# Roadmap to an updated ecosystem typology for groundwater

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## DISCLAIMER



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## ABSTRACT

This groundwater-specific typology work is part of a larger project aiming to develop a unified ecosystem typology for Aotearoa New Zealand. In this current work, existing specific typologies have been assessed against a series of end-user principles and a global ecosystem classification framework; the IUCN GET (International Union for Conservation of Nature Global Ecosystem Typology).

### Mapping Groundwater Typologies to the IUCN GET

We identified four typologies within the scientific literature that were most similar to those in current use in Aotearoa New Zealand for our assessment against the IUCN GET. All selected typologies could be nested under the single IUCN GET functional group SF1.2 Groundwater Ecosystems. However, we note that another functional group exists, SF1.1 Underground streams and pools, which may include cave systems. None of the literature reviewed considers this functional group, and data on these ecosystems is sparse in Aotearoa New Zealand, although groundwater cave species have been discovered.

### Mapping Groundwater Typologies to the End-User Principles

Four typologies were selected for further assessment; however, none of these met all end-user principles. Each typology was updateable, reasonably flexible, generally robust and defined based on a clear rationale. Some mapping had been completed, and the typologies were spatially and/or temporally explicit. However, the typologies were neither comprehensive nor specific to Aotearoa New Zealand, and only one typology used any biotic data.

### Groundwater Typology Roadmap Summary

This report provides a roadmap to define the steps needed to create an Aotearoa-New-Zealand-focused ecosystem typology that is consistent with end-user principles. The roadmap acknowledges that current groundwater typologies do not meet the end-user principles, which is partly due to an absence of data on groundwater ecosystems. We identify necessary steps toward determining whether a groundwater ecosystem classification for the country should be determined by biotic or abiotic factors, or a combination of both. We also highlight considerations and challenges for this project and recognise the need for substantial investment and endorsement from numerous stakeholders.

### Overview of the Proposed Process to Define Groundwater Ecosystems

- Undertake statistical analysis of nationally consistent abiotic datasets to identify provisional category boundaries with a reasonable number of units.
- Carry out a classification case study in an area with good environmental and biodiversity data and coverage.
- Undertake statistical analysis on combined environmental and biological data to determine important chemical or lithological drivers.
- Identify classification boundaries.
- Repeat in other regions with similar lithologies/chemistry to ensure that units are consistent.
- If typology units are not consistent, repeat process until predictive capability is achieved.

## KEYWORDS

Classification, ecosystem, groundwater, IUCN GET, typology, unifying

# 1.0 INTRODUCTION

This groundwater-specific typology work is part of a larger project with the aim to develop a unified and over-arching ecosystem typology for Aotearoa New Zealand. For that over-arching goal, existing environmental domain-specific typologies have been reviewed to ensure that they are fit for this purpose and assessed against a series of end-user principles developed through previous engagement with stakeholders (Collins Consulting 2024) and defined in Sprague and Wiser (2024) ('the end-user principles').

Groundwater and groundwater-dependent ecosystems are the least developed in terms of typology and policy drivers in Aotearoa New Zealand (Collins Consulting 2024). However, identifying and managing groundwater systems is critical and urgent precisely because we know so little about them. Groundwater delivers essential ecosystem functions (e.g. water purification through removal of contaminants and pathogens, biogeochemical cycling, maintenance of hydraulic conductivity) and also has cultural or spiritual values (Griebler and Avramov 2015). Ecosystem services are a direct result of the biodiversity present in an environment and the biological processes that they perform. Information about the diversity and distribution of natural microbial communities within groundwater ecosystems is sparse, although we know that Aotearoa New Zealand has a rich diversity of stygofauna (aquatic invertebrates), with many endemic species (restricted to only Aotearoa New Zealand or geographical regions within the country) (Fenwick et al. 2018). In many areas, interactions between groundwater and rivers, lakes and wetlands are poorly understood, with a need to determine how these dependencies affect classification of each domain.

There are currently no groundwater ecosystem typologies in wide use in Aotearoa New Zealand, although a number of typologies used to classify hydrogeological systems or groundwater exist that may be relevant to an over-arching typology. We suggest that fundamental research is needed to establish drivers of groundwater ecosystem diversity within Aotearoa New Zealand, including physical, chemical, geomorphological and biological characteristics, before being able to classify these systems.

This report provides a roadmap to define the steps necessary to be able to create an Aotearoa-New-Zealand-focused ecosystem typology that is consistent with the end-user principles, including nesting under the IUCN GET (International Union for Conservation of Nature Global Ecosystem Typology).

# 2.0 METHODS

## 2.1 Assessment of How Well the Existing Typologies Meet the End-User Principles

In a series of workshops during 2023, stakeholders from the Department of Conservation, regional councils, the Ministry for Primary Industries and the Ministry for the Environment identified and developed nine national principles and five additional requirements for a standardised ecosystem typology (Collins Consulting 2024). These end-user principles are defined in Sprague and Wiser (2024). We completed an initial assessment of 12 groundwater typologies against the end-user principles (Table A1.1) and presented this to stakeholders. We then completed a more in-depth analysis of four typologies (spheres of discharge, groundwater–surface-water interactions, hydrogeological systems and groundwater health indices) that represent the methods currently used by, or where data could be used by, regional councils to classify groundwater.

## 2.2 Stakeholder Engagement

We met with key stakeholders from regional councils and the Ministry for the Environment on 20 June 2024 to present an overview of the IUCN GET and how existing typologies could nest under this. We also sent out questions (below) to the Groundwater Special Interest Group, with responses received 26 June 2024.

- Will the IUCN GET framework be useful for you and if so, how?
- If not, do you have a preferred unified typology you'd like to use?
- In your role, is what is happening outside of Aotearoa New Zealand relevant to your work (i.e. global red listing of ecosystems)?
- What challenges do you anticipate when updating the existing domain typology to align with the Ministry for the Environment's Principles and Requirements and with aligning to a unifying typology?

## 2.3 Assessment of How the Existing Typology Maps to the IUCN GET

The IUCN GET includes only one functional group (level three) for groundwater (SF1.2 Groundwater ecosystems), so currently all known groundwater typologies would nest under this, with the exception of cave systems.

## 2.4 Roadmap of Steps to Update Existing Typology to Meet the End-User Principles

This roadmap was developed based on gaps identified when the typologies were assessed against the end-user principles (Sprague and Wiser 2024) and IUCN GET in discussion with representatives from regional councils.

# 3.0 RESULTS

## 3.1 Stakeholder Engagement

From engagement with stakeholders, we found that regional councils currently use a range of methods to define and manage their groundwater systems. None of these were exactly the same as published methodologies that we identified. The typologies that were most similar to those in current use for our assessment against the end-user principles are:

- Spring ecosystems – spheres of discharge (Stevens et al. 2021).
- Groundwater–surface-water interactions (Dahl and Hinsby 2013).
- Hydrogeological Systems (e.g. Moreau 2023).
- Groundwater Health Index (e.g. Korbel and Hose 2017).

None of the currently used classification systems are suitable for use as part of an over-arching typology. Our assessment confirmed that a new typology is needed that can incorporate the current council requirements and meet the end-user principles determined for this project (Sprague and Wiser 2024). The Hydrogeological Systems typology was accepted as the potential base typology that can be integrated with other datasets, as it is mappable and provides nationally consistent geological data.

## 3.2 Assessment of How Well the Existing Typologies Meet the End-User Principles

See Table A1.2 for full details.

None of the typologies selected for assessment meet all end-user principles, although all are hierarchical and could be nested under the single IUCN GET functional group. In summary:

- Spheres of discharge for springs (Stevens et al. 2021) does not include biotic data and requires expertise to classify springs from site visits. Information can be updated and mapped. As this typology is only limited to springs, it does not cover all groundwater ecosystem environments.
- Groundwater–surface-water interactions (Dahl and Hinsby 2013) also only uses environmental, not biotic, data for classification but is data-derived, transparent and reproducible.
- Hydrogeological Systems (e.g. Moreau 2023) does not include biotic data but uses consistent, Aotearoa-New-Zealand-specific data for spatially and temporally explicit classification.
- Groundwater Health Indices (e.g. Weaver et al. 2017, 2023; Bolton and Weaver 2021) use both environmental and biotic data but need expert analysis and are time-consuming to determine and assess. These indices are based on Aotearoa New Zealand data but need consistent and larger funding to be developed into a nationwide assessment.

## 3.3 Roadmap of Steps to Amend Existing Typology to Meet the End-User Principles and Align with the IUCN GET

This roadmap acknowledges that current groundwater typologies are not suitable to meet the end-user principles, which is partly due to the lack of data on groundwater ecosystems. An example of an endpoint for an Aotearoa-New-Zealand-specific groundwater typology might be the ability to use microbial and stygofaunal eDNA (biotic classification) → to classify an ecosystem 'type' → to determine groundwater ecosystem health → to identify management priorities. Some progress has been made in this space by improving molecular databases for stygofauna and working to improve primer design (van der Reis et al. 2024).

Currently, the absence of data across all Aotearoa New Zealand groundwater ecosystems means that we do not know how to create a suitable typology. Here, we identify steps needed in order to determine whether groundwater ecosystem classification should be driven by biotic or abiotic factors, or a combination of both. We recognise that this is a long-term project that will need substantial investment and endorsement from a wide range of stakeholders, including regional councils and the Department of Conservation. In addition, we recognise that there are inter-operability challenges between councils, as highlighted by the Parliamentary Commissioner for the Environment (see PCE [2024]).

Overview of the proposed process (see Figure 3.1):

- Undertake statistical analysis of nationally consistent abiotic datasets (e.g. Principal Component Analysis [PCA]) to identify provisional category boundaries with a reasonable number of units.
- Carry out a classification case study in an area with good environmental and biodiversity data and coverage.
    - Case study areas have to be on a regional scale to represent a range of lithologies and chemistries, as well as national proportions of different aquifer types, for example, alluvial, sandy.
    - Case studies could include a sustained sampling effort over time to identify microbes and stygofauna and community stability.
    - Case studies could include boundary areas and integration with other domains, such as a hyporheic zone.
- Undertake statistical analysis on combined environmental and biological data to determine (the most) important chemical or lithological drivers.
- Identify classification boundaries.
- Repeat in other regions with (at least) similar lithologies and chemistry to ensure that units are consistent.
- If typology units are not consistent, repeat the process until predictive capability is achieved.
- Identify a relevant complementary indigenous way of categorisation and/or integrate this as part of the proposed process.

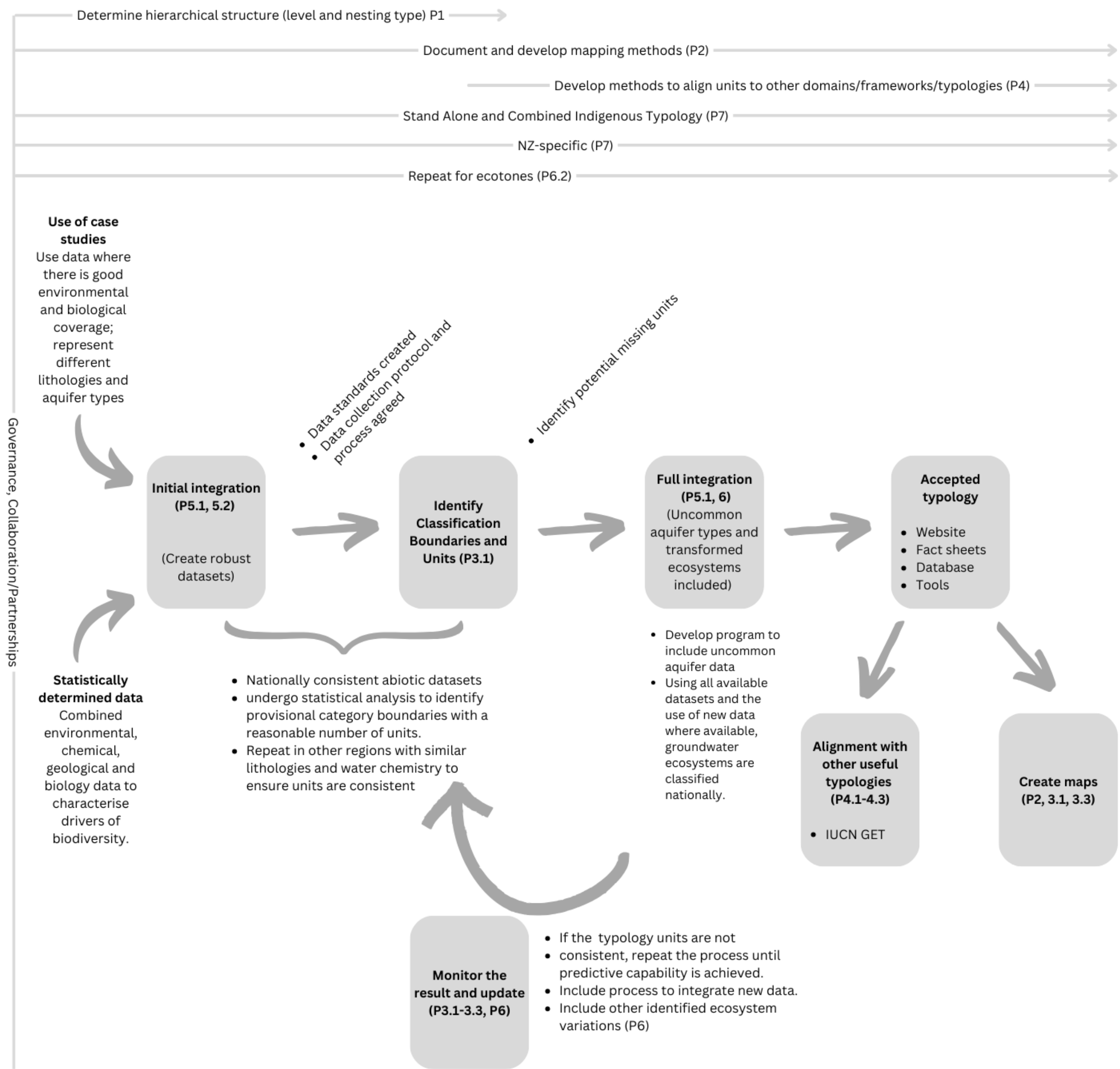


Figure 3.1 Graphic version of the roadmap for a unifying typology for groundwater. This includes how these align with the end-user principles in Table A1.2.

## 3.4 Challenges and Considerations

- All data and the process used to classify into the typology must be standardised, and this needs to be determined at the national or (at least) regional level – this may depend on what data we already have and inter-operability.
- Regional councils / the Department of Conservation must be consulted on categorisation – how many levels and overall units would be useful and practical to include from their viewpoints.
- Areas outside the North and South Islands may have less data, for example, the Chatham Islands (regional council functions administered by Environment Canterbury) and Rakiura / Stewart Island (managed by Environment Southland).
- Limited ecosystem data for large geographical regions of Aotearoa New Zealand exist, particularly for naturally uncommon ecosystems or aquifer types that could be biologically diverse.
- Existing typologies do not consider indigenous views or methods.

- Data for biotic ecosystem interactions, such as food webs, is scarce, although this has been investigated overseas.
- Although the IUCN GET only identifies SF1.2 Groundwater ecosystems, there are several functional groups that will interact with these, such as subterranean tidal or marine, wetlands and rivers. The typology needs to be able to accommodate ecotones and identify missing data. For example, many cave systems are unexplored, although some have been explored by NIWA (National Institute of Water & Atmospheric Research) divers where unique and endemic genera have been found (NIWA 2012).
- The typology must include the hyporheic zones of rivers, floodplains and springs.
- The typology may consider transformed ecosystems such as permeable reactive barriers, constructed wetlands, managed aquifer recharge areas and wastewater treatment plants and their outlets – these may need special reference to nutrient concentrations or surface-water interactions. These are in addition to the 'engineered' transformed subterranean systems identified in IUCN GET, which could include grey, blue and nature-based engineering.
- Groundwater Health Indices refer to deviation from reference or pristine conditions – but we may not be able to identify 'baseline' (i.e. pristine) sites within Aotearoa New Zealand (i.e. not exposed to human disturbances).
- The national map of groundwater ecosystems must be held and maintained, but it is unclear which entity would be responsible for this.
- Microbial and stygofauna data on assemblages (biodiversity) tend to be a snapshot in time, and it is unclear how stable communities are over time.
- It is unclear how groundwater biodiversity responds to climatic events, to changes in groundwater quality or abstraction or to land-use change.

## 3.5 Datasets

Our stakeholder group identified Hydrological Systems as the base typology that can be integrated with other nationally consistent, abiotic, datasets, which may need to be transformed into ordinal data. We outline these datasets and their key features below.

#### 3.5.1 Hydrogeological Systems

**Reference:** Moreau (2023)

https://www.gns.cri.nz/data-and-resources/new-zealand-hydrogeological-unit-map/

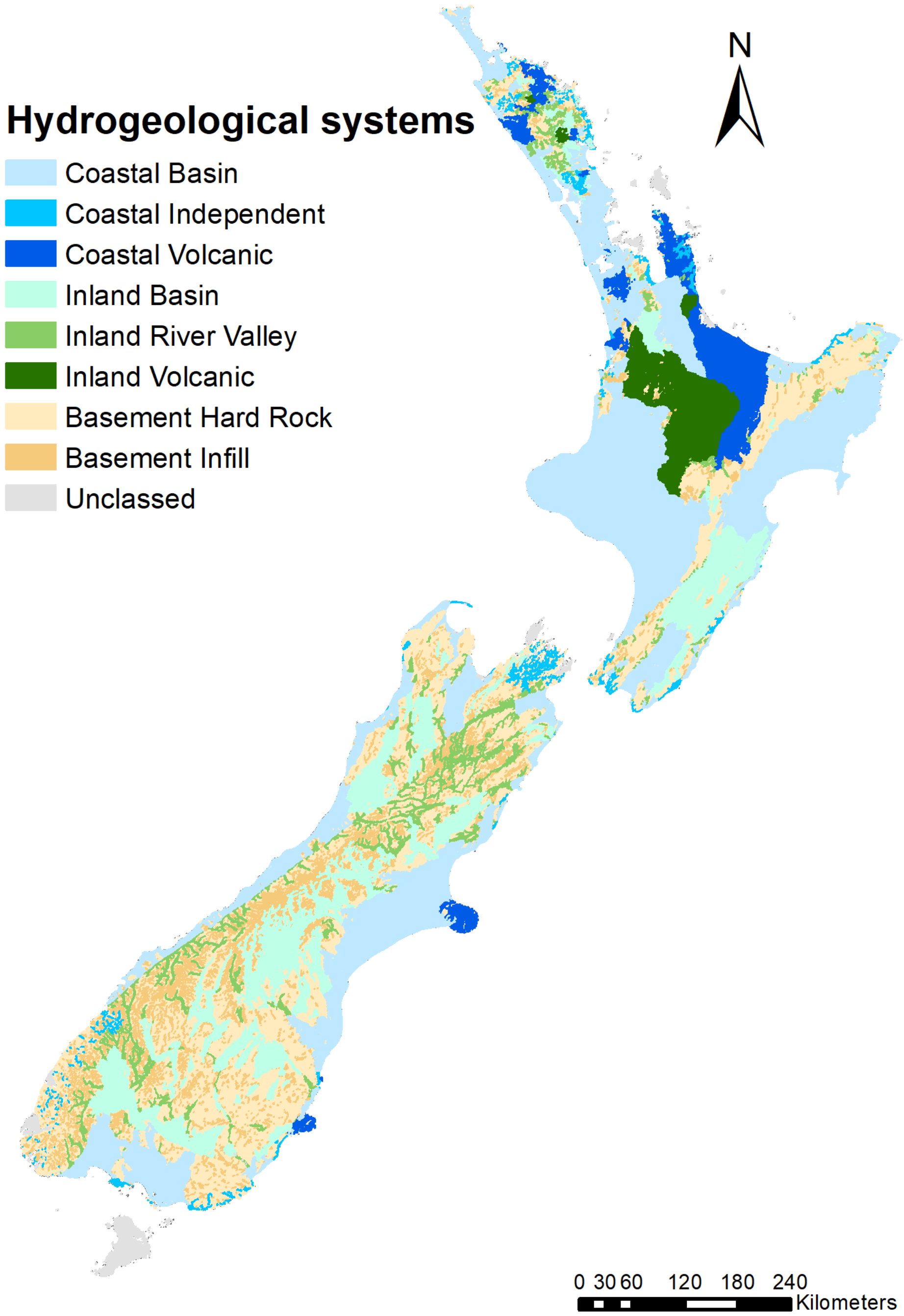


Figure 3.2 New Zealand hydrogeological systems.

**Key features:**

- National, 1:250,000 scale.
- Eight major categories, based on geological and depositional facies (four major categories, with up to nine sub-categories present or absent).
- Revised 2023 – to be updated to three dimensions by 2029.
- Developed and maintained by GNS Science.

### 3.5.2 Predicted Groundwater Redox State Maps

**Reference:** Sarris et al. (in prep.)

https://landuseopportunities.nz/dataset/predicted-groundwater-redox-state-in-new-zealand

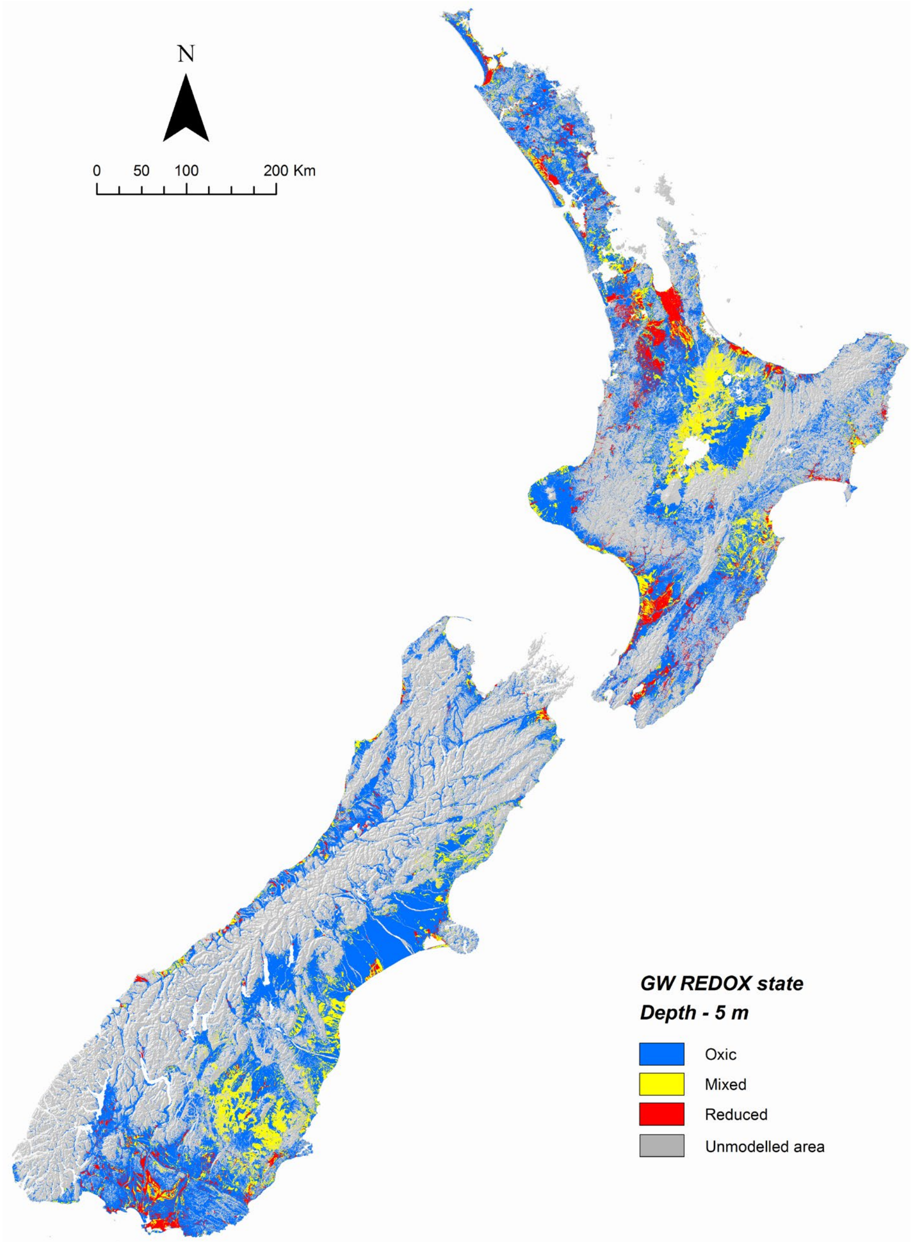


Figure 3.3 Predicted groundwater redox state in New Zealand, 5 m depth.

**Key features:**

- Predicted from a range of physical variables associated with the well locations and available in nationwide geospatial datasets (covering soils, geology, hydrology).
- 250 m spatial resolution.
- Three ordinal categories (oxic, mixed, reduced), with some geographic bias.
- Estimates produced for 5, 15, 30 and 50 m depth below ground level.
- Current version produced January 2024.
- Developed and maintained by ESR / Lincoln Agritech.

### 3.5.3 Groundwater Quality Indicators

**Reference:** Ministry for the Environment and Stats NZ (2020)

https://www.stats.govt.nz/indicators/groundwater-quality/

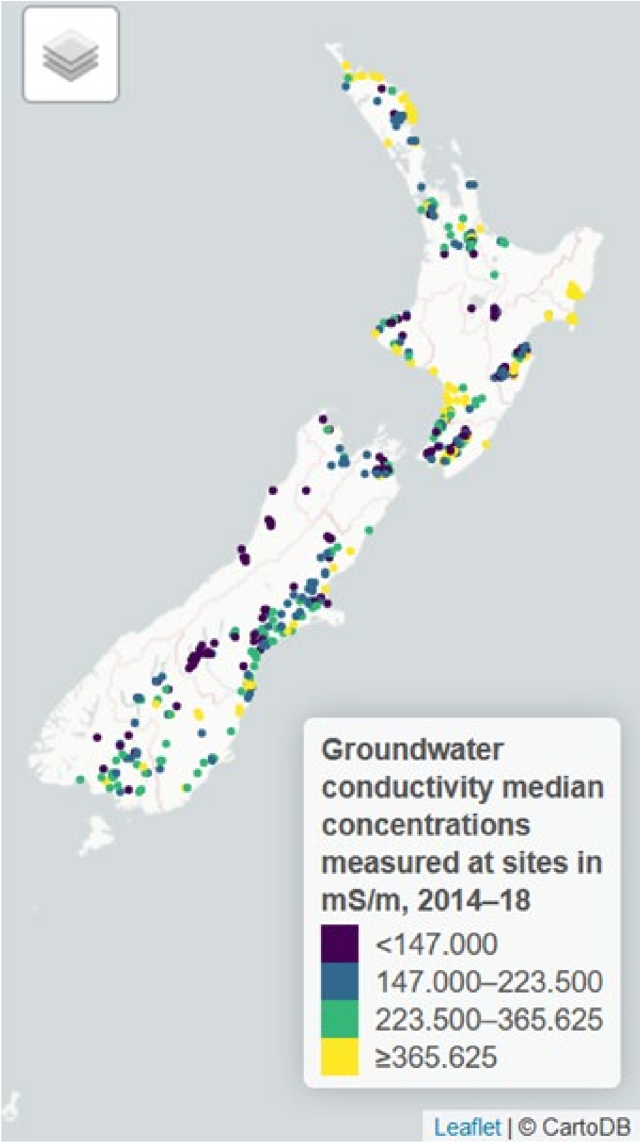


Figure 3.4 Groundwater quality (electrical conductivity) indicator for New Zealand.

**Key features:**

- Quantitative data (nitrate-nitrogen, ammoniacal nitrogen, dissolved reactive phosphorus, chloride, conductivity), each classified into four quartiles.
- Trends for 2009–2018 and/or 1999–2018: five data-derived ordinal categories (very likely improving, likely improving, indeterminate, likely worsening, very likely worsening).
- Up to 500 sites (for conductivity), but fewer sites have trend/temporal data (e.g. 131 sites for $NH_4$-N to 286 for conductivity).
- Biased geographical coverage that is inconsistent across measured parameters.
- To be updated during 2024 (will include State of the Environment [SOE] and National Groundwater Monitoring Programme [NGMP] data).
- Currently maintained by Statistics New Zealand.

### 3.5.4 New Zealand Groundwater Atlas

**Reference:** Westerhoff et al. (2019)

https://data.gns.cri.nz/metadata/srv/eng/catalog.search#/metadata/d2d75745-a4d3-4359-8cff-7a050742524f

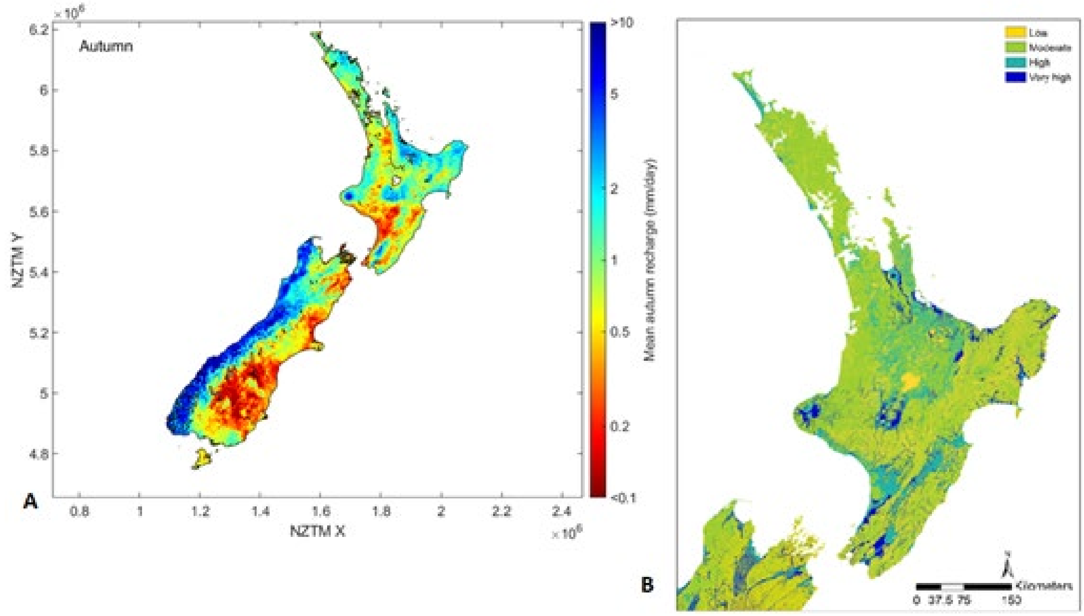


Figure 3.5 Groundwater Atlas groundwater recharge and groundwater flow. (A) Seasonal mean recharge (mm/day, autumn: March-April-May); (B) Groundwater flow classes throughout the North Island.

**Key features:**

- National, scales vary from 250 m grid to 0.05 x 0.05 latitude/longitude arc degrees.
- Includes groundwater recharge, groundwater–surface-water exchange probabilities and the national water table (quantitative).
- Groundwater flow – four data-derived ordinal categories (low, moderate, high or very high).
- Temporal data includes daily rainfall, with monthly and seasonal means.
- To be updated by the New Zealand Water Model (NZWaM) in 2024.
- Developed and maintained by GNS Science.

### 3.5.5 Regional Datasets

Data for other environmental or biotic factors that may drive microbial or stygofauna diversity vary in quality and quantity across regions. These datasets must be identified prior to defining case study areas and included in statistical analysis to determine parsimony and utility of ecosystem units. Data may include water chemistry, water-level data, hydrogeology, aquifer parameters (e.g. hydraulic conductivity and information on surface-water–groundwater interactions).

Many of these factors may be dynamic, with seasonal or intra-seasonal changes and anthropogenic effects, and temporally explicit data is required to identify ecosystem change over time. We note, as recently highlighted (PCE 2024), that freshwater model development across the country is fragmented with overlapping functions, often for specific locations and with varying levels of complexity and flexibility. A national dataset is required to manage groundwater biotic and abiotic factors as part of a nationally consistent typology.

## 4.0 ACKNOWLEDGMENTS

We gratefully acknowledge the input of subject matter experts from the Ministry for the Environment, the Department of Conservation, regional councils and the Ministry for Primary Industries in the initial stakeholder workshops. We especially acknowledge Huma Saeed (Horizons Regional Council), Nicki Wilson (Waikato Regional Council) and Sean Hudgens and Tapuwa Marapara (Ministry for the Environment) for their helpful comments on this report.

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# APPENDICES

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# APPENDIX 1 ASSESSMENT OF GROUNDWATER TYPOLOGIES AGAINST THE END-USER PRINCIPLES

Table A1.1 Initial assessment of groundwater typologies against the end-user principles. Y = Yes; N = No; P = Potentially; U = Unknown; N/A = Not applicable. GW = groundwater; SW = surface water; GDEs = groundwater dependent ecosystems; GWQ = groundwater quality.

| Groundwater Typology | Major Concepts | Hierarchical | Spatially Explicit | New Zealand Diversity | Translatable | Transformed | Updateable | Parsimonious | Consistent | IUCN-Nesting | Data-Derived | Ecotones | Temporally Explicit | Flexible |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kunkel et al. (2004) | Hydrological units (Germany): Primarily lithology/geology, also location, depth, pH, major ions, metals | N | Y | N | P | Y | Y | Y | N/A | Y | Y | N | P | Y |
| Wendland et al. (2008) | Primarily aquifer rock type; also hydrodynamics (recharge, mean residence time, topography), redox, age, dykes, sulfides, clays | Y | Y | N | P | N | Y | Y | N/A | P | Y | N | P | Y |
| Steube et al. (2009) | Physical/chemical parameters; general microbial parameters; microbial community structure; groundwater fauna | N | U | P | Y | Y | Y | Y | P | P | Y | N | P | Y |
| Hahn (2009) | Biogeographic unit (regional geological unit / stygoregion); aquifer type; hydrological exchange | Y | Y | P | Y | N | Y | Y | P | Y | N | N | P | Y |
| Springer and Stevens (2009) (Springs) | Location/emergence, flow rate, confined/unconfined source | N | Y | N | N | N | Y | Y | N/A | Y | N | N | P | Y |
| Stein et al. (2012) | Geographical/stygofauna diversity and abundance | N | Y | P | N | N | Y | Y | Y | Y | N | N | P | Y |
| Larned (2012) | Climate; geology; aquifer; confinement; recharge; hydrofacies; flowpath | Y | Y | N | P | Y | Y | N | N/A | Y | Y | N | P | Y |
| Dahl and Hinsby (2013) (GW–SW interactions) | Landscape type; riparian hydrogeological type; groundwater–surface-water interaction response units; riparian flow path type | Y | Y | N | N | Y | Y | Y | N/A | N | Y | Y | P | Y |
| Serov and Kuginis (2017) (GDEs) | Confinement, consolidation, lithology, water chemistry (mainly salinity), water flow/flux, depth of water table, pressure | Y | Y | N | P | N | Y | N | N/A | N | Y | Y | P | P |
| Korbel and Hose (2017) | Weighted Groundwater Health Index: functional; organisational; stressor indices; environmental variables: reference health state | Y | P | P | N | Y | Y | N | P | N | Y | Y | Y | N |
| Weaver et al. (2017) | NZ Groundwater Health Index (in development) | Y | P | Y | Y | Y | Y | N | N | N | Y | Y | Y | P |
| Moreau (2023) | Technical review of GWQ indicator: hydrogeological systems; consistent properties; similar pressures / management issues | Y | Y | N | P | N | Y | Y | N/A | Y | Y | N | P | Y |

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Table A1.2 Assessment of selected groundwater typologies against the final end-user principles.

| | | Spring Ecosystems / Sphere of Discharge (Stevens et al. 2021) | GW–SW Interactions (Dahl and Hinsby 2013) | Hydrogeological Systems (e.g. Moreau 2023) | Groundwater Health Index (e.g. Korbel and Hose 2017) |
|---|---|---|---|---|---|
| P1. Hierarchical Structure | P1.1 Level type. | Environmental | Environmental | Environmental | Environmental/biotic |
| | P1.2 Nesting type. | Imperfectly nested: each spring type can be further split into micro-habitats, many of which are common across spring types | Imperfectly nested; two hydrogeological types can be split into the same four flow path types. | Not nested (systems); however, underlying hydrological units and age are imperfectly nested. | Imperfectly nested: Tier 2 assessment is done if sites fail any Tier 1 benchmark |
| P2. Spatially explicit | P2.1.1 Is typology mapped? | No | Yes (not Aotearoa New Zealand) | Yes | Partially |
| | P2.1.2 Indicate extent, resolution and accuracy. | N/A | National map of Denmark produced 2022; datasets used range from 10 to 500 m scale (Sechu et al. 2022). | National map of Aotearoa New Zealand; 1:250,000 scale. | Only at selected sites (Aotearoa New Zealand and overseas) |
| | P2.1.3 Also indicate how the ecosystem occurrence is represented (i.e. points, polygons, etc.). | N/A | Polygons | Polygons | Points |
| | P2.1.4 If not mapped, are there data that could be used to produce maps? | Classification of single points only, maps have been produced for various United States of America regions | Needs: elevation model – LiDAR-processed raster data(?); stream network (Y?); soil maps (Y); aquifer boundary maps (Y); artificial drainage models (N); land cover database (Y?) | N/A | Yes, but would be very intensive to cover large areas |
| | P2.2 Extent (current, historical, potential). | - | Current (Denmark only) | Current, last updated 2022. | wGHI 2017 used Italy 2020; ESR currently developing an Aotearoa New Zealand model |
| | P2.3 Are the methods used to map the typology sufficiently well described that they could be reproduced by a third party? | - | Yes | Yes | Partially: expert analysis required, e.g. taxonomic and ecological skills, plus some expert judgement on level of deviation |
| | P2.4 Other comments. | Expertise needed to classify individual springs, probably from site visits only | - | - | - |
| P3.1 Accommodates increased knowledge and change over time: Updateable | P3.1.1 Spatial boundaries on maps can change over time? | N/A | Yes (re-running analysis required). | Yes (re-running analysis required) | Ecosystem types are not mapped; this is more of an index for health of individual sites that could be incorporated into a typology |
| | P3.1.2 Temporal changes can be made to mapped unit attributes? | Presumably | Presumably, currently only one map. | Yes, new work involves 4D facies model. | Presumably – relies on deviation from ‘reference’ so more background data could lead to different analysis |
| P3.2 Accommodates increased knowledge and change over time: Flexible/adaptable | P3.2.1 New ecosystem types can be added. | Yes – 2021 updated and expanded on Springer and Stevens (2009) | Yes – Dahl and Hinsby (2013) updated from 2007 version; 2022 map updated further. | Potentially | Potentially – currently only similar to, mild deviation from and major deviation from reference, so these could be expanded, or underlying data could be used to classify into ‘types’ |
| | P3.2.2 Ecosystems can be split or combined. | No | No | No | Potentially – see above point. |
| | P3.2.3 Methods can be changed to better define ecosystem types. | Yes, but expertise is needed to assess spring classification | Potentially, if updated models/datasets can be included. | No | Yes, rather than deviation from reference, but requires expert knowledge |
| P3.3 Accommodates increased knowledge and change over time: Temporally explicit | P3.3.1 Timespan of underlying data and when typology created documented. Changes have been date-stamped. | Unknown – maps not publicly available | Presumably, currently only one map | Yes | Dates for individual site analyses are known (multiple dates per site) |
| | P3.3.2 If maps have been created, is the time period of application documented? Have any changes been date-stamped? | N/A | Yes | Yes | Yes |

| | | Spring Ecosystems / Sphere of Discharge (Stevens et al. 2021) | GW–SW Interactions (Dahl and Hinsby 2013) | Hydrogeological Systems (e.g. Moreau 2023) | Groundwater Health Index (e.g. Korbel and Hose 2017) |
|---|---|---|---|---|---|
| P4.1 Compatibility across domains and typologies: Compatible | P4.1.1 Rationale behind typology structure clear? | Yes | Yes | Yes | Yes |
| | P4.1.2 Does it build on / acknowledge other typologies? Are relationships to units in other typologies explained? | No | No | Acknowledges and uses hydrogeological units, age, river type and network, tectonics, topography. | Acknowledges previous work: Sites are defined through geological formations, hydraulic conductivity, land use, etc., but these do not feed into the classification. |
| | P4.1.3 Could the typology be cross-walked to other typologies in the domain? | Yes | Yes | Yes, but also needs other typologies mapped to (i.e. nested under) it. | Health assessment could feed into other typologies but would need to be simplified, or only certain factors considered, otherwise each aquifer would be a separate ‘type’. |
| | P4.1.4 Other comments. | Could be used in addition to other typologies to further define ecosystems (level 6) | Could be used in addition to other typologies to further define ecosystems (level 5/6). | - | - |
| P4.2 Compatibility across domains and typologies: Consistent use of species concepts | P4.2.1 Describe whether and how taxonomic changes can be accommodated. | Environmental only | Environmental only | Environmental only. | Taxa are identified at high level (as ‘crustaceans’ or ‘oligochaetes’), so changes in taxonomy would not have any effect. |
| | P4.2.2 Biotic names follow a reference taxonomy (e.g. New Zealand Organisms Register [NZOR]). Please provide name of reference taxonomy. | N/A. Note groundwater organisms not in the NZOR. | N/A. Note groundwater organisms not in the NZOR. | N/A. Note groundwater organisms not in the NZOR. | N/A. Note groundwater organisms not in the NZOR. |
| P4.3 Compatibility across domains and typologies: Nesting under IUCN GET | Yes, No, Partial | Yes – All ‘SF1.2 groundwater ecosystems’ | Yes | Yes | Yes |
| P5.1 Robust: Parsimony and utility | P5.1.1 Detailed descriptions of units exist? | Yes – characteristic features described in detail | Yes – characteristic features described in detail. | Yes | Yes |
| | P5.1.2 Clearly applicable diagnostic criteria to allow identification of units. | Yes, including stepwise key to identification | Yes | Yes | Yes |
| | P5.1.3 Do ecosystem names facilitate identification in the field? | Yes | Yes | If ‘in the field’ can refer to cores. | Taxa are identified at a high level only. |
| | P5.1.4 Are the number of unit manageable? Please specify the number of units at each level. | 13 springs; three of these have subtypes; ‘at least 13’ microhabitats below this | 2013: four landscape types; eight hydrogeological types (nested); four flow path types (only for two hydrogeological types). 2022 map: only five hydrogeological types. | Eight systems (plus unclassed) | If each aquifer is assessed as similar to, mild deviation from and major deviation from reference, then there are only three types. Numerous units for underlying data used to make this assessment. |
| P5.2 Robust: Transparent and reproducible | P5.2.1 Method to produce typology documented and independently reproducible. | Yes, but requires expertise (87% of springs were classified correctly only according to key) | Yes, methods peer-reviewed and published. Analytical skills required to reproduce the analysis. | Yes | Yes, but requires expert analysis and judgement. |
| | P5.2.2 If P5.2.1 is ‘No’, is the method defensible? | N/A | N/A | N/A | N/A |
| | P5.2.3 Was typology data-derived, data-underpinned or expert-derived/qualitative? | Data-derived but needs expert interpretation | Data-derived | Data-derived | Data-derived and expert-derived (classification as mild deviation). |

| | | Spring Ecosystems / Sphere of Discharge (Stevens et al. 2021) | GW–SW Interactions (Dahl and Hinsby 2013) | Hydrogeological Systems (e.g. Moreau 2023) | Groundwater Health Index (e.g. Korbel and Hose 2017) |
|---|---|---|---|---|---|
| P6. Comprehensive | P6.1 Does it accommodate transformed ecosystems, including engineered, passed tipping point, successional, novel? | No | No | No | Yes |
| | P6.2 Does it accommodate ecotones? | No | No | No | Yes |
| | P6.3 Does it distinguish biotic (e.g. species) assemblages that are uncommon? | Environmental only | Environmental only | Environmental only. | No |
| | P6.4 Is there any other form of ecosystem variation that is missing from the typology? | Not known | Not known | Not known | Not known |
| P7. NZ-Specific | P7.1 Reflects Aotearoa New Zealand ecological diversity and processes (if NO, explain why) | No – environmental only | No – environmental only | No – environmental only. | Yes |
| | P7.2 Does the typology use terminology and concepts familiar to Aotearoa New Zealand ecologists and conservation practitioners? | Partial – most springs names are well known | Yes | Yes | Yes |

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