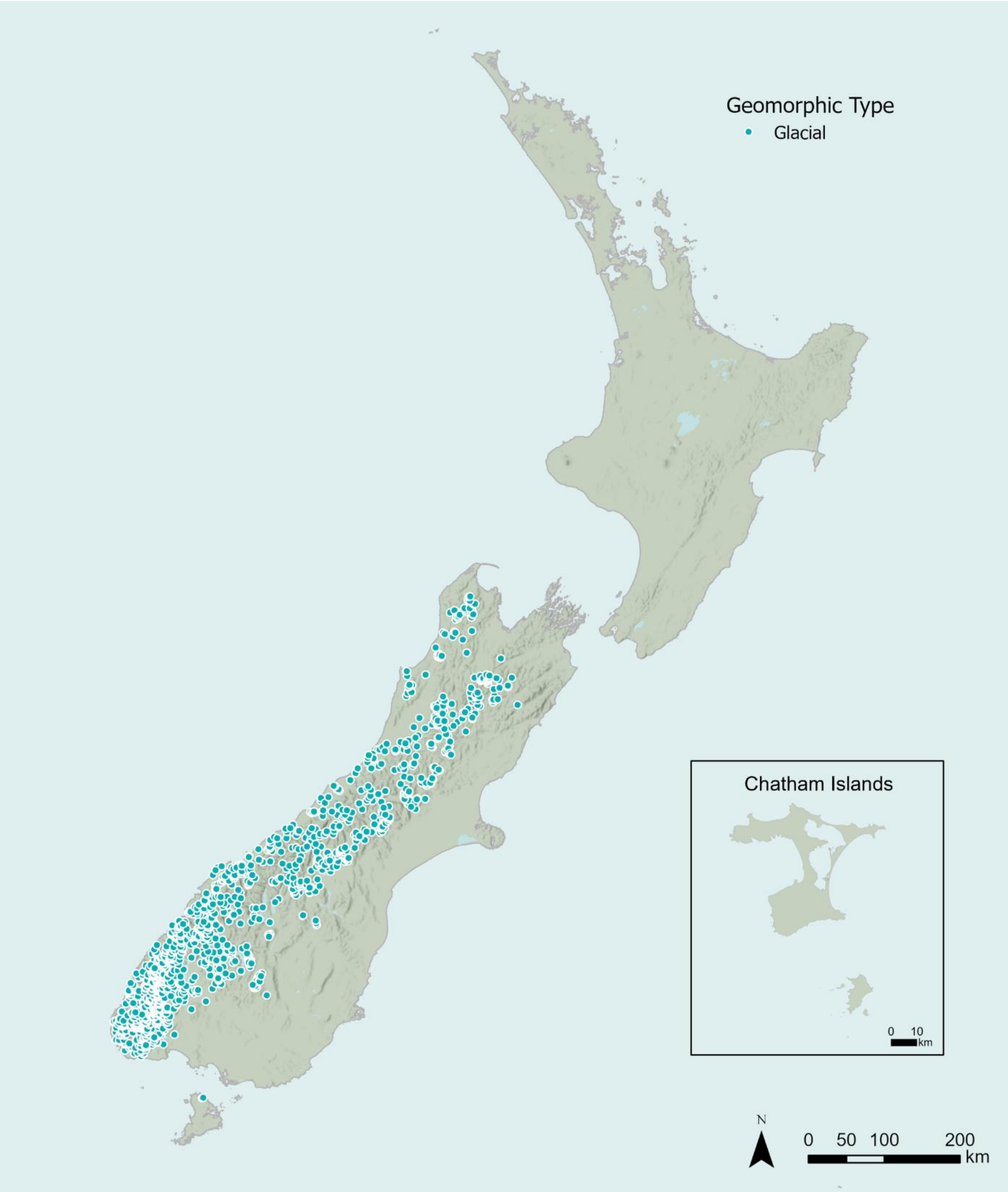

Wellington
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 5 10 20
km

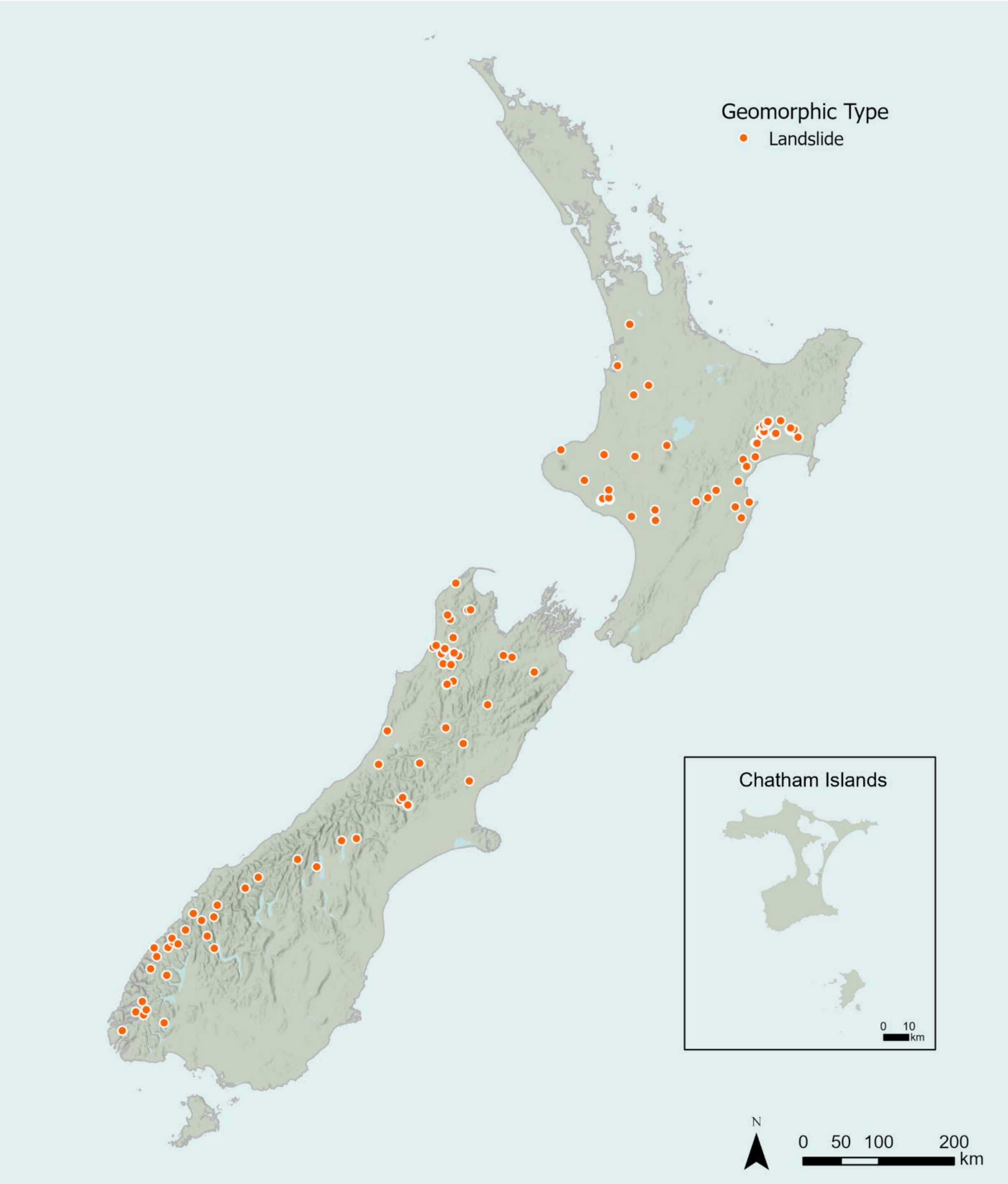

West Coast
Newly added lakes (2024)
Lakes remaining from original FENZ (2010)
N
0 15 30 60
km

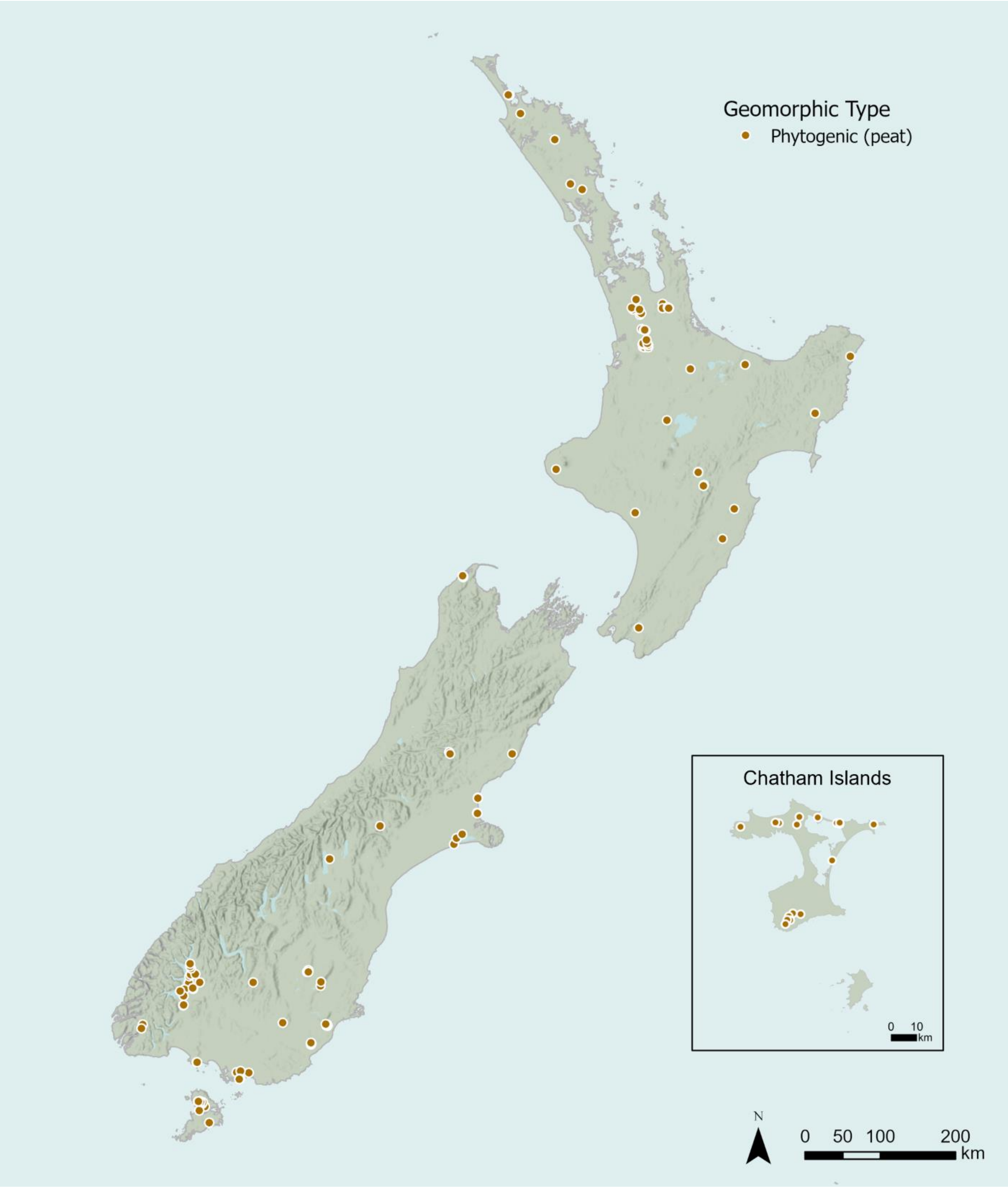
Appendix 3. Distribution of lake geomorphic type

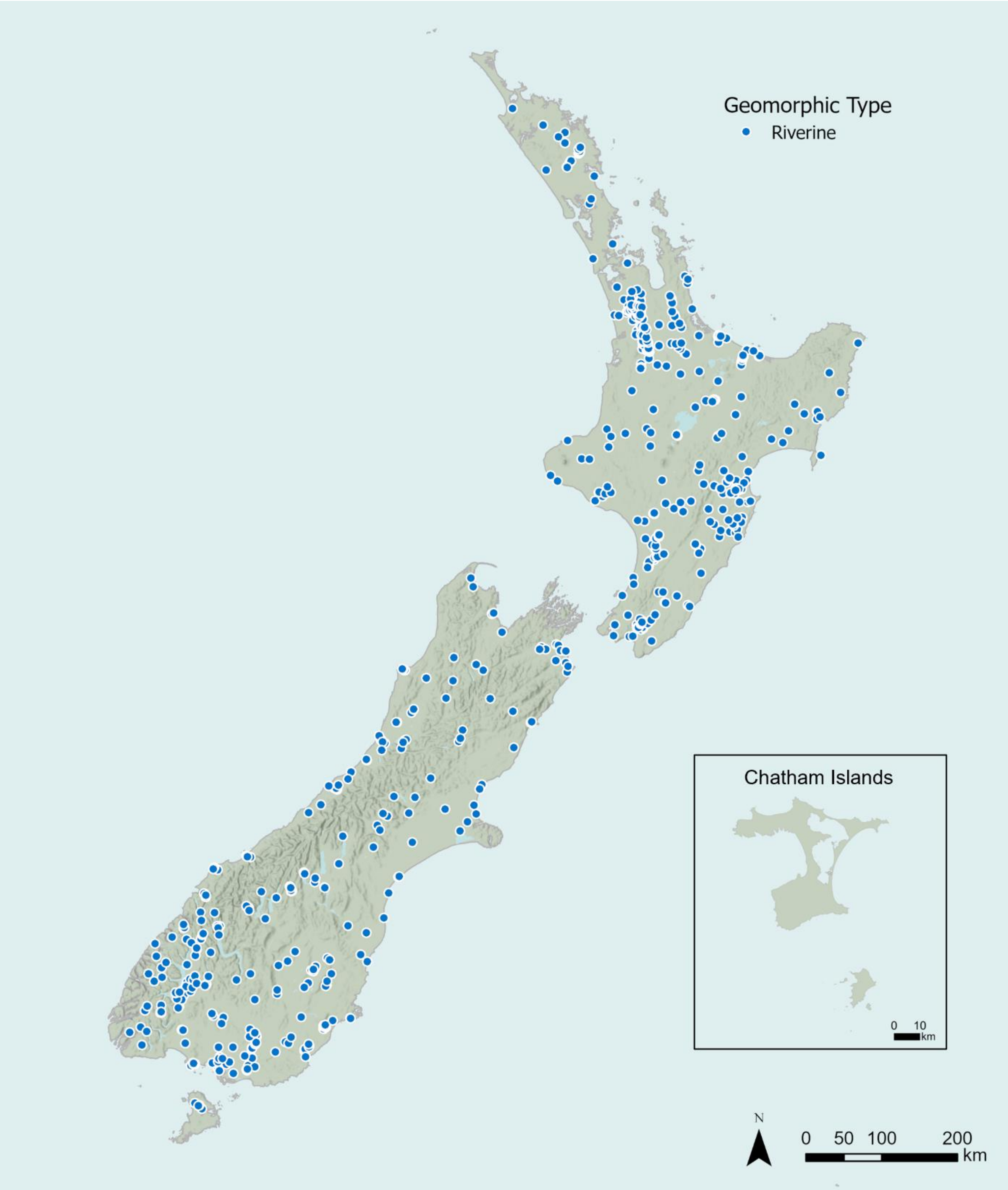



Geomorphic Type
Barrier Bar
Chatham Islands
0 10
km
N
0 50 100 200
km

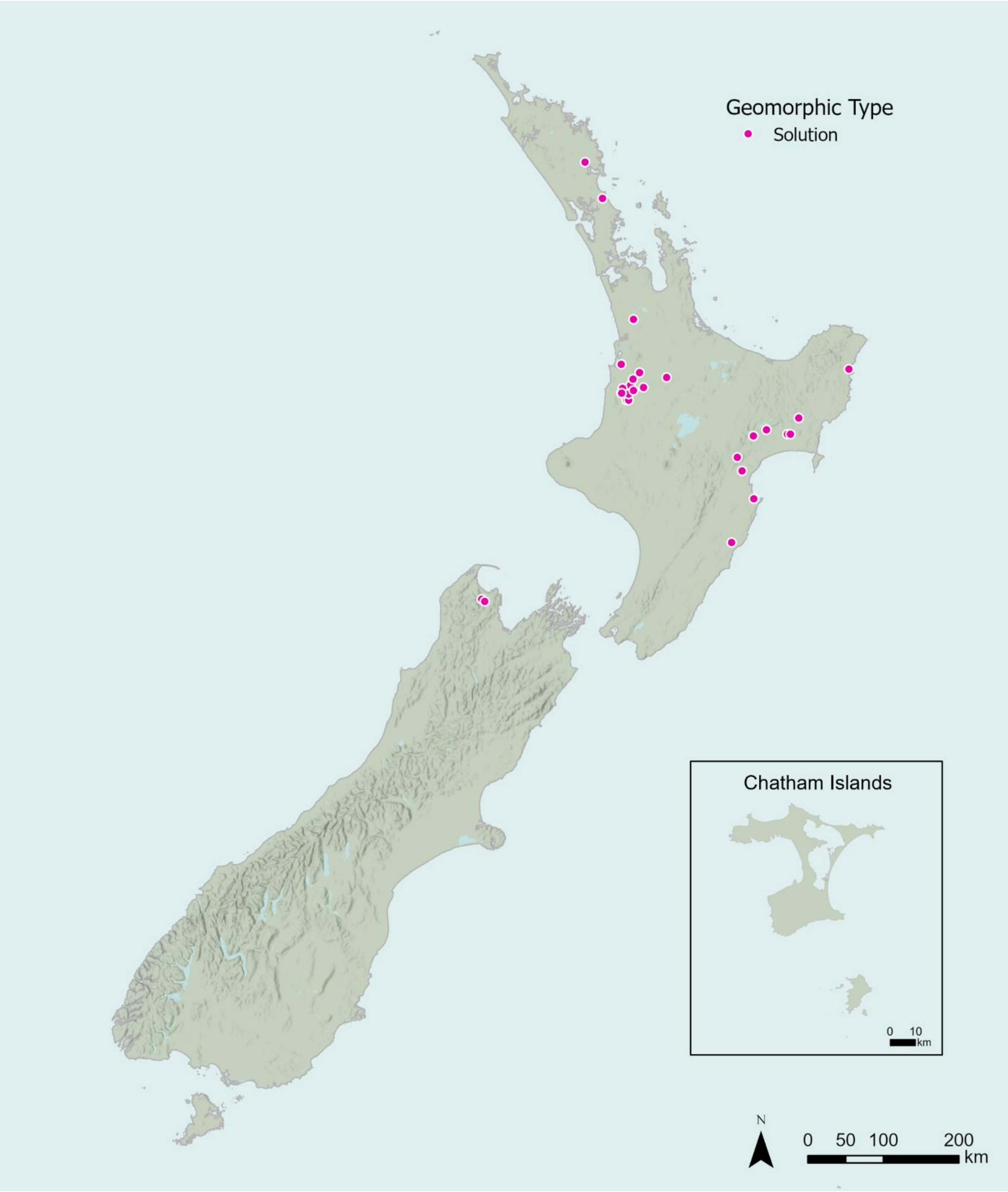

Geomorphic Type
Glacial
Chatham Islands
0 10
km
N
0 50 100 200
km


Geomorphic Type
Landslide
Chatham Islands
0 10
km
N
0 50 100 200
km

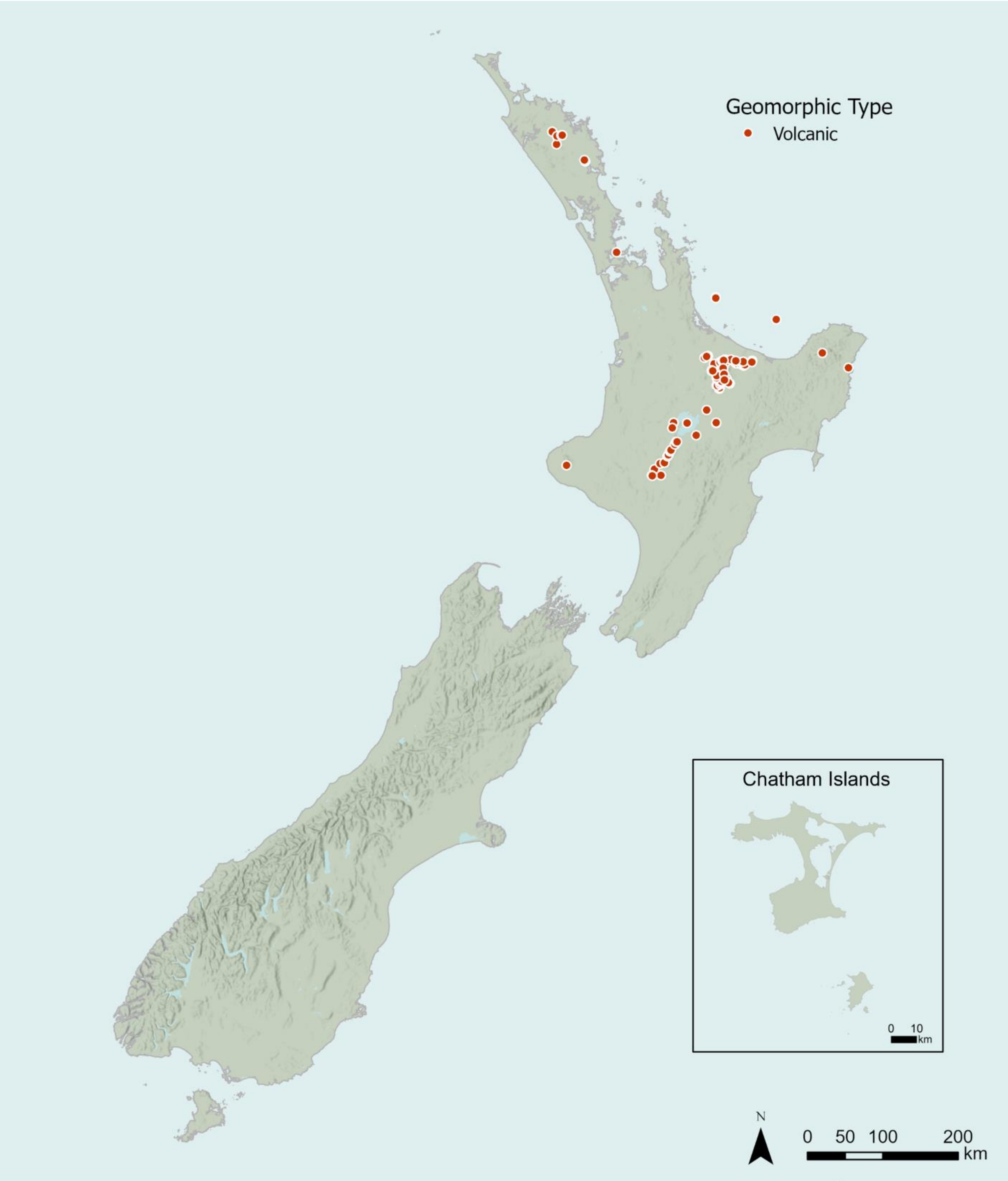

Geomorphic Type
Phytogenic (peat)
Chatham Islands
0 10
km
N
0 50 100 200
km

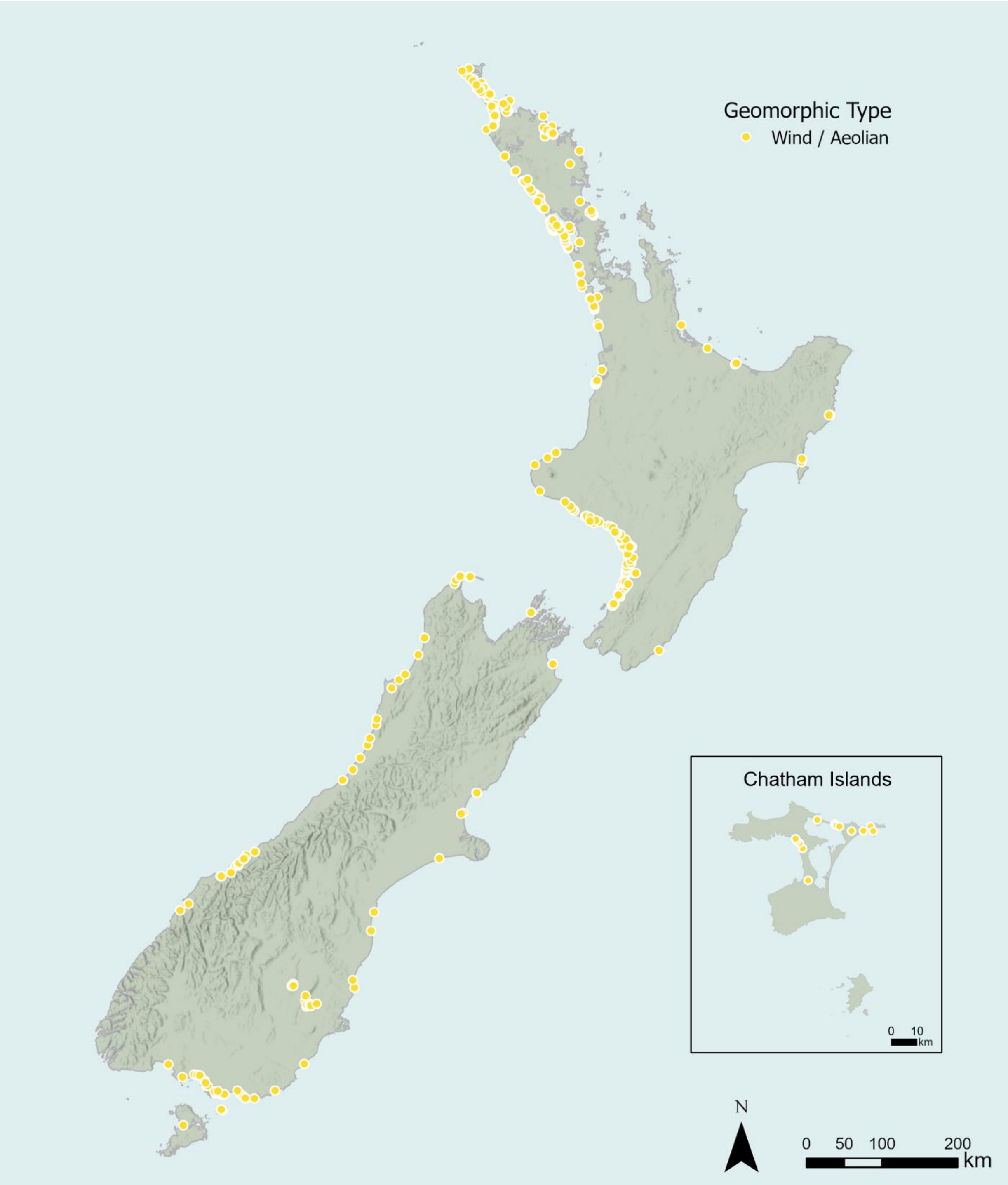


Geomorphic Type
Riverine
Chatham Islands
0 10
km
N
0 50 100 200
km


Geomorphic Type
Solution
Chatham Islands
0 10
km
N
0 50 100 200
km


Geomorphic Type
Tectonic
Chatham Islands
0
10
km
N
0
50
100
200
km


Geomorphic Type
Volcanic
Chatham Islands
0 10
km
N
0 50 100 200
km


Geomorphic Type
Wind / Aeolian
Chatham Islands
0
10
km
N
0
50
100
200
km

Appendix 4. Quick user guide – 'FENZ lake update 2024'

The Freshwater Ecosystems of New Zealand (FENZ) database was published in 2009 (Leathwick et al. 2010). In 2024, Cawthron was commissioned to evaluate waterbodies for inclusion in the lakes portion of the database. This included removing lakes that were no longer lakes, and adding new lakes that were either missed or have formed since the original FENZ layer was developed. In total, 5,301 waterbodies ≥ 1 ha are included in the 'FENZ lake update 2024'.

For a detailed description of the methods used and attributes included, see Section 3. Below, we briefly outline new attributes added in this update, descriptors for codes used in the attribute table and caveats that will be helpful for users of the database.

New attributes

Attributes from the original FENZ database (Leathwick et al. 2010) are included in the 'FENZ lake update 2024' database for those lakes remaining from the original FENZ database. These include the Lake Classification, Pressures, Rankings and Catchments attributes. Please refer to Leathwick et al. (2010, p. 42–46) for these attributes and definitions. Below is a list of new attributes added to the 'FENZ lake update 2024', including modelled water quality attributes from national-scale modelling efforts.

Table A.1. Description of new physical attributes added for lakes in the 'FENZ lake update 2024'.

Attribute	Description
LID	Lake ID number
Name	Lake name
Geomorphic	Geomorphic type
Artificial_info	Type of artificial lake
Oxbow	Lake is an oxbow lake (Y = Yes)
Wetland	Lake appears to be part of a wetland (Y = Yes)
CoordX	x-coordinate (longitude) of lake polygon centroid (NZTM, NZGD2000)
CoordY	y-coordinate (latitude) of lake polygon centroid (NZTM, NZGD2000)
Region	Region in which lake centroid occurs
Area_ha	Area of lake polygon in hectares

Table A.2. Description of modelled attributes added for lakes in the 'FENZ lake update 2024'.

Modelled water quality attributes	Description
SBTI	Modelled Sediment Bacterial Trophic Index (numeric)*
SBTI_Level	Modelled Sediment Bacterial Trophic Index (trophic level)*
Ab_TLI	Abell et al. (2019, 2020) modelled Trophic Level Index**
Ab_TLI_LowerCI	Abell et al. (2019, 2020) modelled Trophic Level Index lower confidence interval**
Ab_TLI_UpperCI	Abell et al. (2019, 2020) modelled Trophic Level Index upper confidence interval**
Ab_TP	Abell et al. (2019, 2020) modelled total phosphorus (mg/m^3)**
Ab_TP_LowerCI	Abell et al. (2019, 2020) modelled total phosphorus (mg/m^3) lower confidence interval**
Ab_TP_UpperCI	Abell et al. (2019, 2020) modelled total phosphorus (mg/m^3) upper confidence interval**
Ab_TN	Abell et al. (2019, 2020) modelled total nitrogen (mg/m^3)**
Ab_TN_LowerCI	Abell et al. (2019, 2020) modelled total nitrogen (mg/m^3) lower confidence interval**
Ab_TN_UpperCI	Abell et al. (2019, 2020) modelled total nitrogen (mg/m^3) upper confidence interval**
Ab_Secchi	Abell et al. (2019, 2020) modelled Secchi disc depth (m)**
Ab_Sec_LowerCI	Abell et al. (2019, 2020) modelled Secchi disc depth (m) lower confidence interval**
Ab_Sec_UpperCI	Abell et al. (2019, 2020) modelled Secchi disc depth upper confidence interval**
Ab_Chla	Abell et al. (2019, 2020) modelled chlorophyll-*a* (mg/m^3)**
Ab_Chl_LowerCI	Abell et al. (2019, 2020) modelled chlorophyll-*a* (mg/m^3) lower confidence interval**
Ab_Chl_UpperCI	Abell et al. (2019, 2020) modelled chlorophyll-*a* (mg/m^3) upper confidence interval**
MfE_TN_Median	Ministry for the Environment modelled median total nitrogen (mg/m^3)***
MfE_NH4_Median	Ministry for the Environment modelled median ammoniacal nitrogen (mg/m^3)***
MfE_TP_Median	Ministry for the Environment modelled median total phosphorus (mg/m^3)***
MfE_Chla_Median	Ministry for the Environment modelled median chlorophyll-*a* (mg/m^3)***
MfE_Chla_An.max	Ministry for the Environment modelled annual maximum chlorophyll-*a* (mg/m^3)***
MfE_Clar_Median	Ministry for the Environment modelled median clarity (m)***
MfE_TLI3_Median	Ministry for the Environment modelled median Trophic Level Index***
MfE_TLI4_Median	Ministry for the Environment modelled median Trophic Level Index***
MfE_Ecoli_Median	Ministry for the Environment modelled median *Escherichia coli* (MPN/100mL)***
MfE_Ecoli_95th	Ministry for the Environment modelled 95th quartile *Escherichia coli* (MPN/100mL)***

* Wood et al. (2023).
** Abell et al. (2019, 2020).
*** Snelder et al. (2022).

Updated geomorphic class

For the 'FENZ lakes update 2024', lakes were assigned a geomorphic type, according to geomorphic classification specified in Lowe and Green (2024), modified from Lowe and Green (1987, 1992), Timms (1992) and Williams (2001), and Håkanson (1981). Given the national scale of the project and the large number of lakes, an in-depth assessment for all lakes was not possible. When a robust geomorphic classification is required, we recommend carrying out in-depth investigations and site visits. When necessary, lakes were assigned more than one geomorphic class, e.g. GR for glacial-riverine. Where there is a high level of uncertainty about the geomorphic classification, it is given in brackets, e.g. (R) or (G). For more information on the geomorphic classes used during this study, see Lowe and Green (2024).

Table A.3. Description of lake geomorphic class codes used in the 'FENZ lake update 2024'.

Geomorphic type	Description
A	Artificial
B	Barrier bar
W	Aeolian / Wind
G	Glacial
L	Landslide
P	Phytogenic
R	Riverine
S	Solution
T	Tectonic
V	Volcanic

When a lake had been classified as artificial (A), further descriptors were provided (**D**: Dam, **M**: Mine, **C**: Constructed)

Caveats

Lake area is calculated from the polygons, and polygons were redrawn only if they were deemed to be > 20% inaccurate. Almost all polygons contain some degree of error. If an accurate lake area is essential, we recommend recreating the lake polygons for those lakes.

Lakes were included in the database based on satellite imagery, which provides only snapshots in time. To allow for this, we have included ephemeral lakes (e.g. lakes that may contain less or no water for periods of the year), based on the previous 5 years of available satellite imagery.

We strongly recommend that the database is updated as additional information becomes available through site visits or other sources, and we urge lake managers to use their discretion when considering lakes for inclusion in regional planning.

Appendix 5. 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 – taken from lake atlases by Irwin (1975; Checklist of New Zealand lakes), Livingston et al. (1986a, 1986b; Inventory of New Zealand lakes: Parts I and II), and Viner (1987) (Inland waters of New Zealand)
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 (Woods et al. 2006).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, 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 (2006)
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 calculated using Equation 1 from de Winton et al. (2009), with invasive macrophyte and fish data excluded
SumPressureEQ1b	Estimated pressure calculated using Equation 1 from de Winton et al. (2009), with invasive macrophyte and fish data included where present
SumPressureEQ2a	Estimated pressure calculated using Equation 2 from de Winton et al. (2009), with invasive macrophyte and fish data excluded
SumPressureEQ2b	Estimated pressure 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 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 attribute (see de Winton et al. 2009)
ActualMacrophyteDepth	Actual measured lower depth limits of macrophytes in the lake, where known, from 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 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 upstream catchment (proportion), computed using cover estimates from LCDBII

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