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Desktop assessment of selected ecosystem services provided by terrestrial geothermal sites in the Waikato region

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Prepared by:
Wildlands

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

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Peer Reviewed by:
Femi Olubode Date August 2018

Approved for release by:
Ruth Buckingham Date November 2018

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DESKTOP ASSESSMENT OF SELECTED ECOSYSTEM SERVICES PROVIDED BY TERRESTRIAL GEOTHERMAL SITES IN THE WAIKATO REGION

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DESKTOP ASSESSMENT OF SELECTED ECOSYSTEM SERVICES PROVIDED BY TERRESTRIAL GEOTHERMAL SITES IN THE WAIKATO REGION

Contract Report No. 4363a

August 2018

Project Team:
Jo McQueen-Watton - Report author and site assessments
Chris Bycroft - Report author and site assessments
Fiona Wilcox - Site assessments
Keely Palmer - Site research
Sarah Beadel - Peer review

Prepared for:
Waikato Regional Council
Grey Street
Hamilton East

99 SALA STREET, WHAKAREWAREWA, 3010, P.O. BOX 7137, TE NGAE, ROTORUA 3042
Ph 07-343-9017; Fax 07-343-9018, email ecology@wildlands.co.nz, www.wildlands.co.nz

EXECUTIVE SUMMARY

The Waikato Regional Council (WRC) is undertaking an ecosystems services approach to identify, value, quantify and describe the geothermal ecosystem services in the Waikato Region. This project will contribute to the WRC Strategic Direction 2016-2019 "*the full range of ecosystem types, including land, water and coastal and marine ecosystems, is in a healthy and functional state"* and '*economic growth ensures natural capital and ecosystem services are maintained*" and to the Waikato Regional Policy Statement, Objective 3.8 which states that *"a range of ecosystem services associated with natural resources are recognised and maintained or enhanced to enable their ongoing contribution to regional wellbeing*" (Gardiner and Huser 2017).

Wetland and freshwater ecosystem values have been assessed previously by other parties; this project assesses 38 geothermal sites (areas of geothermal surface manifestations with associated vegetation) in the Waikato Region. The 38 sites have been previously and extensively surveyed and described by Wildland Consultants (2014a). Geothermal vegetation and communities have compositional, structural and/or growth rate characteristics determined by current and/or former inputs of geothermally derived energy or material (Merrett and Clarkson 1999). The habitats are rare, both in New Zealand and internationally, and have been assessed as Critically Endangered (Williams *et al.* 2007; McLeod 1995; Holdaway *et al.* 2012). They are also of considerable ecological importance for Threatened and At Risk plant species.

The Waikato Region contains about 74% (or 863 hectares, covering *c.*0.03% of the Region) of New Zealand's geothermal vegetation and habitats, with almost all of the remainder in the Bay of Plenty (Wildland Consultants 2014a).

Ecosystem services are defined as the benefits people obtain from ecosystems (MEA 2005). These include provisioning services such as food, water, timber, and fibre; regulating services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, and spiritual fulfilment; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA 2005). The importance of ecosystem services for human wellbeing is now well established (Gardiner and Huser 2017).

Despite the relatively small areas they cover, geothermal habitats provide a range of services of varying values that are beneficial to humanity. Geothermal areas are appreciated for their historical, amenity, cultural, spiritual, conservation, tourism and scientific values. They are of considerable cultural value to tangata whenua. They benefit the Waikato Region's economy through tourist ventures and hot spring bathing (Barns and Luketina 2011; Luketina *et al.* 2016).

The assessment in this report is based on information gathered during earlier surveys of each of the geothermal sites (Wildland Consultants 2014a and 2014b). The purpose of this report is to gain a better understanding of the ecosystem services provided by geothermal habitats in the Waikato Region. Key results are provided by site. These descriptions provide some preliminary indicators of the values that can potentially be represented and discussed in policy and investment decisions.

All geothermal sites in the Waikato Region have a range of intrinsic ecosystem values most of which are difficult to place monetary values on. All are unique landforms and vegetation associations which are rare both in New Zealand and internationally. Many of the Threatened and At Risk species associated with these sites do not occur elsewhere in New Zealand. A large number of ecosystem services are also difficult to quantify or evaluate. We found that, in spite of the range of geothermal surface manifestations between geothermal sites, provision of ecosystem services was similar amongst larger sites. Sites that are accessible to the public, and in particular those associated with bathing or a tourist operation had many more identifiable cultural services than those located on private land, which are generally inaccessible. Because the study was structured around 'sites', not ecosystems, this finding isn't surprising as larger sites would have been more likely to contain a range of ecosystems. Focusing future studies on ecosystem types and corresponding (key) ecosystem services will allow a more cost-effective and in-depth analysis to be undertaken.

Other recommendations for future work include obtaining monetary values for a greater number of ecosystem services, further assessment of some services that were not able to be fully explored in the timeframes and budget of this project, and a full assessment of cultural values, particularly tangata whenua values.

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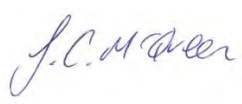


Jo McQueen
Principal Ecologist
Wildland Consultants Ltd

1. INTRODUCTION

1.1 Geothermal vegetation

Geothermal vegetation is defined as "…terrestrial and emergent wetland vegetation… communities that have compositional, structural, and/or growth rate characteristics determined by current and former inputs of geothermally derived energy (heat) or material (solid, fuel or gas)" (Merrett and Clarkson 1999). Geothermal vegetation and habitats are naturally rare in New Zealand (Williams *et al.* 2007) and internationally (McLeod 1995). In New Zealand, four types of geothermal ecosystems (fumaroles, geothermal stream sides, geothermal heated ground, and hydrothermally altered ground (now cool)) have been assessed as Critically Endangered (Holdaway *et al.* 2012). Geothermal wetlands (as defined by Clarkson *et al.* 2004 and Johnson and Gerbeaux 2004) have not been included in these assessments of rare ecosystems (Holdaway *et al.* 2012, Williams *et al.* 2007), but are also of considerable ecological importance for Threatened and At Risk plant species (as per de Lange *et al.* 2013). One nationally uncommon geothermal vegetation type identified in Holdaway *et al.* (2012), hydrothermally altered ground, has particularly poor protection, with less than 20% of its current extent formally protected (Wiser *et al.* 2013).

The varied nature of geothermal surface manifestations, due to varying combinations of temperature, chemistry, hydrology and localised protection from frosts, produces rare and unusual habitats for plants (Burns 1997b, Given 1980 & 1989). These include plants capable of surviving high soil temperatures, populations found a considerable distance from other populations (usually confined to warmer climates) and locally endemic species including distinct forms arising where ground temperatures are sufficiently stable (Given 1989). Many geothermal sites are dynamic and unstable, and changes in surface geothermal activity are reflected in relatively rapid changes in the extent and composition of geothermal vegetation (Beadel *et al.* 2018). Geothermal vegetation includes populations of several plant species which have a national threat classification of Threatened or At Risk as per de Lange *et al.* (2013) cited in Beadel *et al.* (2018).

The Waikato Region contains approximately 74% of the total extent of New Zealand's geothermal vegetation, although this vegetation only covers *c.*0.03% of the regions land area (Wildland Consultants 2014a). Geothermal habitat occurs mostly in relatively small, widely scattered areas in the southeast of the Waikato Region within the Taupō Volcanic Zone (within Rotorua and Taupō Districts), but small areas of geothermal activity occur elsewhere in the region (e.g. hot springs near Kawhia and at Hot Water Beach in the Coromandel). The areas outside the Taupō Volcanic Zone are all small and contain minimal, if any, geothermal vegetation. As such, this report only assesses the geothermal sites within the part of the Taupō Volcanic Zone within the Waikato Region.

1.2 Ecosystem services

The Millennium Ecosystem Framework (MEA) defines ecosystem services as the benefits people obtain from ecosystems (MEA 2005). These include provisioning services such as food, water, timber, and fibre; regulating services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, and spiritual fulfilment; and supporting services

such as soil formation, photosynthesis, and nutrient cycling (MEA 2005). The importance of ecosystem services for human wellbeing is now well established (Gardiner and Huser 2017), and ecosystem services are starting to become integrated into Waikato Regional Council policy. This includes consideration in the Council's Strategic Direction 2016-2019 "*the full range of ecosystem types, including land, water and coastal and marine ecosystems, is in a healthy and functional state"* and '*economic growth ensures natural capital and ecosystem services are maintained*". The Waikato Regional Policy Statement, Objective 3.8 states *"a range of ecosystem services associated with natural resources are recognised and maintained or enhanced to enable their ongoing contribution to regional wellbeing*".

As part of integrating ecosystem services into policy, the council has undertaken a range of ecosystem services projects in the Waikato Region. Freshwater ecosystem services were examined by Scion (Baillie and Yao 2015 & 2018) and wetland ecosystem services were examined by Kessels Ecology (2015). The MEA framework (Olubode-Awosola 2016) was used as the basis for these assessments. The framework and indicators developed in these projects were utilised in the assessment of geothermal habitats.

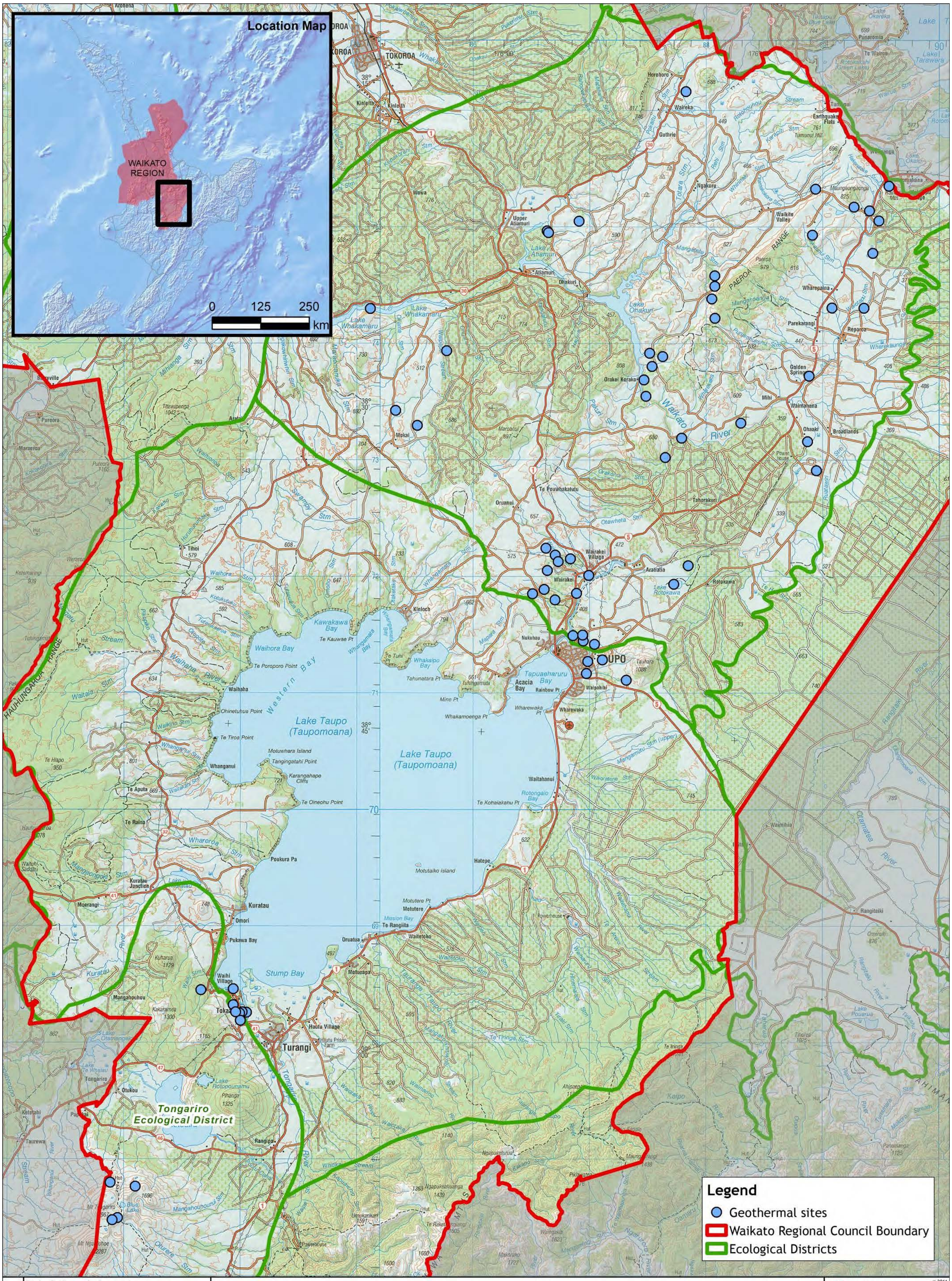
Despite the relatively small area it covers, geothermal habitats provide a range of services of varying values that are beneficial to humanity. Geothermal areas are appreciated for their historical, amenity, cultural, spiritual, conservation, tourism and scientific values. They are of considerable cultural value to tangata whenua. They are also of considerable importance to the Waikato Region's economy (Barns and Luketina 2011 & Luketina *et al.* 2016).

In 2008, geothermal attractions were identified as the third highest (500,000 visitors), and hot pools (382,000 visitors) as the sixth highest, nature-based activities for international tourists to New Zealand. A similar assessment was undertaken on domestic tourism, where hot pools were identified as the third highest nature-based activity (982,000 visitors) and geothermal attractions (69,000 visitors) as the 24th highest activity (Ministry of Tourism 2009).

Many values associated with geothermal habitats have been lost as a result of a decline in the extent and the degradation of, natural vegetation and habitats at many sites (Wildland Consultants 2014a). This has occurred as a result of flooding geothermal sites, drainage and infilling of geothermal wetlands, extraction of the geothermal resource for energy production, spread of weeds (most notably wilding conifers), pest animals, clearance for farmland and urban development, genetic pollution, human-induced fire, degradation of features and vegetation by people (due to poorly managed access), dumping of rubbish, extraction of minerals, construction of roads, and planting of forestry and shelterbelts (Beadel *et al.* 2018). Active ecological restoration of geothermal sites is being undertaken by a range of parties within the region, both on public and private land.

This report presents an assessment of the ecosystem services provided by 38 key geothermal sites in the Waikato Region (Figure 1[1]). The assessment is based on information gathered during earlier surveys of each of the sites (Wildland Consultants 2014a and 2014b). The purpose of the report is to gain a better understanding of the ecosystem services provided by geothermal habitat in the Waikato Region.

[1] Note that previous reports (Wildland Consultants 2014a) refer to 64 sites, which have been merged into 38 sites in this report. The figure shows 64 mapped sites.



Data Acknowledgment

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Report: 2348
Client: WRC
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File: Figure1 Location of geothermal sites.mxd

Figure 1. Location of Geothermal Sites in the Waikato Region

0 7.5 15 km

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Scale:	1:300,000
Date:	07/10/2014
Cartographer:	RPB
Format:	A3

2. ECOSYSTEM SERVICES CONCEPTS AND FRAMEWORK

2.1 Important definitions

Ecosystems comprise the natural capital 'stock' from which a flow of services originates.

Habitat is the area or natural environment in which a population normally lives and is made up of both biotic (e.g. predators) and abiotic factors (e.g. soil).

Geothermal 'sites' are areas of surface expression that have geothermal vegetation present and have been visited and assessed by ecologists. They may contain a range of ecosystems or habitat types within them. Geothermal sites derive their heat and mineralised water and steam from their host geothermal system (see Section 3). There are usually several geothermal sites supported by any particular geothermal system.

Natural capital is the stock of natural assets, including soil, air, water and all living things. It is from the natural capital that humans derive the ecosystem services.

Biodiversity means the variability within and amongst living organisms and the ecological complexes which they are a part of, and can occur at a range of scales of biological organisation (e.g. genes to species) and any geographical scale. Biodiversity forms a part of natural capital.

Wellbeing in a human sense has multiple facets, and can include the basics required for a good life, being freedom, choice, health, social relations and security. Of course, perceptions differ among people, and are situation dependent.

2.2 Ecosystem services framework

Ecosystem services are flows of biophysical features, quantities or qualities that directly or indirectly benefit humanity (Boyd and Banzhaf 2007 cited in Olubode-Awosola 2016). The assessment of ecosystem services relates to the concept that ecosystems provide certain functions (services) and that these functions provide benefits to humans. In this study, the MEA framework (MEA 2005) was applied.

The MEA focuses on the linkages between ecosystems and human well-being and in particular on "ecosystem services" - the benefits people obtain from ecosystems.

The MEA assesses the indirect and direct drivers of change in ecosystems and their services, the current condition of those services, and how changes in ecosystem services have affected human wellbeing. It uses a broad definition of human well-being, examining how ecosystem changes influence income and material needs, health, good social relations, security, and freedom of choice and action.

There is no single way of describing ecosystem services, and Gardiner and Huser (2017) provide a discussion on the various assessments. The MEA assessment was used to be consistent with the studies previously undertaken by Waikato Regional Council on freshwater and wetlands in the region (Scion 2015; Baillie and Yao 2018; Kessels 2015).

Four broad categories of ecosystem services are used in the MEA framework and these are:

1. Provisioning services - the products obtained from the ecosystem e.g. fibre.
2. Regulating services - the benefits obtained from regulation of natural processes such as water purification.
3. Cultural services - the non-material benefits people obtain from ecosystems, e.g. recreation.
4. Supporting services - the services that are necessary for the production of all other ecosystem services, such as soil formation.

The relationship of these services to human well-being is shown in Figure 2 (adapted from Baillie and Yao 2018).

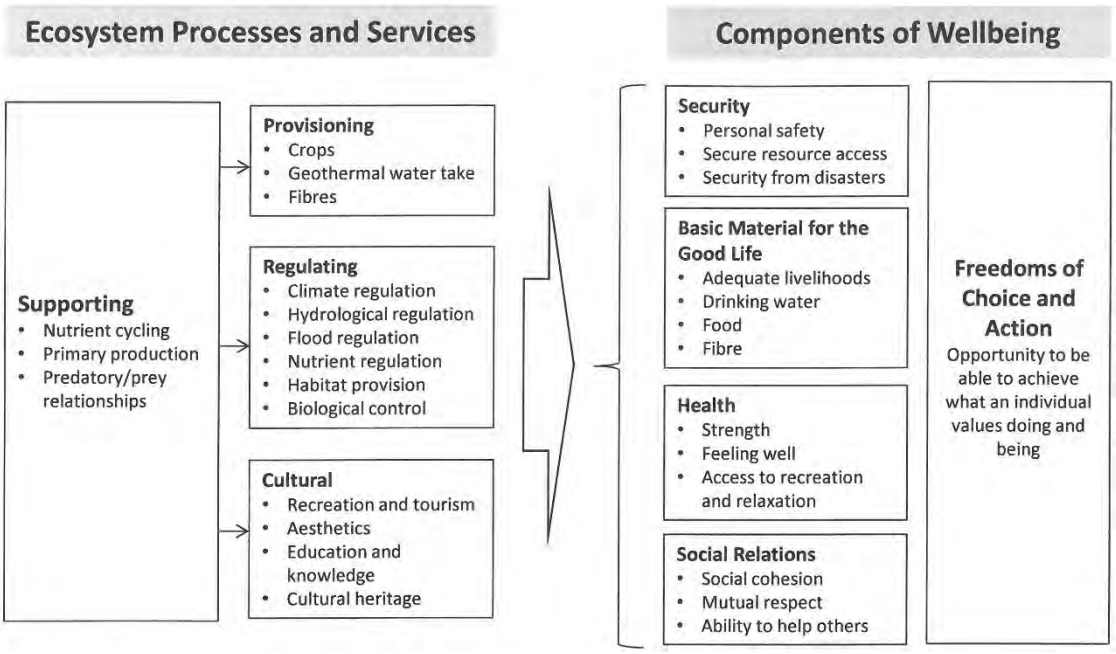

Figure 2: Flow diagram showing the relationship between ecosystem processes and services and human well-being.

The classification of natural capital, and the flow of ecosystem services that they provide, has been identified by Landcare Research (Hart *et al.* 2013) and used by the previous studies (Table 1).

Table 1: High level ecosystem services framework for NZ.

PROVISIONING Products Obtained from Ecosystems	REGULATING Benefits from Regulation of Ecosystem Processes	CULTURAL Non-Material Benefits Obtained from Ecosystems
Biochemical, Natural Medicines, and Pharmaceuticals Food and Fibre Freshwater Genetic Resources Ornamental Resources	Air Quality Maintenance Biological Control Climate Regulation Erosion Control Human Disease Regulation Pollination Storm Protection Water Purification Water Regulation	Aesthetic Values Cultural Heritage Values Cultural Diversity Educational Values Inspiration Knowledge Systems Recreation and Ecotourism Sense of Place Spiritual and Religious Values Social Relations
SUPPORTING **Services Necessary of the Production of all Other Ecosystem Services**		
Nutrient and Water Cycling Primary Production Production of Atmospheric Oxygen	Provisioning of Habitat Soil Formation and Retention	

3. SURVEY SITES

A geothermal system is an individual body of geothermal energy (including geothermal water) not believed to have any other connection in the upper few kilometres of the earth's crust (Luketina 2012). There are 15 known high temperature, and approximately 31 low temperature geothermal systems in the Waikato Region (Luketina 2012). Some of these have surface expressions of geothermal energy that provide habitat for geothermal vegetation, while others do not.

Waikato Regional Council has classified the region's geothermal systems into five categories[1]:

- Development
- Limited Development
- Research
- Protected
- Small

Classification is based on ranking each system's characteristics and aims to balance development with the protection of highly valued surface features. There is a different management approach for each category.

[1] https://www.waikatoregion.govt.nz/environment/natural-resources/geothermal/classifying-geothermal-systems/ (accessed 11 July 2018).

In areas classified for *Development*, large-scale uses are allowed as long as they are undertaken in a sustainable and environmentally responsible manner.

In *Limited Development* systems, geothermal takes that will not damage surface features are allowed.

Research systems are those where not enough about the system is known to classify it as either Development, Limited Development, or Protected. In these systems, only small takes and those undertaken for scientific research into the system are allowed.

Protected systems contain vulnerable geothermal features valued for their cultural and scientific characteristics. Their protected status ensures that their underground geothermal water source cannot be extracted and that the surface features are not damaged by unsuitable land uses.

Small systems are isolated springs or sets of springs. These can only sustain small takes and are not suitable for electricity generation.

Geothermal sites are areas of surface expression that have geothermal vegetation present. These have been most recently reported on in an inventory of geothermal vegetation of the Waikato Region (Wildland Consultants 2014a) and an assessment of management priorities (Wildland Consultants 2014b). A good overview of the ecological values present was obtained during these assessments. In consultation with Waikato Regional Council, Wildland Consultants (2016a) amalgamated 64 geothermal sites into 38 sites (Table 2) to better align sites with geothermal systems, and it is these 38 sites that are used in this report. All but two sites (Hipaua and Ketetahi) have been visited by at least one of the authors since 2007.

To ensure that this study was manageable in size, it assesses the ecosystem services provided by the above ground manifestations that had been previously mapped as natural geothermal sites by Wildland Consultants (2014a). Underground resources, such as extraction to generate electricity, have not been assessed in this study, although above ground ecosystems and their function are affected by underground processes. The underground geothermal energy, minerals and water that feed geothermal surface features are not known to support ecosystems except at or very close to the surface. As mentioned above, a geothermal system generally supports several geothermal ecosystem sites. For example, on the Wairakei-Tauhara system, Table 2 below lists seven sites. Therefore, although the economic value associated with such electricity production and other uses of extracted geothermal fluid are well-quantified (Luketina *et al.*., 2016) such values cannot be logically assigned to an individual site on the system, but are derived from the system as a whole.

The scope of the assessment of geothermal sites did not include assessment of wetland or river and stream values. Some wetlands and lakes (Kessels 2015) and streams and rivers (Scion 2015) have already been assessed for their ecosystem services, and this work is continuing. Therefore, where a site also included a stream, river or wetland, we have made no attempt to fully quantify the services associated with these. Instead, we have focused only on the geothermally unique aspects of the ecosystem, such as bathing in the case of hot streams. It is expected that some merging of the geothermal

services and the services provided by streams, rivers or wetlands could be used to capture the full value of services at a later stage.

Table 2: Amalgamated geothermal sites in the Waikato Region. This table allows cross-referencing of sites between this report and those assessed in Wildland Consultants (2014a). The relevant geothermal system is also listed.

Geothermal Site	Geothermal Site Name from 2014 Geothermal Vegetation Report	Geothermal System
Horohoro	- Horohoro	Horohoro
Waikite Valley	- Waikite Valley	Waikite-Waiotapu-Waimangu
Northern Paeroa Range	- Northern Paeroa Range	Waikite-Waiotapu-Waimangu
Maungaongaonga	- Maungaongaonga	Waikite-Waiotapu-Waimangu
Waiotapu	- Ngapouri - Waiotapu North - Waiotapu South	Waikite-Waiotapu-Waimangu
Maungakakaramea (Rainbow Mountain)	- Maungakakaramea (Rainbow Mountain)	Waikite-Waiotapu-Waimangu
Whakamaru	- Whakamaru	-
Waipapa Stream	- Waipapa Stream	Mokai
Tirohanga Road	- Tirohanga Road	Mokai
Paerata Road	- Paerata Road	Mokai
Whangapoa Springs	- Whangapoa Springs - Upper Atiamuri	Atiamuri
Matapan Road	- Matapan Road	Atiamuri
Te Kopia	- Te Kopia - Western Te Kopia - Mangamingi Station	Te Kopia
Murphy's Springs	- Murphy's Springs	Te Kopia
Waihunuhunu	- Waihunuhunu - Akatarewa East	Orakeikorako
Orakeikorako	- Akatarewa Stream - Orakeikorako - Red Hills	Orakeikorako
Waikato River Springs	- Waikato River Springs	Ngatamariki
Orakonui	- Orakonui	Ngatamariki
Whangairorohea	- Whangairorohea	Whangairorohea
Longview Road	- Longview Road	Reporoa
Wharepapa Road	- Wharepapa Road	Reporoa
Golden Springs	- Golden Springs	Reporoa
Ohaaki	- Ohaaki Steamfield West - Ohaaki Steamfield East	Ohaaki
Otumuheke	- Otumuheke - Spa Thermal Park - Kathleen Springs	Wairakei-Tauhara
East Taupō	- Broadlands Road - Crown Road - Crown Park	Wairakei-Tauhara
Waipahihi Valley	- Waipahihi Valley	Wairakei-Tauhara
Mountain Road	- Mountain Road	Wairakei-Tauhara
Wairakei Valley	- Te Rautehuia - Te Rautehuia Stream - Upper Wairakei Stream (Geyser Valley) - Lower Wairakei Stream	Wairakei-Tauhara
Te Kiri O Hine Kai	- Wairakei Borefield - Te Kiri O Hine Kai Stream Catchment/Wairoa Hill	Wairakei-Tauhara

Geothermal Site	Geothermal Site Name from 2014 Geothermal Vegetation Report	Geothermal System
Karapiti	- Karapiti Forest - Craters of the Moon - Waipouwerawera Stream/Tukairangi - Hall of Fame Stream	Wairakei-Tauhara
Rotokawa	- Lake Rotokawa - Rotokawa North	Rotokawa
Hipaua	- Hipaua	Tokaanu-Waihi-Hipaua
Tokaanu Lakeshore Wetland	- Tokaanu Lakeshore Wetland	Tokaanu-Waihi-Hipaua
Maunganamu	- Maunganamu West - Maunganamu East - Maunganamu North Wetland - Tokaanu Tailrace Canal	Tokaanu-Waihi-Hipaua
Tokaanu	- Tokaanu Thermal Park - Tokaanu Urupa Mud Pools	Tokaanu-Waihi-Hipaua
Te Maari Craters	- Te Maari Craters	Tongariro
Ketetahi	- Ketetahi	Tongariro
Emerald Lakes/Red Crater	- Emerald Lake - Red Crater	Tongariro

4. METHODOLOGY

A one-day WRC-led scoping meeting was held with the other parties involved in regional ecosystem services projects to outline the project scope, and determine the sites to be included in the assessment (see Section 3). This was also an opportunity to learn from the experiences of the freshwater and wetlands teams and to ensure the geothermal work aligned with these.

The Waikato Regional Council (WRC) provided a blueprint template for data collection and ecosystem service assessment. This was a comprehensive list of all potential indicators that may be found in natural ecosystems, and was subsequently used to develop a set of indicators relevant to geothermal ecosystems in the Waikato Region (Appendix 2). These indicators were approved by WRC before further analysis occurred. The resulting template spreadsheet was then used to evaluate the geothermal sites. Separate Microsoft Excel worksheets were completed for each of the 38 sites assessed, and these were provided to Waikato Regional Council alongside this report. Ultimately, the data as reported in the spreadsheets will be added to the database behind the final output of the main project (Freshwater Ecosystem Services) which is a webmap of ecosystem services and their values. Ecosystem services were identified based on existing ecosystem services literature, using both national and international studies.

The evaluation focussed on three groups of ecosystem services: provisioning, regulating and cultural. The fourth ecosystem service (supporting) was not included to avoid double counting and to provide a consistent approach with freshwater and wetland analysis.

Data was entered into the spreadsheets, based on the most recent site survey information collected by Wildland Consultants (2014a, 2014b, and 2015), and the authors' knowledge of the sites. Much of the data was collected for our work on

geothermal indicators (Wildland Consultants 2016a). This included a number of assessments of all sites against factors such as pest plants, pest animals, threatened species, key species, site condition and protection. Other sources of information included internet searches, other scientific literature, and GIS data. These sources are all listed in the spreadsheets. For cultural ecosystem services, we used the Google Scholar search engine to identify any scientific publications relevant to the site, published from 1965 onwards.

Three of the 38 sites were revisited in 2017 to collect further information on ecosystem services. It was concluded, in consultation with WRC, that only minor, opportunistic information was gained by the revisits (such as photographs of man-made structures) and therefore the existing 2014 survey information was sufficient for this study. Therefore, the current analysis can be considered to be a desktop exercise.

Where possible, ecosystem service provisions were quantified and given an economic value. Where the services provided by wetlands or rivers/streams habitats overlap with geothermal ecosystems, we have attempted to use the same measure as Kessels (2015) and Scion (2015) (e.g. the value of mānuka honey is based on the area of mānuka at the site).

All New Zealand species have been ranked to determine their threat classification based on the classification system of Townsend *et al.* 2008. Taxa groups have then been ranked, and these are periodically updated. This report uses the Threat rankings of de Lange *et al.* 2013 for vascular plants and Robertson *et al.* 2013 for birds, being the most current rankings at the time of writing, Wildlands (2014a) from which this information was extracted.

5. SCOPE AND LIMITATIONS

- The analysis was limited by the resources available and several indicators that have not been assessed are likely to have values identified if more analysis was undertaken. For example, flood risk layers could have been assessed as a GIS exercise to determine services provided by flood abatement, but it was outside of the current project budget to do so.

- Where possible, ecosystem service provisions were quantified and given an economic value. However, very few of the services were actually able to be quantified, and it may be that this is a role for economists.

- Assessments of non-geothermal wetlands or stream values were not undertaken as part of this assessment, due to potential overlap with other parties working on these aspects in the region.

- Assessment of the underground geothermal resource was not undertaken, as discussed above.

- For cultural ecosystem services, we used the Google Scholar search engine to identify any scientific publications relevant to the site. This will not have captured all unpublished literature, or some published documents such as research reports published by Crown Research Institutes, or the Waikato Regional

Council's published Technical Reports, available on its website, in hard copy, and via research libraries.

- We recognised numerous cultural values associated particularly with Māori around the use of the geothermal resource. However, it was outside the scope of this study to investigate these more fully. General recreational values associated with hot pool bathing and tourism were the only values to be assessed in this study.

- The economic value of sites to tourism and other economic uses was based on the published work by Luketina *et al.* 2016, but the brief of this project did not include discussion with landowners, concessionaires or land managers on the economic value of specific geothermal sites.

- The desktop assessment provided a 'snapshot' assessment of ecosystem services of geothermal sites in the Waikato Region and has limited scope to incorporate a temporal component in the assessment methodology.

- The extent of the desktop assessment was governed by time and budget availability, and therefore no results are provided for some indicators (see Recommendations). We acknowledge that there are gaps in this assessment and that there may be more appropriate indicators to include.

6. RESULTS

The final template spreadsheet evaluated 90 ecosystem services: 12 provisioning services, 33 regulating services, and 45 cultural services. The ecological values and ecosystem values provided by each of the 38 geothermal sites were summarised, and are provided in Appendix 1. Separate Microsoft Excel workbooks were completed for each of the 38 sites assessed as a desktop exercise and these have been provided to Waikato Regional Council and should be used in conjunction with this report. The authors' knowledge of the sites, gained through many years of site surveys, was heavily relied upon to provide additional site information of value when assessing ecosystem services.

Factors that impact on ecosystem services of a site include pest plants and pest animals, both of which can cause local extinctions while resulting in a homogenisation of sites. Pest animals can also directly impact sensitive geothermal features through trampling. Clearance and development are also major issues for geothermal sites in the Waikato Region.

Indicators were carefully chosen to best reflect the values of geothermal sites and are presented in Appendix 2. For example, an intact site will have a naturally low floral diversity because only a limited suite of species grow in the geothermal environment. The presence of pest plants can increase biodiversity in the short term, but may result in local extinction of indigenous species in the long term. Pest animals also reduce ecosystem service values through herbivory, predation and direct disturbance of geothermal substrates.

The presence of domestic stock was included as a provisioning service. Farming in geothermal areas could benefit stock through warming in winter (a service), but could also have negative consequences for stock (e.g. burns). There are also possible negative effects on the geothermal habitat of trampling, soiling, decomposition of carcases attracting further exotic fauna and altering soil characteristics and veg cover. We were not able to find any information on benefits or otherwise on stock health in geothermal areas, and there may be other drivers and regulatory pressures for fencing to exclude stock.

Habitat type was included as a regulation and maintenance ecosystem service because different habitat types will provide different regulating and maintaining services throughout a site. Eight key habitat types were used in this assessment (noting that these are slightly different to those recognised by WRC). These are:

- Fumaroles
- Geothermal stream sides
- Heated ground
- Hydrothermally altered ground
- Geothermal wetland
- Springs and/or sinter
- Mud pools
- Geothermal water.

The number of phylotypes present in geothermal manifestations at each site was obtained from studies undertaken by Stott (2011). Stott (2011) noted the incredible diversity of microbial communities in the Taupō Volcanic Zone, but also highlighted the inadequacy of molecular technologies available. Therefore, more phylotypes may be present then currently reported. Not all of the 38 sites assessed in this report have been tested for microbial communities.

Since then, that study has been further reported on (Power *et al.* 2018) and almost all of the 38 sites of this present study were reported on, barring the alpine sites on Mts Tongariro. Power *et al.* report the diversity and biogeography of microbial communities found in geothermal springs, collected as part of the 1000 Springs Project. This project aimed to catalogue the microbial biodiversity and physicochemistry of New Zealand geothermal springs to serve as a conservation, scientific, and indigenous cultural knowledge repository. Community analysis was undertaken of the bacterial and archaeal population (16S rRNA gene amplicon sequencing) from 1019 spring samples obtained form 925 hot springs within the TVZ and quantified 46 physicochemical parameters for each sample. From these 925 springs, a total of 28,381 operational taxonomic units (OTUs; 97% similarity) were generated for diversity studies.

Hydrogen sulphide (H_2S) discharge is included as an ecosystem service because it can provide a unique habitat for microbial communities, and the production of sulphur crystals which are visually appealing are often part of tourism ventures. Sulphur mining has also been an important economic activity associated with geothermal sites in the past. H_2S at low concentrations may also provide some benefit to human health, such as reducing the severity and rates of Parkinson's disease (Cakmak 2017).

The presence or absence of human entry restrictions to a site, such as fencing and the requirement for permits or areas of restricted access, was included as a cultural ecosystem service because it implies that the site has a recreation value and restrictions on people's access to it are required, either for their own safety or to protect a sensitive environment. Protection status of a site was included as an indication of a cultural ecosystem service; protected sites have a perceived value that is worth protecting under various laws.

Geodiversity of sites, and the significance of the geothermal features of sites (as defined by Cody 2007) were also included as a cultural ecosystem service because sites with a greater diversity of features, and/or more significant features are visually appealing and are often the basis of tourism ventures. Geodiversity within a site also is likely to provide a wider range of other ecosystem services.

Health benefits associated with geothermal sites, in particular, bathing, were not included as an indicator. Bathing in hot water is frequently used as an alternative medicine, and is a popular form of treatment for arthritis. However, there is no clear evidence that it provides any real health benefits (Kamioka *et al.* 2010). Bathing *per se* is included as a cultural ecosystem service, and bathing for health benefits (perceived or real) can be considered a subset of this. Some facilities charge an entry fee for bathing, which could be used to obtain a value of this service.

Geothermal sites are a hazardous environment to humans, both through harmful gas inhalation, high temperature water and steam burns, and harmful pathogens such as an amoeba which can cause meningitis in rare cases if the bather allows it to enter the nasal cavity by immersing their head. Injuries and even death can result from walking or bathing in these sites. Injuries and death are not an ecosystem service, but the cost of these to society could be considered in an overarching summary of the value of geothermal sites in New Zealand.

7. CONCLUSIONS AND RECOMMENDATIONS

This study identified and summarised qualitative descriptions of ecosystem services of terrestrial geothermal vegetation in the Waikato Region. These descriptions provide some preliminary indicators of the values that can potentially be represented and discussed in policy and investment decisions.

Geothermal vegetation and habitats in Waikato region, while only covering a relatively small area (not much more than 1,000 hectares; Wildland Consultants 2014a) provide a range of ecosystem services that improve human well-being. All geothermal sites in the Waikato Region have a range of intrinsic ecosystem values. All are unique landforms and vegetation associations which are rare both in New Zealand and internationally. Many of the Threatened and At Risk species associated with these sites do not occur elsewhere in New Zealand. However, a large number of ecosystem services are difficult to quantify or evaluate, and most are difficult to place monetary values on. While we have relatively good information on the key vegetation types and significant vascular plant populations at most geothermal sites, information is lacking in other areas such as invertebrate diversity and non-vascular plant diversity, and we only have limited data on microbiological values. Gascon

et al. (2015) highlights the importance of species to ecosystems, but assessing the value of species is difficult and will always remain incomplete; many values accrue unexpectedly or are wholly unanticipated. This highlights the importance of collecting information on taxa that are poorly understood at geothermal sites.

In spite of the range of geothermal surface manifestations between geothermal sites, provision of ecosystem services was similar amongst larger sites. Sites that are accessible to the public, and in particular those associated with bathing or a tourist operation had many more identifiable cultural services than those located on private land which are generally inaccessible. Several sites are very small and inaccessible to the public. While these still provide ecosystem services, it is probably not necessary to complete the full site assessment sheet for these sites in future revisions. Large sites generally contain a number of different ecosystem types, while many of the smaller sites are likely to be similar ecosystem types. Focusing future studies on ecosystem types and corresponding (key) ecosystem services will allow a more cost effective, generic and in-depth analysis to be undertaken. A more in-depth but generic analysis similar to that undertaken by Mark *et al.* (2013) for tussock grasslands may be a more appropriate approach in the future. This would involve an overview of the ecosystem services of key ecosystem types within geothermal ecosystems rather than an assessment of individual geothermal sites.

The key recommendations that we have identified based on this evaluation include:

- Determine if assessment of key ecosystem types within geothermal ecosystems would result in a better analysis of ecosystem services.
- Reconsider the assessment of sites (and possibly ecosystems) under one hectare due to the difficulty of assessing such small sites.
- Consider a more detailed assessment to gather additional quantitative and qualitative data. The desktop exercise is a good starting point for collecting information on ecosystem services on geothermal sites. Some further sources of information were identified during this exercise, but were not obtained due to the time and cost involved. Future work could consider obtaining these data.
- Investigate cultural and spiritual values of geothermal sites. These are likely to be significant, and should be further researched using appropriate methodology.
- Employ economists to assign monetary values to many of the ecosystem services identified in this assessment.
- Investigate the ecosystem services produced over a whole geothermal system given the linkage between below- and above-ground aspects of geothermal sites. This may require an interdisciplinary team to fully capture all the information, and would require further thought on how to define what areas to work on, given the interconnections of the underground system.
- Future projects should consider how streams and wetlands contribute ecosystem services within geothermal sites.

- Consider assessing flood risk layers as a GIS exercise to determine services provided by flood abatement.

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