Classification of Lakes in the Bay of Plenty Region, New Zealand

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Executive Summary

The Bay of Plenty Regional Council (BOPRC) is undertaking a stocktake of lakes in their region as part of their obligations under the National Policy Statement for Freshwater Management 2020 (NPSFM). It currently monitors 12 of the Rotorua Te Arawa Lakes that are of volcanic origin. However, there are numerous other water bodies in the region, and it is not clear whether these are lakes or not. eiQ NZ was approached to assist with:

- Reviewing scientific literature and policy to document criteria used in classifying lakes in New Zealand and overseas environments
- Identifying, mapping and categorising possible lakes in the Bay of Plenty region
- Cataloguing attributes (including location, size, characteristics etc) of all water bodies investigated, even if they are eventually not classified as lakes.

The review of literature and policy highlighted that there are various criteria in which lakes may be categorised. This includes measurements of morphological characteristics (e.g. size, shape, depth), mixing patterns, marine connectivity and ecology, as well as determinations of geomorphic origin. However, there was no clear consensus on how these criteria may be used to differentiate lakes from other standing water bodies such as wetlands and ponds.

A data-driven approach was used to identify, map and categorise water bodies in the Bay of Plenty. Datasets were integrated and analysed to assess whether the water bodies were likely to lakes, or not. A total of 64 sites have been classified as possible lakes based on their size, permanence of water and characteristics. These include:

- 37 volcanic lakes
- 12 riverine lakes
- 8 artificial lakes
- 5 shoreline lakes/lagoons (3 freshwater and 2 coastal)
- 1 peat lake
- 1 landslide lake

The remaining water bodies are likely to be ponds or wetlands. However, these classifications are provisional and based on an initial desktop analysis. They will be optimised with the inclusion of expert local knowledge, cultural values and definitions, ground-truthing, and the development of specific criteria for identification, all of which are recommended as next steps for the Council.

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1 Introduction

The National Policy Statement for Freshwater Management 2020 (NPSFM) (Ministry for Environment, 2020) requires that lakes are identified by regional councils. Important ramifications of these classifications include the application of particular attributes and "national bottom lines" for lakes that are detailed in the NPSFM. Regional Councils must monitor these attributes, as well as setting baseline, current and target attributes states in each Freshwater Management Unit (FMU), or part of an FMU. If a water body is not classified as a lake, the attribute state bands and bottom lines for lakes in the policy do not apply. However, other 'non-lake' attributes may apply.

The task of identifying and categorising lakes is currently complicated by the lack of national guidance. There is also no scientific consensus on how to differentiate lakes from other standing water bodies such as ponds, lagoons and wetlands. The Bay of Plenty Regional Council (BOPRC) have determined that the 12 Rotorua Te Arawa Lakes are lakes of volcanic origin. However, there are numerous other water bodies in the region, and it is not clear whether these are classified as lakes or not. Many are not monitored and, if they are deemed to be lakes, the BOPRC will need to consider how to apply NPSFM attributes and set appropriate target attribute states for these water bodies.

The BOPRC intends to deliver a robust, defensible, science-based approach to classifying lakes. eiQ NZ was approached to assist in this task. Specific objectives include:

- Identifying, mapping, naming and classifying lakes in the Bay of Plenty Region
- Cataloguing attributes (including location, size, characteristics etc) of all water bodies investigated, even if they are eventually not classified as lakes.

This report will begin with a background section, providing an overview of the Bay of Plenty region and a literature review that examines the physical (hydrological and in lake processes) and ecosystem characteristics and attributes that define lakes and other standing water bodies such as ponds and wetlands. Lake definitions that have been applied in New Zealand and international environments will also be explored. After that, the analytical methods used to classify lakes in the Bay of Plenty will be detailed. The results of this analysis will then be described and discussed, followed by recommendations for next steps. This work is an important first step in ensuring that the NPSFM is applied correctly with respect to lakes in the Bay of Plenty.

2 Background Information

The purpose of this background section is provide a short overview of the Bay of Plenty, the region in which this study focusses. It then will attempt to inform the reader of the possible methods used to categorise lakes, and how they might differ from other inland standing water bodies such as ponds, lagoons and wetlands. This requires a holistic examination of the different fields of limnology, the scientific study of inland waters which has subdisciplines of geology, physics, chemistry and biology (Cole & Weihe, 2015). The section will conclude by exploring working definitions that have been applied for research and applied purposes in both New Zealand and overseas.

2.1 The Bay of Plenty region

The Bay of Plenty region is on the east coast of the North Island of New Zealand. The region takes in the full sweep of the coastline from Pōtikirua in the east, to Waihī beach in the west, and includes 18 offshore islands extending out to the 12 mile nautical boundary. The area of the region is 21,837 square kilometres comprising 12,254 square kilometres of land and 9,583 square kilometres of coastal marine area. Inland, the region extends generally to the ridges of the catchments which drain into the Bay of Plenty. The eight major rivers emptying into the Bay are the Wairoa, Kaituna, Tarawera, Rangitāiki, Whakatāne, Waioeka, Mōtū and the Raukōkore.

Prominent features of the region include islands such as Matakana, Mayor (Tūhua), Mōtītī and an active volcano Whakaari / White Island, which is part of the Taupo Volcanic Zone. Other distinctive landmarks include Mauao (Mt Maunganui), Mt Tarawera and Mt Pūtauaki (Mt Edgecumbe), the Tauranga and Ōhiwa Harbours and the lakes of the Rotorua district. There also five other major estuaries - the Maketū, Waihī, Whakatāne, Waiotahe and Waioeka / Otara estuaries.

The Bay of Plenty is home to Te Arawa (Rotorua) Lakes which contribute to this region being one of New Zealand’s most popular tourist destinations. The lakes have significant cultural, recreational, and natural values. Te Arawa lakes are taonga to local iwi/hapu. They are a place for healing, cleansing and inspiration, swimming, and gathering kai. The BOPRC manages water quality in the region's lakes and has been monitoring them since 1990. It currently monitors 12 volcanic lakes in the region. All have a diversity of water quality, owing to their

varying catchments and depth, geothermal activity, and the extent of development and human impact on the landscape. In 2000 the BOPRC, in partnership with Rotorua District Council and Te Arawa Māori Trust Board, initiated a lakes strategy in response to the decline in water quality in many of the lakes. The Rotorua Te Arawa Lakes Programme (RTALP) is a programme of protection and restoration for the Rotorua Te Arawa lakes.

2.2 Background - methods

A review of scientific literature and policy related to the definitions of standing water bodies in New Zealand and overseas environments was carried out with web and library sources. Scientific articles and books in the field of limnology, and policy applications were reviewed for this purpose. The aim was to identify and examine physical (hydrological and in-lake processes) and ecosystem characteristics and attributes that might define a lake. Relevant information has been summarised, detailing the definitions and scientific categories of standing water bodies.This literature review was limited to papers published in the English language.

This literature review was also limited in its consideration of the cultural definitions of lakes, and that of mātauranga Māori. However, it is recognised that further consultation with local iwi is ongoing, and Māori cultural values, definitions and monitoring is needed to incorporate Māori values, tikanga, and mātauranga Māori of different iwi/hapū into environmental plans and decisions, and track the effectiveness of these plans.

2.3 Background - what is a lake?

Lakes are generally defined as localised bodies of water, occupying a basin and surrounded by land. The water occupying the basin may be sourced from any combination of rainfall, inflows from streams, rivers or groundwater (Lowe & Green, 1992).

Kuusisto & Hyväurinen (2000) previously stated that a water body should meet the following requirements to be called a lake:

- It should fill or partially fill a basin or several connected basins
- It should have essentially the same water level in all parts, with the exception of relatively short occasions caused by wind, thick ice cover, large inflows, etc

- Even if the water body may be located in the immediate vicinity of the sea coast, it does not have a regular intrusion of sea water
- The water body should have so small an inflow-to-volume ratio that a considerable portion of suspended sediment is captured
- The area of the water body should exceed a specified value, e.g. 1 ha, at mean water level.

Lakes are commonly classified by their shapes and sizes, how they are formed (geomorphic lake types), by the mixing pattern of their water, and how they may be connected to the marine environment. A summary of these classification systems is provided below.

2.3.1 Morphological classifications

Lakes exist in all shapes and sizes and are commonly classified on their morphological characteristics. These include physical measurements of surface area, volume, depth (maximum and minimum), shape of the lake and shoreline length. These physical attributes affect the residence time, sediment delivery, stratification, productivity and resuspension characteristics in lakes. All of these attributes in turn influence the structure and function of the water body (Cole & Weihe, 2015).

Lake depth is particularly relevant for the categorisation of lakes. Both scientists and policy-makers commonly classify lakes as being “shallow” or “deep” due to their functional differences. Shallow lakes are generally considered to be less than 10m deep, encouraging the mixing of the water and preventing thermal stratification. Shallow water may also allow for sunlight to reach the lake bottom, supporting the growth of rooted plants, while the resuspension of muddy sediments by wind action can result in turbid waters. In contrast, deep lakes (> 10 metres) will often have shallow shorelines that can support rooted plant growth. However, sunlight will not penetrate to deeper regions of the lake (Wetzel, 2001). They will also thermally stratify, discussed in more detail in Section 2.3.3.

It is useful to understand the geographical distribution of monitored lakes and how their location in the landscape can affect lake condition. In New Zealand, lowland lakes are often smaller and shallower than upland lakes. They are also often located in catchments with higher proportions of agricultural, urban or other development. Because upland lakes are relatively deep, comparing the health of deep lakes with shallow lakes yields similar results to comparing lowland vs upland lakes. In New Zealand, deeper lakes are more likely to have good water quality compared with shallower lakes (LAWA, 2021b).

2.3.2 Geomorphic classifications

Lakes may form through a variety of different geological and manmade processes. New Zealand has an extensive variety of lake types, owing to its diversity of geological processes and landscapes that contribute to lake formation. Lowe & Green (1992) have previously categorised New Zealand's major lakes, detailing the various geological processes that result in distinctive lake basins. The geomorphic origin of lakes in New Zealand are now commonly classified according to their following criteria:

- **Volcanic, tectonic**, and **geothermal lakes** are formed by various volcanic and geological processes and are primarily found in the Central Volcanic Plateau in the North Island. Geothermal lakes are commonly differentiated to other volcanic lakes due to the active geothermal influence in the catchment or within the lake.
- **Riverine lakes** commonly form in water filled depressions on river floodplains as river channels shift and migrate. These lakes are commonly found in the lower floodplains of rivers.
- **Landslide lakes** are commonly formed in valleys that are blocked by rock falls or avalanches. They are commonly found in seismically active areas.
- **Dune Lakes (aeolian lakes)** are often formed by wind-blown sand deposits and sand dunes.
- **Peat lakes** are created as a result of the accumulation of peat, although some lakes that are created by other processes have been modified by peat growth and may now be considered peat lakes.
- **Glacial lakes** can be formed by combination of different processes, including ice-excavated rock depressions, glacial moraine, and depressions created by melting ice blocks in retreating glaciers.
- **Shoreline lakes** (or barrier-bar lakes) are formed by long-shore drift of a barrier bar or spit across a coastal embayment near the sea. Their water is commonly brackish. Shoreline lakes may also form along the shorelines of larger lakes.
- **Solution Lakes** occur in areas composed of carbonate rock (e.g. limestone and marbles).
- **Artificial lakes** are created by human intervention where a lake would not normally exist (Gibbs & Hickey, 2012). They may be developed by the damming of river valleys, or the artificial construction of a basin area. Artificial lakes may be developed for many uses, such as for hydroelectric power generation and for domestic water supply.

Systematic differences of lake water quality and condition is often intuitively associated with the respective lake type. Dune, peat, and riverine lakes are commonly located in relatively fertile, low elevation areas that may be developed for agricultural land use. As a consequence they may often be nutrient enriched and exhibit poor lake condition. Volcanic lakes are generally of intermediate lake condition, but it is notable that phosphorus concentrations can be naturally elevated due to volcanic rock and acidic volcanic soils in these areas (LAWA, 2021b).

2.3.3 Mixing patterns

Lakes are also commonly classified on their thermal mixing regime. Most small, shallow lakes in New Zealand are 'polymictic'. These lakes are too shallow to develop thermal stratification and will mix frequently. In contrast, 'monomictic' lakes, also known as stratified lakes, are characterised by a water column that stratifies into distinct thermal layers. This includes: the epilimnion, comprising the top warm layer; the thermocline; and the colder hypolimnion extending to the floor of the lake. Stratification commonly occurs in the summer months, resulting in varying geochemical conditions at different depths of the lake. The temperature and dissolved oxygen concentrations of the water are commonly effected, changing with depth in the water column. Stratified lakes will commonly mix when waters cool in the autumn months in New Zealand (LAWA, 2021a).

2.3.4 Marine connectivity

The connectivity of a lake to the marine environment is commonly used for the purposes of categorisation. The term 'lagoon' is commonly used in New Zealand to classify shallow lakes associated with river mouths. They are often elongated parallel to the coastline and separated from the ocean by barriers of sand and gravel. These barriers are often not permanent and are frequently modified by flood events, wave action, and changes associated with storm events. As a result, they can have varying degrees of tidal mixing and water that varies from fresh to brackish (Johnson & Gerbeaux, 2004).

It is important to note that the term 'lagoon' can also be used to describe lakes that are intermittently connected with rivers or deeper lakes.

2.3.5 Productivity and ecology

Lakes are monitored for a range of water quality (chemical-physical and bacterial) and ecological indicators. The differences in conditions may be used to categorise lakes and their management.

The most common indicator used to describe lake health in New Zealand is that of the Trophic Level Index (TLI). This indicator combines several measures of lake water quality to provide an integrated summary of lake condition. It is calculated using the concentrations of key nutrients (total nitrogen and total phosphorus), an indicator of algae biomass (chlorophyll a - the photosynthetic pigment present in all plants), as well as a measure of water clarity. Increasing TLI scores indicate that a lake is becoming nutrient enriched with an increasing likelihood of algae bloom events, which are associated with reduced water clarity. The TLI is calculated once every year and provides regional councils, unitary authorities and lake managers with an integrated measure of water quality that can be tracked over time (Schallenberg & van der Zon, 2019).

The Lake Submerged Plant Indicator (LakeSPI) index is a commonly used indicator of lake macrophyte condition in New Zealand. It is a bio-assessment tool to monitor the composition of native and invasive plants growing in lakes, and the depths in which these plants grow. Submerged aquatic plants are highly suitable biological indicators because they are easy to observe and reflect environmental conditions within a lake over an extended period of time. Higher LakeSPI scores are associated with greater proportions of native macrophytes and better water quality, which can provide an indication of lake ecological condition (Clayton & Edwards, 2006).

Additional ecological assessments that may be undertaken in lakes include measurements of native fish species, zooplankton, macroinvertebrates, periphyton and plankton communities. However, comparative assessments have been complicated by lake-specific conditions, a lack of established sampling protocols and prohibitive costs (Schallenberg et al., 2011).

In recent years, New Zealand lakes and ponds have started to be monitored for freshwater crayfish/koura (Kusabs et al., 2015; Kusabs et al., 2018). These are an important traditional food source for Māori, particularly for Te Arawa and Ngati Tuwharetoa of the Central North Island.

2.4 Background - what isn't a lake?

Limnologists and policy makers have made numerous attempts, for both research and practical purposes, to define the difference between lakes and other standing water bodies such as ponds and wetlands. Unfortunately, no consensus has been reached, largely due to

the variety of complexities associated with this task. Firstly, the categorisation of lentic water bodies is hampered by the lack of naming conventions. Many water bodies that may in fact be lakes have names that end with the words ‘pond’, ‘lagoon’, ‘wetland’ or ‘tarn’. Furthermore, standing water bodies are transitory features in the landscape. Once formed, lakes will eventually be infilled by sediments, evolving from lake to pond and finally, wetlands over geologic time. There are no precise definitions of when these transitions occur (Lowe & Green, 1992).

A brief overview of standing water bodies not generally regarded to be lakes is provided below.

2.4.1 Ponds

Ponds (and other small water bodies) are amongst the most numerous freshwater environments globally. They are recognised as playing a critical role in maintaining freshwater biodiversity and the delivery of ecosystem services, including that of carbon cycling. They are also recognised as being some of the best remaining examples of intact freshwater habitats and are the most likely to remain unpolluted in undeveloped catchments (Biggs et al., 2017). Despite this, small water bodies remain the least investigated waterways and are largely excluded from water management planning (Søndergaard et al., 2005).

It is generally accepted that ponds are enclosed bodies of water, smaller than lakes and are often artificial (Biggs et al., 2017; Johnson & Gerbeaux, 2004). Søndergaard et al. (2005) previously outlined reasons why ponds and small water bodies differ from larger lakes. These include:

1. Having shallow and wind protected morphology that may allow for submerged and floating macrophytes to cover large areas of the water body.
2. Having relatively stagnant water favouring certain species of flora and fauna
3. Having a relatively low input of water and water volume
4. Greater isolation compared to large catchments and the riverine inflows of large lakes
5. Greater influence of bottom sediments on nutrient content in water
6. Closer contact with the adjacent terrestrial environments and a greater relative littoral zone (the area close to the shoreline)
7. Exhibiting a lack of fish due to winter fish kill and summer dry out. Invertebrate predators may take over the role of fish when absent.
8. Fish are largely found to be absent in water bodies smaller than 0.1 ha.

It is clear that there are functional differences between small and large standing water bodies. However, there continues to be uncertainty in defining the precise scientific differences between lake and ponds. Various definitions have attempted to use attributes such as size, water supply, geographical location, geomorphic formation and water quality to classify ponds (Oertli et al., 2005). A recent review of compiled definitions suggests that surface area and depth are the two most commonly used variables defining the differences between lakes and ponds (Richardson et al., 2022).

2.4.2 Wetlands

Wetlands are defined in the Resource Management Act (1991) as including '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'. They are commonly found in areas of poor drainage, along hillsides where there is a change in slope or geology, on stream and river floodplains, in low-lying areas among flat landscapes, in coastal areas where sand dunes trap water runoff, and along the margins of rivers, lakes and estuaries. Wetlands may even be geothermal in origin (Johnson & Gerbeaux, 2004).

The prolonged presence of water in wetland environments creates conditions that favour the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils. There is significant variation in wetland characteristics across New Zealand because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors, including human disturbance. Johnson & Gerbeaux (2004) previously grouped wetlands into nine classes for identification purposes. These classes include: bog, fens, swamp, marsh, seepages, shallow water, ephemeral, pakahi gumland, and saltmarsh.

It is recognised that nature is both highly variable and dynamic, and sometimes cannot be divided into precise categories. For this reason, distinguishing wetlands from other standing water bodies can be challenging. In many situations there is no clear boundary between a wetland and surrounding lakes or other water bodies. The full extent of some shallow lakes may be included within a natural wetland and considered part of the extent of the natural wetland. These situations must be assessed on a case-by-case basis, using an ecological assessment where necessary, to distinguish whether a wetland comprises lakes and/or rivers (Ministry for Environment, 2021).

2.5 Background - applied definitions

A variety of applied definitions, differentiating lakes from other water bodies, have been used for both research purposes and policy development. This section briefly reviews a number of known definitions that have been applied in the New Zealand and overseas environments.

2.5.1 New Zealand

Applied definitions used for research and policy development in New Zealand generally make use of morphological characteristics to differentiate lakes from other standing water bodies. For example, an early stocktake of New Zealand lakes focussed on standing water bodies with a major dimension of 0.5 km or more (Irwin, 1975). More recently, the FENZ geodatabase (Leathwick et al., 2010) provided modelled data for 3594 water bodies classified as lakes and with a surface area greater than 1 hectare. This cut-off size is commonly referred to in the New Zealand literature (Gluckman et al., 2017; Ministry for Environment, 2020; Schallenberg et al., 2013). It has also been recently used by the Horizons Regional Council in their comprehensive review of requirements under the NPSFM relating to the management of their lakes (Wood et al., 2022).

Definitions have been applied for the purposes of conservation management and policy development in New Zealand. The Conversation Act 1987 defined lakes as having a surface area of eight hectares or more. However, the Resource Management Act 1991, now guiding the development of policies and plans prepared at the national, regional and district levels, defines a lake as a ‘body of fresh water which is entirely or nearly surrounded by land’.

Lake definitions have been utilised for policy development in New Zealand. These are summarised in Table 1.

Table 1. Examples of lake definitions applied in the New Zealand policy context.

Resource Management Act 1991	**Lake** means a body of fresh water which is entirely or nearly surrounded by land.
Conservation Act 1987	**Lake** means a body of fresh water whose bed has an area of 8 hectares or more and which is entirely or nearly surrounded by land.
Te Arawa Lakes Settlement Act 2006	**Te Arawa/Rotorua lakes** means Lakes Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotoma, Rotomahana, Rotorua, Tarawera, and Tikitapu
Overseas Investment Act 2005	**Lake** means a lake (as defined in section 2(1) of the Resource Management Act 1991) that has a bed that exceeds 8 hectares in area.
Public Works Act 1981	**Artificial lake** means a body of water formed or impounded by a government work or by a work acquired by the Crown. **Natural lake** means a lake that is not an artificial lake.
National Water Conservation (Ahuriri River) Order 1990	**Lake** includes pond, tarn, and lagoon; but does not include swamp, marsh, bog, or other wetland.

The recent NPSFM sets a national framework for how freshwater is to be managed across the country. Regional and district plans are required to give effect to it according to its terms. The NPSFM is delivered under the RMA, and therefore the RMA definition of a lake prevails. No further definition of what a lake has been provided by the NPSFM, nor is there guidance on how lakes may be defined. However, certain references to lakes are made which include:

- Appendix 3 (National target for primary Recreation) – Reference to 'specified lakes' for the purposes of national targets for primary contact. Lakes with a perimeter of 1.5 km or more are included in the targets.
- Appendix 2[A] (Attributes requiring limits on resource use) - Reference to lakes and lagoons that are 'intermittently open to the sea', requiring monitoring data to be analysed separately during open and closed periods.

- Appendix 2[A] Mid-hypolimnetic dissolved oxygen – Reference stating that seasonally stratifying lakes require monitoring for their mid-hypolimnetic dissolved oxygen concentrations.

These references provide important clues on the different ways lakes must be categorised, in order to fully apply the requirements of the legislation. These will be explored in more detail in Section 4.3.

The BOPRC has previously used a data-driven approach to assess the hydrological and ecological characteristics of Lakes Matahina and Aniwaniwa. Both of these water bodies are artificially dammed and utilised as storage reservoirs for hydroelectric power generation. Analysis of available data demonstrated that both lakes have low retention times compared with natural lake systems. However, the deeper Lake Matahina exhibits typical lake characteristics, while Lake Aniwaniwa may be better characterised as a "run-of-the-river" system. For this reason, different attributes were recommended for routine monitoring based on the requirements to meet freshwater objectives in an applied and practical manner (Scholes, 2018).

2.5.2 International Examples

Various working definitions have been developed for research, applied and policy purposes overseas.

Australia

In Australia, the Lakes Act of 1976 states that a lake is 'any area declared by the Minister to be a lake', while the Water Act of 2007 states that a lake is 'a natural lake, pond or lagoon (whether modified or not)' and 'includes a part of such a lake, pond or lagoon'.

The United Kingdom

In the United Kingdom, the Water Resources Act of 1991 unhelpfully states that a lake or pond 'includes a reservoir of any description'.

During the 1990s, the requirement for a practical working definition of what constituted a pond led biologists in the United Kingdom to develop a definition characterizing ponds as being 'between 1 m^2 and 2 ha in area which may be permanent or seasonal, including both man-made and natural water bodies' (Biggs et al., 2005).

The United States of America

The Environmental Monitoring and Assessment program has also previously stated that a lake is 'a standing body of water greater than 1 hectare (about 2.5 acres) that has at least 1000 square meters (about 0.25 acre) of open water and is at least 1 meter (about 3 feet) deep at its deepest point'.

More recently, the US EPA and Department of the Army have published the 'Revised Definition of Waters of the United States'. The document specifically states that there is considerable uncertainty about defining the difference between lakes and ponds, and no current accepted definition of either term across scientific disciplines exists. It lists working definitions including that used by:

- The US Army Corps - "The term lake means a standing body of open water that occurs in a natural depression fed by one or more streams from which a stream may flow, that occurs due to the widening or natural blockage or cut-off of a river or stream, or that occurs in an isolated natural depression that is not a part of a surface river or stream. The term also includes a standing body of open water created by artificially blocking or restricting the flow of a river, stream, or tidal area"
- The U.S. Fish and Wildlife Service - "Lakes and ponds are either semi-permanently or permanently flooded during a typical year and may or may not exhibit hydrophytic vegetation."

In 1975, the Army Corps proposed a minimum size requirement on lakes of five acres to be waters of the United States. However, such size requirement received many negative comments that the size was too small, too large or did not account for seasonal changes in sizes of lakes. Many also commented on the legality of imposing size limitations on lakes.

Canada

Lake definitions are not provided in either the Canada Water or Environment Acts. The government of New Brunswick does provide reference to lakes, defining a lake as 'a very slow flowing body of open water which occupies a land depression. This group of water bodies includes ponds and impoundments. Lakes do not include artificially created ponds, excavations, containment structures for agricultural purposes, ponds constructed for wastewater treatment, fish culture, fire protection, or on golf courses'.

The European Union

In the EU Water Framework Directive lakes are defined as a 'body of standing inland surface water'. There is specific guidance in the collection of data related to lake characteristics,

composition and biological population structure. These include altitude, depth, geology and size. Optional factors include the mean water depth, lake shape, residence time, air temperature, mixing characteristics (e.g. monomictic, dimictic, polymictic), acid neutralising capacity, nutrient status, substratum composition, water level fluctuation. Lakes may then be classified into different types based on their morphological and chemical characteristics (Lyche Solheim et al., 2019; Søndergaard et al., 2020).

2.5.3 A data-driven classification system

Richardson et al. (2022) recently proposed a method to differentiate small lakes, lakes, ponds and wetlands based on the measurements of three different criteria - depth, surface area, and emergent vegetation (Figure 1). They identified varying relationships between these water bodies from the analysis of comprehensive chemical and biological datasets collected by the US EPA and the European Environmental Agency. Ultimately, they proposed the following definitions:

- Lakes have a surface area > 5 ha and depth > 5 m
- Small lakes have a surface area < 5 ha and depth > 5 m
- Shallow lakes have a surface area > 5 ha and depth < 5 m
- Ponds have a surface area < 5 ha and depth < 5 m
- Wetlands have depths < 5 m and emergent vegetation > 30%

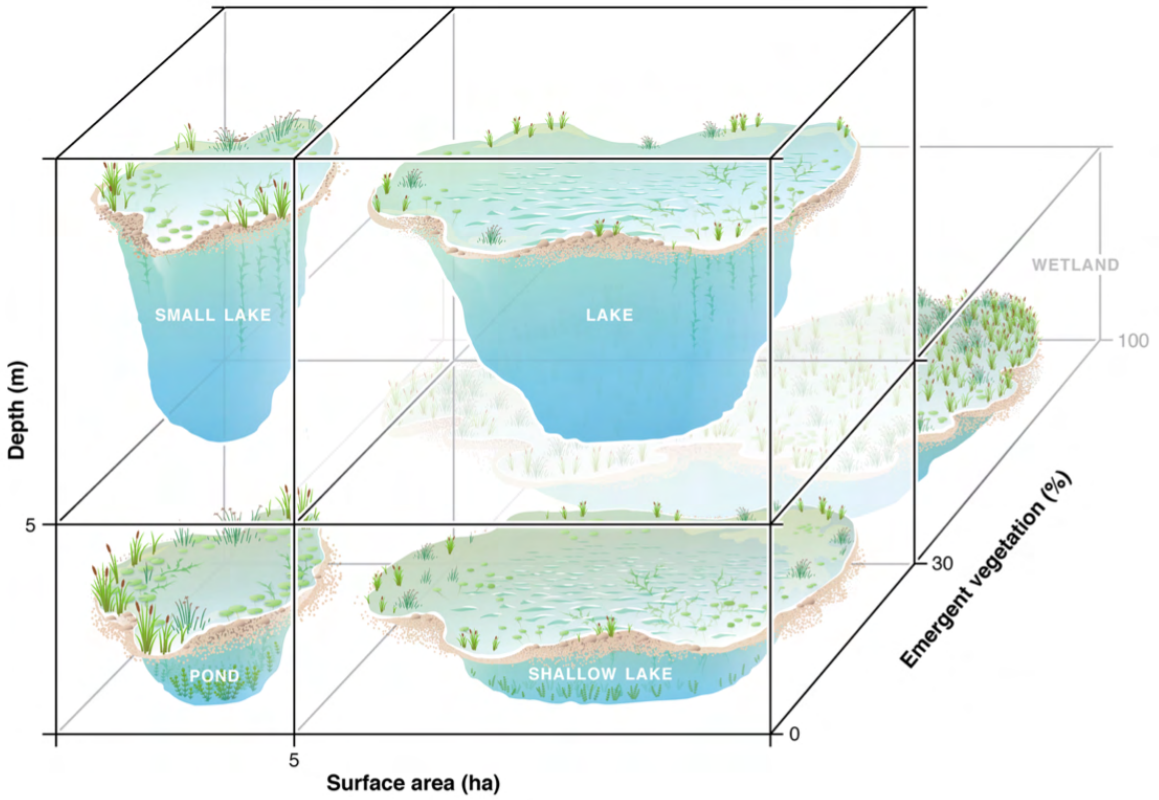

Figure 1. Conceptual model of water bodies based on three different criteria (depth, surface area, and emergent vegetation). Original figure: Richardson et al. (2022)

The use of this conceptual classification system will be further discussed in Section 4.

3 Lake Classification in the Bay of Plenty

This section details the analytical methods used in the desktop analysis of lakes in the Bay of Plenty region. The results are then described and discussed.

3.1 Lakes classification - methods

Water bodies in the Bay of Plenty region were analysed with a collection of best available datasets in this work. These included:

- Bay of Plenty Aerial photography datasets (2003 and 2015 – 2017) – Published by Land Information New Zealand (LINZ, 2022)
- Topographical digital vector data (Topo50 1:50,000) – published by LINZ (LINZ, 2022)
- New Zealand Primary Parcels - published by LINZ (LINZ, 2022)
- Freshwater Ecosystems of New Zealand (FENZ) geodatabase – Published by Department of Conservation (Leathwick et al., 2010)
- Land Cover Database (LCDB Version 5) - Published by Manaaki Whenua Landcare Research (LRIS, 2022)
- New Zealand Place Names – Published by Land Information New Zealand (LINZ, 2022)
- QMap, 250K (1:250,000) geological units map – Published by GNS Science (GNS, 2022)
- New Zealand protected areas (Crown property) – Published by the Department of Conservation (DOC) and Land Information New Zealand (LINZ, 2022)
- Lake structures, dam consents and surface water allocation datasets – supplied by the BOPRC via the Accela database
- Bay of Plenty landuse layer (hydro features and wetlands) – developed by Lynker analytics for the BOPRC
- Bay of Plenty wetland extent layer – supplied by the BOPRC

Datasets were downloaded in NZ Transverse Mercator (EPSG:2193) format for analysis in GIS software QGIS (LTR version 3.22). The FENZ geodatabase, previously developed to categorise lakes in New Zealand > 1 hectare in size, was used as a preliminary dataset for this project. Polygons identified as lakes by FENZ were compared to hydrological features identified in more recently updated Topo50 (1:50 000 lake, pond and reservoir features), the Lynker dataset (hydrological features identified in the Bay of Plenty) and the LCDB V5 (lake

or pond). Any new features not included in the FENZ geodatabase were merged into a new layer with associated metadata.

Additional metadata fields were created for use in visual analysis with aerial imagery collections. The metadata fields and a brief description of their purpose are provided below:

- **Permanent_water** – Is standing water present in all aerial/satellite imagery?
- **Intermittent** – Is there evidence of the water body drying up?
- **Hydraulic_connectivity** – Is there obvious surface water connectivity between the standing water body and other waterways (e.g, lakes, wetlands, streams or rivers)?
- **Structures** – Are there manmade structures present?
- **Dammed** – Is the standing water body obviously dammed for hydroelectric power generation or water storage?
- **Protected_land** – Does the standing water body occur in protected land?
- **Forested** – Is any surrounding area of the water body forested?
- **Pastoral** – Is any surrounding area of the water body used for pastures?
- **Residential** – Is any surrounding area of the water body residential?
- **Coastal** – Does the water body occur in close proximity to the regional coastline?
- **Thermal_features** – Are there obvious geothermal features?
- **Proposed_waterbody** – Based on available evidence, the proposed water body (e.g. lake, wetland, pond, river, geothermal)
- **Proposed_geomorphic_type** – Based on available evidence, the proposed geomorphic type of the water body
- **Notes** – Notes made during the data-driven and visual assessment of the water body.

Additional meta-data from intersecting features in QMap (underlying geology and rock group), NZ protected areas (conservation area name and type), LINZ NZ place names and New Zealand primary parcels layers were joined to the resulting dataset. These are described in the appendix of this report.

For the sake of practicality, water bodies less than 1 hectare in size were filtered out of the resulting layer for analysis. The remaining water bodies were visually (desktop) assessed using both 2003 and 2017 aerial imagery and Topo50 gridless basemaps developed for the Bay of Plenty region. Topo50 hydraulic features (River lines and polygons), QMap geological features, as well as wetland extent and consenting datasets provided by the BOPRC were considered throughout the visual assessment. Features identified as possible wetlands by the BOPRC were recorded.

Water bodies were visually assessed from largest to smallest, with additional meta-data fields populated manually. Water features were redrawn where there were clear inaccuracies in the current delineation compared to aerial imagery collected in both 2003 and 2017. The perimeters and area of the resulting water bodies were then recalculated.

A number of exclusion criteria were used when proposing the classification of standing water bodies in the Bay of Plenty Region.

- Is the water body a manmade structure used for agricultural purposes (water or effluent storage), stormwater or wastewater treatment, fish culture, fire protection or water bodies located in excavations/quarries?
- Is the water body a natural pooling area on a river stretch?

The culmination of this analysis is a comprehensive spatial database that can be visualised, filtered, sorted and analysed in desktop and online geospatial software such as ArcGIS or QGIS.

3.2 Lakes Classification - Results

Initial filtering of the FENZ geodatabase returned 101 water bodies > 1 ha in size in the Bay of Plenty region. This number was increased to 150 water bodies > 1 ha with the addition of polygons from the most recently updated New Zealand Topo50, LCDB (V5) and Bay of Plenty Lynker datasets (Figure 2).

Preliminary analysis of these combined lake polygons indicate:

- 2 sites were dry areas of pastural or forested land and may be classified as land.
- 3 sites were channels of free-flowing rivers
- 4 sites may classify as active geothermal areas.
- 28 sites may be classified as likely ponds due to their obvious appearance as wastewater or stormwater treatment, farm storage or excavation sites.
- 47 sites may be classified as likely wetlands due to their overlap with features previously identified as wetlands by the BOPRC, or their obvious appearance of shallow waters, dominance of emergent vegetation or ephemeral nature.
- 64 sites may be classified as possible lakes based on their size, permanence of water and characteristics.

An additional 1097 water bodies < 1 ha in size are included in the database. Of these features, just three have names ending with ‘lake’.

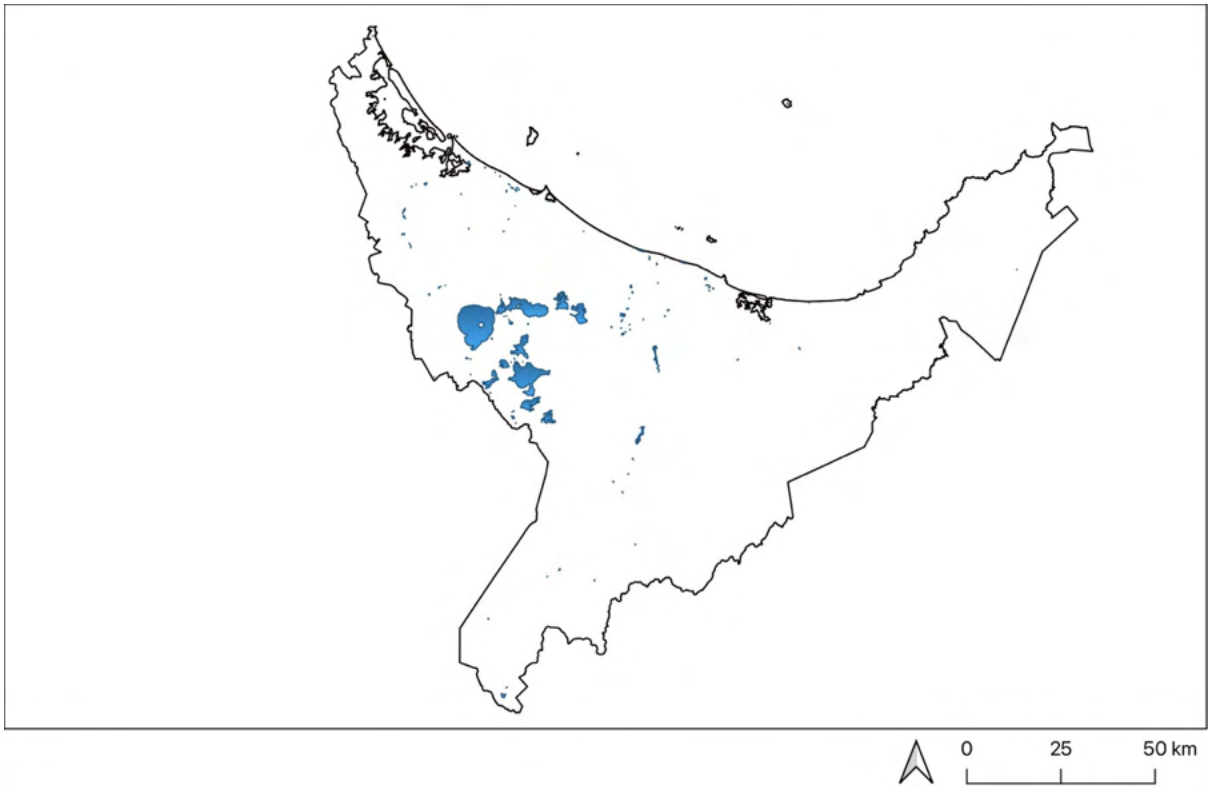

Figure 2. 150 water bodies with surface areas greater than 1 hectare were identified in the Bay of Plenty Region. The Bay of Plenty region is outlined in black in this map. Water bodies > 1ha are highlighted in blue.

3.2.1 Lake Types in the Bay of Plenty

A summary of the different geomorphic lake types identified in the Bay of Plenty Region is provided below.

Volcanic Lakes

Based on the desktop landscape analysis undertaken in this study, 37 water bodies were classified as volcanic lakes, ranging in size from 1.06 – 8063.7 ha. All have underlying volcanic geology and are located in close vicinity (< 25 km) from volcanic lakes currently monitored by the BOPRC. The most distant are those north of Kawerau and west of the Tarawera River.

Figure 3 demonstrates that many of the volcanic water bodies are small compared to the Te Arawa/Rotorua lakes monitored by the BOPRC (identified with an orange marker). Twenty-six (70%) of these water bodies have official names ending with ‘lake’ or ‘lagoon’.

Figure 3. Thirty seven volcanic water bodies > 1 ha in size were identified in the Bay of Plenty region. The located on the mainland are identified in blue. Routine water quality monitoring is undertaken at 12 of these water bodies, identified by orange markers.

There are various examples of small water bodies with volcanic origin in the Bay of Plenty. Many of the smaller, subcircular water bodies occupy explosion craters. Examples include Lakes Rotokawau, Rotongata, and Rotoatua, formed by basaltic eruptions about 3500 years ago. Small water bodies occupying former craters are also common (Lowe & Green, 1992). Figure 4 provides an aerial overview of Lakes Rotoatua (7.2 ha) and Lake Rotongata (0.7 ha), located in the Waione Block Reserve. Both lakes have significant cultural, recreational and ecological significance in the region. Both have also been identified as possible open water wetlands by the BOPRC.

Two possible lakes of volcanic origin are also located on the offshore Mayor Island. Lakes Aroarotamahine (9.81 ha) and Te Paritu (3.22 ha) are prominent water bodies with underlying volcanic geology. The visual appearance of these water bodies in aerial imagery suggests they have very different physicochemical characteristics, despite their close proximity on the island.

Figure 4. Lakes Rotongata (0.7 ha) and Rotoatua (7.2 ha) are volcanic water bodies located in the Waione Block Reserve, 16 km north-east of Rotorua.

Figure 5. Lakes Aroarotamahine (9.81 ha) and Te Paritu (3.22 ha) are water bodies of volcanic origin, located on the offshore Mayor Island. Despite their close proximity, it is likely these two lakes have very different characteristics.

Riverine Lakes

Twelve water bodies were classified as likely riverine lakes, ranging in size from 1.1 – 20 ha. All have underlying gravels and are located in close vicinity to the main stems of the Wairoa, Kaituna, Tarawera, Rangitaiki and Whakatane Rivers (Figure 6). None are routinely monitored by the BOPRC.

The water bodies located near the Kaituna and Whakatane Rivers have characteristic oxbow shapes (Figure 7) and have been previously documented as riverine lakes (Lowe & Green, 1992). Most have been identified as possible wetlands by the BOPRC.

Lakes Otumahi and Taikehu, located near foothills north-east of Te Mahoe (Figure 8), have a combination of underlying gravels and volcanic geology. Ground-truthing is recommended to verify the geomorphic types of these lakes.

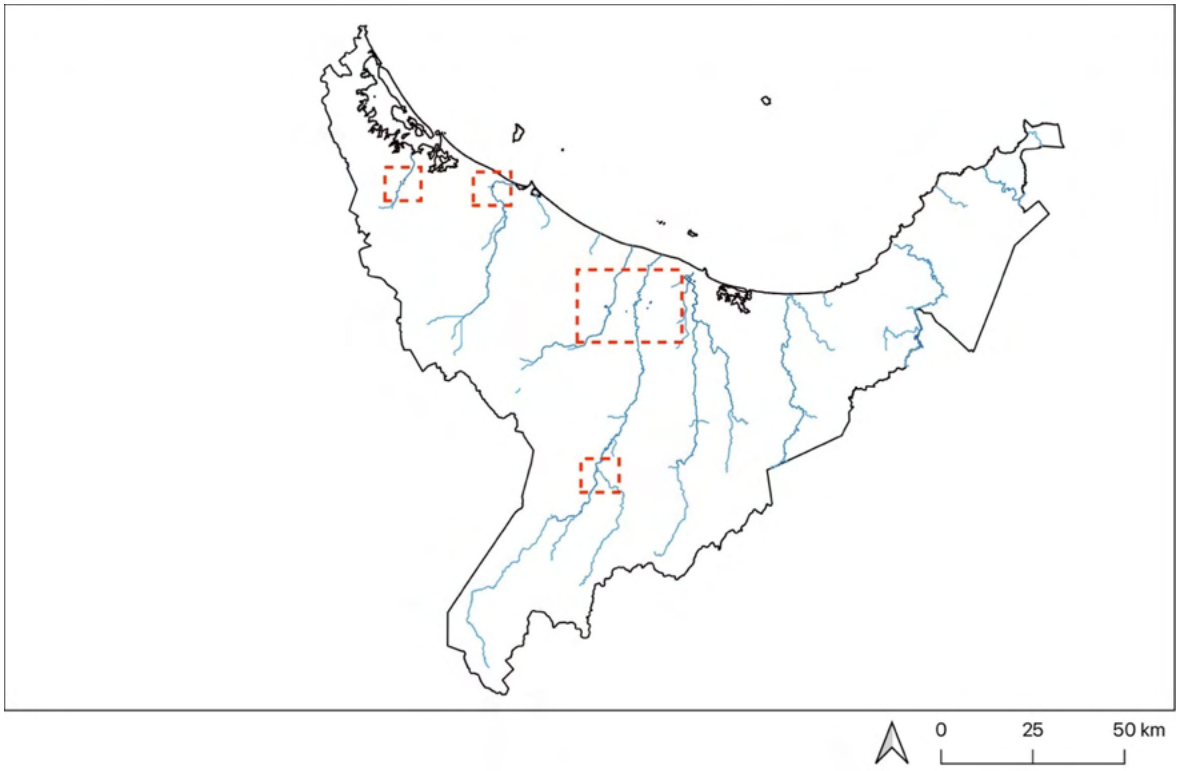

Figure 6. There are 12 possible riverine lakes in the Bay of Plenty Region. Their locations are displayed in blue and highlighted with red boxes in this map. Major rivers in the Bay of Plenty region have been included for reference.

Figure 7. Awatapu Lagoon is an oxbow shaped water body located in the Whakatane township and east of the Whakatane River. It was formed when a section of the Whakatāne River was isolated as part of a flood control scheme by the then Bay of Plenty Catchment Commission in 1970.

Figure 8. Lake Otumahi, and example of a possible riverine lake located 5 km east of Te Teko and the Rangitaiki River.

Shoreline Lakes

Five water bodies were classified as shoreline lakes/lagoons, ranging in size from 9.0 – 18.8 ha. Three of these water bodies, Whakarewa, Te Onewhero and Matahī Lagoons are associated with the shoreline of the larger Lake Rotomā, separated by distinct barrier bars (Figure 9). The degree of hydraulic connectivity between these water bodies is unknown. However, it is likely that these water bodies will have differing conditions compared to their larger neighbour. None are routinely monitored by the BOPRC. Matahī Lagoon has been identified as a possible wetland by the Council.

The remaining two water bodies, Thornton (Figure 10) and Matata Lagoons, are coastal water bodies located at the Rangitaiki and Tarawera River mouths respectively. Evidence doesn't suggest that these lagoons intermittently open to the sea, indicating that they should not be classified as Intermittently Open and Closed Lakes and Lagoons (ICOLLs). However, previous sampling of the Matata Lagoon demonstrates the intrusion of saltwater into the water body. This is unsurprising given the hydraulic connectivity with the Tarawera River and close proximity to the sea.

Figure 9. Whakarewa (11.7 ha) and Te Onewhero (11.1 ha) Lagoons are located on the Eastern shorelines of Lake Rotomā. They have been classified as possible shoreline lakes in this study.

Figure 10. The Thornton Lagoon is an example of a coastal shoreline lake, located at the mouth of the Rangitaiki River, 10 km north-west of Whakatane.

Peat Lakes

One of the 64 lakes, Lake Pouarua, was identified as a possible peat lake due to the dominance of underlying peat substrate. It is located in the southern-corner of the Bay of Plenty, 40.5 km south-east of Taupo. The lake has a surface area of 82.0 ha with wetlands on its western and eastern shores. This lake is located on private property in Lochinvar Station. The BOPRC has classified the entire water body as a possible wetland.

Figure 11. Lake Pouarua is a large water body (82 ha surface area) located in the south of the Bay of Plenty, 40.5 km south-east of Taupo. It has been classified as a peat lake in this study.

3.2.2 Artificial Lakes

Eight of the 64 possible lakes have been classified as shoreline lakes/lagoons, ranging in size from 1.2 – 218.5 ha (Figure 12). Six of the water bodies, Lakes Matahina, Āniwaniwa, McLaren, Mangapapa, Mangaonui and Flaxy Lake are used as storage for hydroelectric power generation. Lake Taurikura is the only water body located in the urban setting of 'The Lakes' subdivision in Tauranga. It also functions as a stormwater drainage reserve. The remaining small water body, impounded by Raymond Dam, is located 8.5 km south-west of Te Puke and is used for the storage of municipal water supplies.

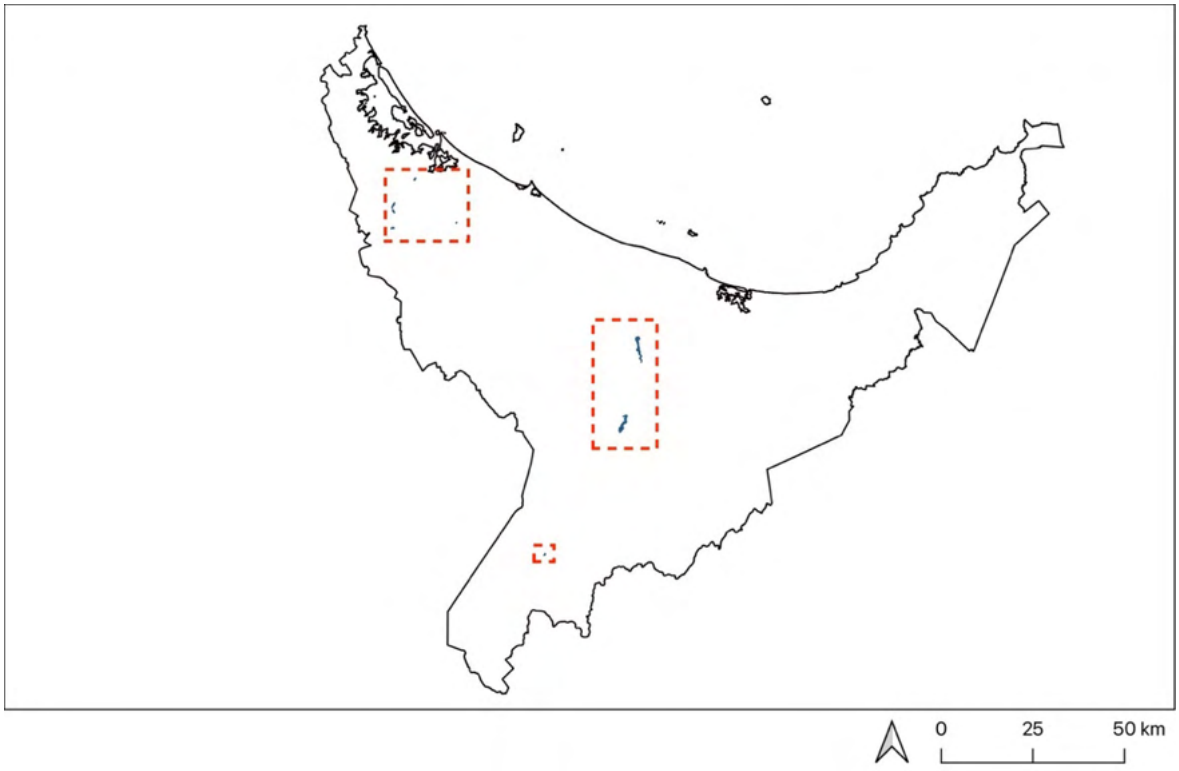

Figure 12. There are 8 artificial water bodies classified as possible lakes in the Bay of Plenty Region. Their locations are displayed in blue and highlighted with red boxes in this map.

Figure 13. Lake Matahina is an example of a large artificial water body (218.5 ha) used for hydroelectric power generation. It is located south of Te Mahoe in the Bay of Plenty region.

Landslide Lakes

One of the 64 possible lakes has been classified as a landslide lake (Figure 14). Lake Mangatutara is extremely remote, 1.15 ha in size and located in the Raukumara Forest Park, 55 km east of Opotiki. It has been classified as a landslide lake on account of predominant landslides in the area, and a lack of geological explanations to classify otherwise. The BOPRC has classified it as a possible wetland.

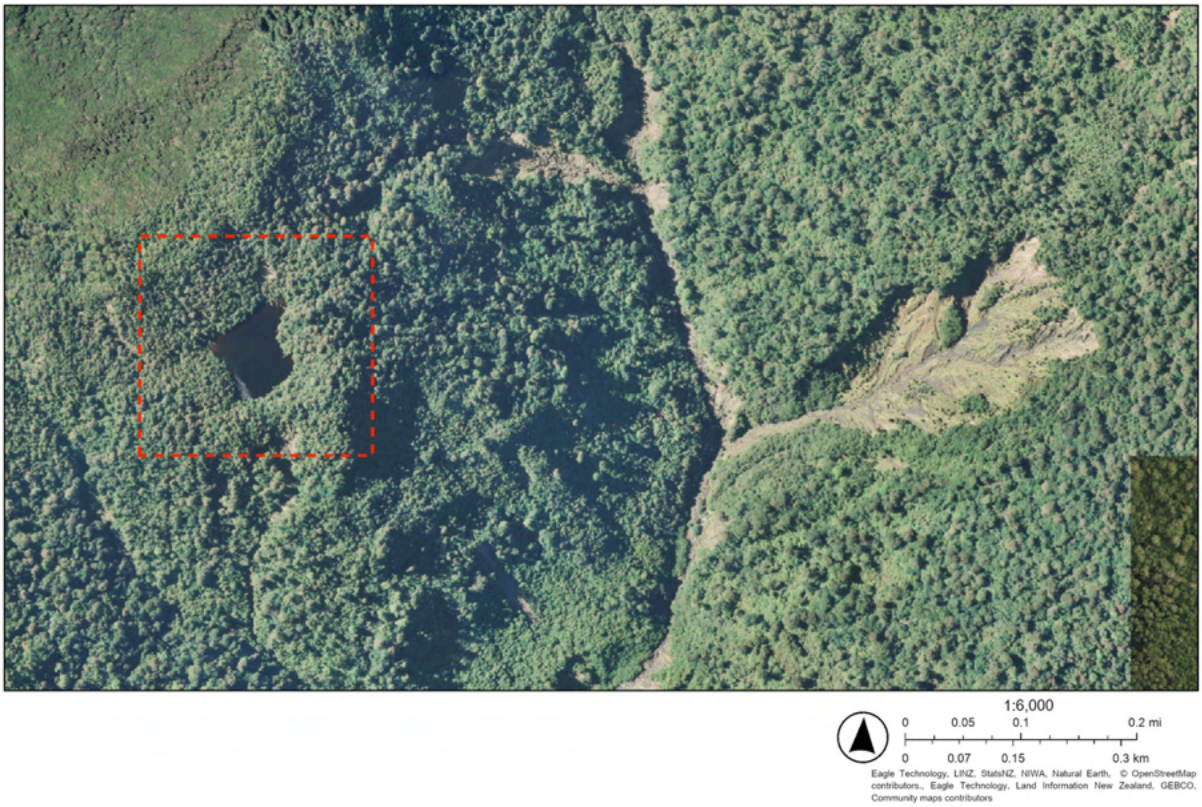

Figure 14. Lake Mangatutara is a remote water body located deep in the Raukumara Forest Park. It has been classified as a possible landslide lake in this study. Its location is highlighted within the red box. Notable landslides are present in the image.

3.2.3 Excluded water bodies

Wetlands

The majority of water bodies excluded from classification as lakes are likely to be wetlands. Most of these water bodies have been previously characterised as possible wetlands by the BOPRC, and may have had the obvious appearance of wetland vegetation or an ephemeral nature in comparisons of aerial imagery. An example is provided in Figure 15 with the Tumurau (Braemar) Lagoon, a 15.8 ha open water body with surrounding wetland vegetation

located 8 km west of Edgecumbe. It is likely that this is a shallow water wetland, characterised by the presence of open standing water less than a few metres deep.

Many of the water bodies classified as possible wetlands in this study are not present in the Bay of Plenty wetlands layer. For example, the remnant oxbow-like water body located in close vicinity of the lower Kaituna wildlife reserve (Figure 16).

Figure 15. The Tumurau (Braemar) Lagoon (15.8 ha) is located 8 km west of Edgecumbe. It has been previously identified by the BOPRC as a wetland environment.

Figure 16. Oxbow-like water body located north-east of the Kaituna wildlife reserve. This water body has been classified as a likely wetland, but has not been identified in the possible Bay of Plenty wetlands spatial layer.

Ponds

Water bodies classified as likely ponds in this study included wastewater or stormwater treatment ponds and reserves, farm storage reservoirs and excavation sites. Figure 17 provides an example of wastewater treatment ponds excluded in this study. More challenging classifications included the 2.7 ha water body shown in Figure 18, a 2.7 ha water body that is part of the Te Ara ō Wairākei stormwater reserve in Papamoa.

Figure 17. An example of wastewater treatment ponds located on the north-eastern shoreline of Rangataua Bay in Tauranga.

Figure 18. An example of a newly developed water body in Papamoa, developed as part of the Te Ara ō Wairākei stormwater reserve.

Geothermal water bodies

Water bodies with obvious geothermal activity were excluded for the purposes of this study. This classification was introduced into this study due to the known differences in geochemical and ecological conditions of geothermal water bodies (Neilson et al., 2010). An example of multiple geothermal water bodies is provided in Figure 19. These are located within the Whakarewarewa geothermal area in Rotorua City.

Figure 19. An example of geothermal ponds located on the Arikikapakapa golf course in Rotorua, a geothermal area located in the greater Whakarewarewa thermal environment in Rotorua.

4 Discussion

4.1 Background and Literature Review

The review of scientific literature has highlighted that there are various criteria in which lakes may be characterised and categorised. This includes measurement of morphological characteristics (e.g. size, shape, depth), mixing patterns, marine connectivity and ecology, as well as determinations of geomorphic origin. Varying use of these characteristics have been used to differentiate lakes from other standing water bodies for both research and policy applications. However, there does not appear to be any consensus on such criteria. Most are based on morphological measurements of surface area and perimeter, likely due to the simplicity and practicality of such measurements.

Richardson et al. (2022) has recently proposed a functional, data-driven approach to differentiating lakes (shallow, small and large) from ponds and wetlands using measurements of surface area, depth and emergent vegetation. This approach is both scientific and logical, presenting the BOPRC with a framework that could be used to differentiate standing water bodies in the region. However, water body depth data required to support these classifications is not sufficient. It must also consider cultural definitions and the inclusion of specific wetland identification criteria which, at time of writing, is still being developed.

4.2 Lake Classification

A desktop based, data-driven approach with visual assessments was used in this study to classify standing water bodies > 1 ha in size in the Bay of Plenty. This approach has determined that there are 64 water bodies that may be classified as lakes. Most are of volcanic origin. However, there is additional diversity with water bodies that are likely to have riverine, artificial, shoreline, peat and landslide origins.

The assessment of spatial data and aerial imagery in this study has determined that there is obvious discrepancies between water bodies classified in the FENZ database and what now exists in the region. Reasons for this include: initial misclassification by FENZ; addition of new water bodies into the region; drainage or shrinkage of waterways, intermittence of surface water (e.g. wetlands); or recent conversion into pastures. These findings are

comparable to a comprehensive stocktake of lake environments recently undertaken by the Horizons Regional Council (Wood et al., 2022).

There are 1097 additional polygons < 1ha in size in the spatial database that may be natural or manmade water bodies. Examining these in detail is beyond the scope of this work. However, it is likely that there are examples that have both ecological and cultural significance. Named examples include the Opal Lake and Lake Rotongata (Figure 4). It may be appropriate to classify these water bodies as lakes or wetlands to ensure they have a degree of protection under new management frameworks. However, this must be reviewed by the Council and any implications determined.

4.3 Management Implications

The BOPRC monitors the condition of 12 of the Rotorua Te Arawa lakes, all of which are volcanic in origin. This study has highlighted that there are additional water bodies with varying geomorphic origins that may credibly be classified as lakes. However, it is important to note that this desktop assessment is provisional. Ground-surveying and the inclusion of expert local knowledge will enhance this assessment, particularly where there is uncertainty in differentiating lakes from other water bodies of regional importance such as wetlands.

Recognising the existence of additional lakes in the region has important implications for their management, as the BOPRC may need to develop a more representative monitoring programme. Each water body will need to be located in a freshwater management unit (FMU), in which the Council must identify monitoring sites, primary contact sites, habitats of threatened species and outstanding water bodies. Prioritising the monitoring lakes should also include the consideration of morphology, geomorphic origins, mixing patterns, ecological conditions and cultural significance.

For the purposes of this report, two conceptual scenarios have been developed, providing the reader with a sense of the different numbers of possible lakes associated with simple morphological classifications of surface area and perimeter in the Bay of Plenty.

Water bodies larger than 1 hectare

This scenario makes use of the 1 ha size limit commonly used in New Zealand to differentiate lakes from other standing water bodies. A total of 64 possible lakes exist. These include:

- 37 volcanic lakes
- 12 riverine lakes

- 8 artificial lakes
- 5 shoreline lakes/lagoons (3 freshwater and 2 coastal)
- 1 peat lake
- 1 landslide lake

Water bodies with perimeter > 1.5 km

This scenario is based on the requirement by the NPS-FM 2020 to monitor 'specified lakes' for the purposes of national targets for primary contact. A total of 33 potential lakes exist. These include:

- 17 volcanic lakes
- 7 artificial lakes
- 5 shoreline lakes (3 freshwater and 2 coastal)
- 3 riverine lakes
- 1 peat lake

Unfortunately, it was not possible to apply the classification criteria proposed by Richardson et al. (2022) and detailed in Section 2.5.3 of this report. This is due to a lack of reliable data relating to water body depth and vegetation characteristics. Quantitative surveying of water bodies in the region will be required if the Council would like to test this framework. This could also complement the councils efforts to identify monitoring sites and wetland environments as part of their obligations under the NPSFM.

5 Recommendations and Conclusion

This study has demonstrated that the collection and integration of spatial datasets has been a valuable tool in the identification and categorisation of water bodies in the Bay of Plenty region. Sixty-four possible lakes with varying shapes, size, character and origin have been identified in this study. However, it is important to note that these classifications are provisional based on an initial desktop analysis, and will be optimised with the inclusion of expert local knowledge, cultural values and definitions, ground-truthing, and the development of specific criteria for identification. The following next steps are recommended:

Expert panel

It is recommended that the geodatabase developed for this study is assessed by an expert panel. The incorporation of knowledge specific to the region may assist with further categorisation of water bodies identified in this study.

Surveying and ground-truthing

Surveying and ground-truthing may be required where there is uncertainty in the categorisation of water bodies identified in this desktop study. The determination of depth (min and max) will be particularly useful for the purposes of this work. Water quality sampling, bathymetric profiling and/or targeted ecological surveys (flora and fauna) will greatly assist with categorisation and the development of new baseline datasets. However, it is acknowledged that there are significant time commitments and costs associated with this work.

Confirm delineation of wetland environments

The delineation of wetlands in the Bay of Plenty is ongoing. There are many examples in the region where a water body may be classified as a lake or wetland. Both will confer a degree of protection under regulations imposed by the NPSFM. However, the monitoring requirements for lakes differ. Such delineation processes should be integrated with ground-truthing conducted for lakes where appropriate.

Consultation with iwi/hapū

The Bay of Plenty has 37 Iwi and more than 200 hapū. Many have management plans in place that outline the cultural values and interests of local tangata whenua. It is important that they are consulted throughout this process, as the inclusion of mātauranga Māori will ensure the categorisation of water bodies is culturally informed and that the co-design of policy is both

robust and enduring. The BOPRC maintains a placeholder for cultural definitions of lakes. This entrusted information will be included when it is available, strengthening the regions policies.

Develop a classification criteria

Ultimately, the development of specific identification criteria will greatly assist the council in identifying lakes where there is uncertainty. Such criteria could be based on a scientific and practical framework such as the approach proposed by Richardson et al. (2022).

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7 Appendix

7.1 Geospatial Database

A spatial database of standing water bodies in the Bay of Plenty region was developed for this study. The database contains 1247 polygons which may represent some form of stranding water body including lakes, wetlands, ponds and reservoirs. It is important to note that there are examples of polygons that are not representative of water bodies. These are likely misclassifications by the Topo50 database.

Each polygon in the database has joined metadata, integrated from spatial datasets described in Section 3.1. Water bodies > 1 ha in size also have notes based on a visual assessment of aerial imagery. Descriptions of the meta-data fields are provided below:

- **fid:** A unique identifier allocated to each feature (polygon) in the database
- **t50-fid:** A unique identifier associated with features from the LINZ Topo50 NZ database
- **name_ascii:** Water body name (if available) in American Standard Code for Information Interchange
- **macronated:** Indicates whether name is macronated of not (Y/N)
- Name: Water body name
- **FENZ_LID:** Lake identifier number (if available) from the FENZ database
- **source:** Data source of polygon
- **source_layer:** Data source layer of polygon
- **FENZ_geomorphic_type:** Original geomorphic type of water body proposed by FENZ
- **FENZ_max_depth:** Modelled maximum depth of water body by FENZ
- **FENZ_lake_volume_m3:** Modelled lake volume by FENZ
- **FENZ_residence_time:** Modelled residence time of water by FENZ
- **NIWA_lake_type:** Lake mixing type as detailed in model developed by NIWA for report 'Water quality state and trends in New Zealand lakes'
- **elevation_m:** Elevation of lake calculated from NZ 8m DEM
- **area_ha:** Calculated area of water body
- **perimeter_m:** Calculated perimeter of water body
- **primary_geology:** Primary underlying geology as modelled by QMap (GNS Science)

- **primary_rockgroup:** Primary rock group as modelled by QMap (GNS Science)
- **permanent_water:** Was water permanent between observations of historic and current aerial imagery?
- **intermittent**: Was water intermittent between observations of historic and current aerial imagery?
- **hydraulic_connectivity:** Is there obvious hydraulic connectivity between surrounding streams and other standing water bodies?
- **structures:** Are manmade structures present (e.g. jetties)?
- **Dammed:** Is the water body obviously dammed?
- **protected_area:** Does the water body occur in areas protected by the Conservation, Reserves or National Parks?
- **protected_area_name:** The name of protected area (if applicable)
- **protected_area_type:** The type of protected area (if applicable)
- **property_titles:** Property titles associated with land (if applicable)
- **property_statutory_actions:** Details about the current statutory actions as recorded against specific parcels
- **forested:** Is the surrounding area of the water body forested?
- **pastoral:** Is the surrounding area of the water body used for pasture?
- **residential:** Is there residential developments in the close vicinity of the lake?
- **coastal:** Is the lake located on the coastline?
- **thermal_features:** Are there obvious geothermal features?
- **proposed_waterbody:** The proposed waterbody, based on visual and data-driven assessment.
- **proposed_geomorphic_type:** The proposed geomorphic type, based on data-driven assessment.
- **BOPRC_wetland:** Does the water body intersect with a possible wetland as mapped by the BOPRC?
- **lake_notes:** Notes recorded about the water body during assessment.

Suggested Use

This layer is intended to be used in conjunction with the Bay of Plenty wetlands layer and high-resolution imagery (aerial or satellite) to support decision-making. The metadata attributes can be filtered and styled in either desktop or online geospatial software such as ArcGIS or QGIS.