

Geothermal Vegetation of the Waikato Region - An Update Based on 2007 Aerial Photographs

Prepared by:
Wildland Consultants Ltd

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

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Approved for release by:
Ed Brown

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GEOHERMAL VEGETATION OF THE
WAIKATO REGION - AN UPDATE
BASED ON 2007 AERIAL PHOTOGRAPHS



Geothermal Vegetation of the Waikato Region - An Update Based on 2007 Aerial Photographs

Contract Report No. 2348

Project Team:

Wildland Consultants Ltd

Chris Bycroft - Report preparation, field work.
Sarah Beadel - Peer review, report preparation.
Lisette Collins - Report preparation, field work.
Mieke Kapa - Report preparation, field work.
Jo McQueen-Watton - Report preparation.
Fiona Wilcox - Report preparation.
Roger Bawden and Marle Rossouw - GIS.

Geophysical Assessments

Manfred Hochstein (2007 assessments; University of Auckland)
Juliet Newson (2010 assessments; Independent Consultant, Mt Albert, Auckland)
Julian McDowall (2010 assessments; Independent Consultant, Herne Bay, Auckland)

Prepared for:

Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
Hamilton 3240

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SUMMARY

This study was undertaken for Waikato Regional Council and provides an updated inventory of the current distribution and extent of geothermal vegetation, and assessment of the relative significance of each site based on 2007 aerial photographs and field survey of selected sites during 2010 and 2011. Approximately 70% of the extent of New Zealand's geothermal vegetation occurs within the Waikato Region. Associated with geothermal sites are characteristic plant species and vegetation types. These include plants capable of surviving high soil temperatures, disjunct populations found a considerable distance from other plants of the same species which are usually confined to warmer climates, and local endemic species and distinct genetic forms arising where ground temperatures are sufficiently stable. Many geothermal sites are dynamic and unstable and changes in surface geothermal activity are reflected in changes in the extent and composition of geothermal vegetation. The geothermal vegetation of the Waikato Region includes populations of several plant species which in New Zealand have a national threat ranking.

For this survey, *c.*734 ha of geothermal vegetation (including nonvegetated raw-soilfield) over 64 sites in fifteen geothermal fields was described, mapped, and ranked from field surveys and existing information. An additional *c.*106 ha was mapped as geothermal water where it was an integral part of a geothermal site. The grouping of individual areas of geothermal habitats as sites can be somewhat arbitrary, however groupings are generally based on areas of geothermal surface manifestations that are located nearby each other, and are easy to discuss together as a single unit. There are likely to be some small areas of unmapped geothermal vegetation on hill slopes above Tokaanu that have not been mapped in this report. Geothermal vegetation and habitats were mapped into three broad categories, nonvegetated raw-soilfield (*c.*92 ha in the Waikato Region), emergent wetland (*c.*81 ha in the Waikato Region) and terrestrial vegetation (*c.*561 ha in the Waikato Region). Terrestrial vegetation is all vegetation that was not mapped as geothermal wetland, and nonvegetated raw-soilfield and includes (but is not limited to) forest, scrub, shrubland, fernland and mossfield. For 19 sites, a geophysical assessment was carried out.

The vegetation of each site has been described and classified using predefined vegetation structural classes and a protocol for assigning type names based on the dominant plant species. Site condition, current threats, modifications and vulnerability were assessed, and management requirements outlined. Each site was assessed for significance and then assigned a relative significance level of International, National, Regional, or Local. Significance and relative significance were assessed using the criteria in the Waikato Regional Policy Statement (applying the guidelines delineated in 2002 updated in accordance with the revised threat classification lists). Vegetation type boundaries have been digitised and the extent calculated of each geothermal vegetation type. Topographical location maps of each site are provided and vegetation maps of each site are presented in this report.

Each of the 64 sites meets one or more of the criteria for ecological significance in the Waikato Regional Policy Statement and each site was ranked as being of International, National, Regional or Local Significance. Four sites were ranked as being of International Significance and part of one of other site (with other parts of this site being ranked as Regional and Local Significance), encompassing *c.*205 ha or 24% percent of the geothermal vegetation in the Waikato Region. Eight sites were of National Significance, with two sites

being partly of National Significance and partly of Local Significance encompassing *c.*382 ha or 46% of geothermal habitat in the Waikato Region. Twenty-three sites were identified as being of Regional significance, with an additional two sites being partly of Regional and Local significance. In total, *c.*242 ha or 29% of geothermal habitat in the Waikato Region was identified as being Regionally Significant. The remainder of sites (25) were identified as being of Local Significance (*c.*11 ha or *c.*1% of geothermal habitat).

Wildland Consultants (2004) used Ecological Districts as the framework of the study. While ecological districts are used to show the distribution of geothermal sites in the landscape, greater emphasis is placed on recognised Geothermal Fields in this report. Geothermal Fields are more likely to show differences in character between geothermal sites than ecological districts as sites within the same geothermal field are thought to be sourced from the same geothermal reservoir, which is the source of water in geothermal surface manifestations. The character of 17 Geothermal Fields are described in this report, with geothermal vegetation mapped and described for sites. The following areas of geothermal vegetation were mapped in each geothermal field by size: Waiotapu (*c.*221 ha), Wairakei-Tauhara (*c.*151 ha), Rotokawa (*c.*104 ha), Tokaanu-Waihi-Hipaua (*c.*60 ha), Te Kopia (*c.*60 ha), Orakeikorako (*c.*58 ha), Tongariro (*c.*25 ha), Waikite (*c.*25 ha), Ohaaki (*c.*19 ha), Reporoa (*c.*7 ha), Mokai (*c.*3 ha), Ngatamariki (*c.*2 ha), Atiamuri (*c.*0.1 ha); two fields have less than 0.1 ha of geothermal vegetation (Horohoro and Whangairorohea), and two fields have no known geothermal vegetation (Mangakino and Horomatangi).

The majority of geothermal vegetation in the Waikato Region occurs in Atiamuri Ecological District (*c.*86%), while Taupo and Tongariro Ecological Districts contain *c.*9% and *c.*5% of the vegetation of the region respectively. Geothermal vegetation in the Waikato Region is distributed relatively evenly between two local authorities; Rotorua District (51%) and Taupo District (*c.*49%).

Historical site changes were assessed using a combination of historical photos and existing literature. The extent of geothermal vegetation was found to have decreased in 23 sites between the 1940s or 1960s and the present day. In six sites, the extent of geothermal vegetation has increased compared to what was historically present. There has been no discernible change to the extent in vegetation cover at eight sites. No information was able to be found for the remainder of the sites.

In the Atiamuri Ecological District there has been a significant decline, estimated to be approximately 30%, in the extent of geothermal vegetation since European settlement. However there has been an estimated gain of approximately 4% in the Taupo Ecological District. The overall decline in geothermal vegetation is the result of a number of factors. These include energy and hot water draw-off from the geothermal fields, damming of the Waikato River to form Lake Ohakuri, clearance and burning of vegetation, weed invasion, livestock grazing, modification of groundwater tables, dumping of rubbish, and other activities associated with forestry, farming, tourism, and recreation. The ecological sustainability of geothermal vegetation in the Waikato Region is under ongoing threat from plant and animal pests and from the activities of humans, especially on private land. Monitoring, protection, and restoration, wherever possible, are essential to halt the decline of these fragile and unique ecosystems.

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Reviewed and approved for release by:



Sarah Beadel
Director
Wildland Consultants Ltd

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1. INTRODUCTION

This study was undertaken for Waikato Regional Council and provides an inventory of the current distribution and extent of geothermal vegetation in the Region, and assessment of the relative significance of each site. This information will enable management of the varied characteristics of the geothermal resource, as required by the Waikato Regional Policy Statement. This report collates information from a number of previous reports undertaken by Wildland Consultants for Waikato Regional Council between 2004 and 2007, as well as updated information based on site inspections of selected sites, improved knowledge about sites from other studies, and inspection of better quality aerial photographs (2007 WRAPS¹) than were present during the 2004 study (which was based on 2002 aerial photographs).

The Waikato Region is located in the upper part of central North Island. It extends from Coromandel-Colville in the north to Mt Ruapehu in the south; as far west as Mokau, and east to include part of Kaingaroa Forest (refer to Figure 1). The Waikato Region comprises part or all of 34 ecological districts, three of which, Atiamuri Ecological District, Taupo Ecological District and Tongariro Ecological District, contain all areas of geothermal vegetation larger than 1 hectare. While small isolated surface geothermal expressions occur elsewhere in the Waikato, in general they are very small (usually small surface springs) and are not known to contain any geothermal vegetation of ecological significance. Many of these have been converted into hot pools, while others are hot springs amongst sand on the ocean edge that do not support any vegetation.

Wildland Consultants (2004) used ecological districts as the framework for the study. While ecological districts are used to show the distribution of geothermal sites in the landscape, greater emphasis is placed on recognised geothermal fields in the updated project. Geothermal fields are more likely to show differences in character between geothermal sites than ecological districts as sites within the same geothermal field are thought to be sourced from the same geothermal reservoir, which is the source of water in geothermal surface manifestations. Assessments based on ecological districts become an issue where the same geothermal field extends across two ecological districts, as occurs at Tokaanu-Waihi-Hipaua geothermal field (Tongariro and Taupo Ecological Districts) and Wairakei-Tauhara Geothermal Field (Atiamuri and Taupo Ecological Districts).

Almost 80% of New Zealand's geothermal systems occur within the Waikato Region (Environment Waikato 1998). Associated issues and values range from exploitative resource use, such as thermal energy extraction and the utilisation of mineralised fluids, to historical, amenity, cultural, spiritual, conservation and scientific values (Environment Waikato 1998; Merrett & Clarkson 1999) and the environmental management objectives of Waikato Regional Council are derived from these. The objectives are to maintain the variety of characteristics and to achieve protection and efficient take of the regional geothermal resource (Environment Waikato 1998). Pest plants and pest animals are degrading ecological values at many sites and if these are not controlled then the ecological values of these sites are likely to decline. Tourism operations at geothermal sites are also of significant economic importance to the

¹ WRAPS = Waikato Region Aerial Photograph Syndicate.

region. Other economic uses, such as power generation, may have negative impacts on ecological and geophysical characteristics of geothermal sites, and aspects of tourism operations at sites also require monitoring to ensure sites are not degraded.

Geothermal areas are often characterised by unusual assemblages of plants, such as disjuncts which are normally found in climates warmer than that of the surrounding region, plants capable of surviving high soil temperatures or hydrothermally altered soils (Given 1980) and local genetic forms arising where ground temperatures are sufficiently stable.

This report updates the 2004 report (Wildland Consultants 2004), and incorporates extra information about geothermal sites collected in 2006 and 2007 (Wildland Consultants 2006, 2007a&b). Selected sites were revisited in 2010 and 2011 for this report. Vegetation maps and descriptions have been updated using new vegetation descriptions and codes, including the addition of broad vegetation classes. New codes for sites have been used to replace the codes based on the New Zealand Topographical map series NZMS260, which is no longer in use. New site codes relate to the geothermal field each site is located in. Threatened species rankings have been updated using de Lange *et al.* (2009) for plants and Miskelly *et al.* (2008) for birds. Additional information has been included from the 2004 report, including information on site changes (generally either since the last field survey, or within the last ten years, if known); historical site changes; and incorporation of more fauna information where available. Historical site change assessments were determined through examination of aerial photographs held by Waikato Regional Council from between 1941-1961 and compared with recent (2007) aerial photographs to determine the extent of change of geothermal sites over this timeframe. A summary of changes that could be clearly identified are presented for each site.

The ecological significance of each site was reassessed as either being of international, national, regional, or local significance as determined by the updated criteria defined in the Waikato Regional Policy Statement (2002). This has been revised to reflect more recent changes to the New Zealand Threat Classification Lists (refer to Appendices 10 and 11). Ecosystem Ranking assessments were completed for all sites with a relative significance of Regional, National, or International Significance (see Wildland Consultants 2011a).

The objectives of this project were to identify, map and classify known areas of geothermally-influenced terrestrial and emergent wetland vegetation in the Waikato Region. Relevant existing information was collated, and field investigations have been carried out for all sites (see Appendix One) between 2003 and 2011. The exceptions are Hipaua and Ketetahi Springs, Maunganamu North, and parts of Tokaanu Lakeshore Wetland for which permission to undertake field survey was withheld. Of the 64 sites reported on in detail in this report, 31 sites were re-surveyed in 2010/2011, including 13 sites which previously had not been surveyed in detail. Each site has been remapped using 2007 aerial photography and all boundaries have been checked at high resolution. Any parts of sites that were unsafe to access due to the geothermal hazards were assessed based on aerial photographs and information collected elsewhere at the site. Threats, modifications, vulnerabilities, and the relative significance of each site have been assessed in a regional context.

This report includes an index of the geothermal sites, and the appendices include information on sites for which field work was undertaken, unranked sites, vegetation codes, a glossary of technical terms including threatened and uncommon plant categories, and notes on the vascular flora of geothermal areas.

A list of sites of geothermal surface expressions not known to comprise any significant geothermal vegetation, found elsewhere in the Waikato Region are presented in Appendix 3. These sites are all generally small and many have been altered for recreational use, such as swimming, or have been altered for farming or commercial uses. Several are also on the sea margin in sand and contain no vegetation.

Project Assignment

Waikato Regional Council commissioned Wildland Consultants to update the 2004 Wildland Consultants (Report No. 896) on geothermal vegetation of the Waikato Region to the 2007 aerial photographs (WRAPs). This report incorporates information from a series of other reports undertaken for Waikato Regional Council between 2004 and 2007 (Wildland Consultants 2006, 2007a and 2007b). Information collected is compatible with the Waikato Regional Council biodiversity prioritisation project.

2. PREVIOUS WORK

The botany of many of the geothermal areas of the central North Island has been surveyed, documented and assessed in numerous reports (see Bibliography). Rankings of the relative scientific or conservation significance of some sites containing geothermal vegetation and flora have been assigned in Given 1978 & 1980a, Clarkson 1987a, and various other reports. Given (1989a & 1996) assessed the relative botanical significance of geothermal sites in the Central Volcanic Plateau Ecological Region within the Waikato Region.

Merrett and Clarkson (1999) compiled an annotated bibliography of reports relevant to geothermal vegetation occurring within the boundaries of the Waikato Region. Beadel and Bill (2000) and Wildland Consultants (2004) provide important resources on which future reports have been based.

This report is an updated and expanded report of Wildland Consultants (2004), including additional sites updated and described in Wildland Consultants 2006, 2007a and 2007b. Selected sites have been resurveyed and 13 sites not previously included in this study have been included. Some site names have been changed on occasion to better reflect Waikato Regional Council preferred place names (where a site name has been changed, the site report has been annotated appropriately). Site numbers have also been changed, as outlined above, and are now based on geothermal field. 2004 site numbers are included in footnotes to allow cross referencing. The relative ecological significance of all sites has been re-evaluated.

3. METHODOLOGY

3.1 Existing information

Existing information on the distribution and botany of geothermal areas in the Waikato Region was compiled from published and unpublished sources (see Bibliography). Geothermal sites containing, or likely to contain, geothermal vegetation were identified from Cave *et al.* (1993), Mongillo and Clelland (1984), Leathwick *et al.* 1995, Given 1989a & 1995, Spring-Rice unpublished, Department of Conservation 1997, and personal knowledge. Department of Conservation staff provided some additional information on geothermal sites for this 2011 study.

For each geothermal site, existing information was compiled for the following categories; grid references, site names, local authority, ecological district, geothermal field (from Merrett and Clarkson 1999), bioclimatic zone (from Leathwick *et al.* 1995), tenure, altitude, notable indigenous flora, fauna, threats/modification/vulnerability, management requirements, significance/justification, and previous botanical rank (from Given 1996), and Wildland Consultants 2004, 2006, and 2007a&b.

3.2 Ecological districts

Three ecological districts in the Waikato Region contain sites with geothermal vegetation. These are Atiamuri Ecological District, Taupo Ecological District (both of which occur within the Central Volcanic Plateau Ecological Region) and Tongariro Ecological District (within the Tongariro Ecological Region).¹ A tiny portion of Maungakakamea occurs in the Rotorua Lakes Ecological District (<1 ha) and also in the Bay of Plenty Region.

3.3 Field survey

Field survey of 37 sites was carried out between June 2010 and June 2011 using a survey team of two people for safety reasons. Sites were visited where there was the greatest expectation of change (e.g. new road construction in the vicinity of the site), if there were major changes indicated on 2007 aerial photographs, or if the site had not been inspected before. It should be noted that change may have occurred at some sites such as Lake Rotokawa and Rotokawa North, but field survey was beyond the resources allocated to this study. Some sites were not field surveyed as access from landowners could not be arranged, e.g. some Tokaanu field survey sites.

Geothermal vegetation types were described for each site, and the extent of each type was mapped onto colour printouts of digital aerial photographs (2007) (scale c.1:5,000). Field assessments addressed the following components: the extent and

¹ Leathwick *et al.* (1995) placed 2 ha of geothermal vegetation in the Waikato Region in the Rotorua Lakes Ecological District. However following refinement of the Rotorua Lakes Ecological District boundary as part of the Rotorua Lakes Ecological District PNAP survey (Beadel *et al.* 1998), only a very small area of geothermal vegetation now lies within the Rotorua Lakes Ecological District in the Waikato Region.

type of vegetation present; indigenous flora (including the presence of any threatened plants); fauna present (which included a literature review for each site); current condition; invasive exotic plants; human impacts; grazing; adjoining land use and management requirements.

The year of field survey for each site is provided in Appendix 2. Known geothermal sites that were not field surveyed are listed in Appendix 3.

3.4 Geophysical properties

Geophysical assessments have been undertaken for all or parts of 19 sites (listed in Table 1). Specific methods for these assessments varied slightly between the geophysical consultants, but generally the following methods were used. Locations for each feature were recorded using a GPS. Direct temperature measurements were made with a thermocouple on a 4.4 m long wire, or a 100 mm long rigid probe, connected to a Fluke multimeter. If the surface to be measured was not accessible, a Fluke IR thermometer was used, however this is subject to limitations, particularly if steam is present. The pH was measured with a Hanna Instruments pH meter with a maximum operating temperature of 50°C; if the spring temperature was > 50°C the water was cooled to less than 50°C before the pH measurement was taken or a pH paper strip was used. Further details are provided on each site sheet.

Table 1: Sites and dates for which geophysical assessments were carried out. The assessments are included in the site reports contained in Appendix 1.

Site Number	Site Name	Date of Assessment
WAV02	Northern Paeora Range	29 & 30 June 2010
WTV03	Waiotapu North	26 & 29 July 2010
WTV05	Waiotapu South	27, 29 & 31 July 2010 (about 1/3 of site)
WTV04	Maungakakamea (Rainbow Mountain)	26 July 2010 (about 1/2 of site)
MKV03	Tirohanga Road	5 February 2007
ATV01	Upper Atiamuri West	5 February 2007
ATV02	Whangapoa Springs	5 February 2007
TKV04	Te Kopia West Mud Pools	29 June 2010
TKV05	Te Kopia Red Stream	29 June 2010
TKV03	Te Kopia Northwest	29 June 2010
TKV02	Murphy's Springs	29 June 2010
TKV06	Mangamingi Station	28 June 2010
OKV03	Orakeikorako	1 August 2010 (about 1/2 of site)
RPV02	Wharepapa Road	30 July 2010
TOV10	Maunganamu East	7 February 2007
TOV07	Maunganamu West	13 February 2007
TOV14	Tokaanu Tailrace Canal	7 February 2007
TOV08	Tokaanu Thermal Park	7 February 2007 (about 1/2 of site)
TOV09	Tokaanu Urupa Mud Pools	7 February 2007

3.5 Vegetation and habitat types

The previous editions of this report (e.g. Wildland Consultants 2004, 2007a&b) based vegetation assessments on Merrett and Clarkson (1999), with some additional types added. This study bases its classification of geothermal vegetation and habitat types on methods used in a similar study undertaken in the Bay of Plenty Region, specifically Wildland Consultants (2005a&b). This was based on methodology outlined in Wildland Consultants (2003) and Atkinson (1985). This report follows broad types outlined in Wildland Consultants 2007b, as well as additional broad types and structural types found during field survey for this report. These are listed below in Table 2, by structural class and broad type.

Table 2: List of geothermal vegetation types and habitats. (Note this table includes vegetation types identified in Wildland Consultants (2004) and a study of geothermal vegetation in the Bay of Plenty Region (Wildland Consultants 2005), not all of which occur in the Waikato Region.

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
01	01	Pohutukawa-dominant forest 01 Pohutukawa × northern rata-kamahi forest 02 Pohutukawa × northern rata/mingimingi-prostrate kanuka forest 03 Pohutukawa forest 04 Pohutukawa-kanuka forest 05 Pohutukawa × northern rata/prostrate kanuka-mingimingi forest
01	02	Wattle forest 01 Black wattle forest
01	03	Treefern-dominant forest
01	04	Kanuka-dominant forest 01 Kanuka/mingimingi forest 02 (Eucalyptus)/kanuka-Tasmanian blackwood/mingimingi forest 03 Kanuka forest 04 Kanuka-kohuhu/koromiko-blackberry forest 05 Kanuka-radiata pine/manuka-mingimingi forest 06 (Rewarewa)/kanuka forest. 07 Eucalyptus/kanuka forest 08 Kanuka-pohutukawa forest 09 Kanuka-grey willow-crack willow-arrow bamboo/broom-blackberry forest 10 Kanuka-rewarewa forest 11 Kanuka forest⇒kanuka shrubland
01	05	Exotic pines forest 01 Radiata pine/kanuka/mingimingi forest 02 Macrocarpa/prostrate kanuka forest 03 Maritime pine -false acacia forest 04 Radiata pine/mingimingi forest 05 Radiata pine forest 06 Maritime pine-radiata pine/manuka-mingimingi forest
01	06	Willow-dominant forest 01 Grey willow/ <i>Schoenoplectus tabernaemontani</i> -raupo-swamp kiokio forest 02 Grey willow/wheki forest 03 Grey willow forest
01	07	Kamahi-dominant forest 01 Kamahi-pohutukawa/manuka forest 02 Kamahi-kanuka-manuka forest
01	08	Kahikatea-dominant forest 01 Kahikatea forest
01	09	Plantation-mixed indigenous forest 01 Tasmanian blackwood-manuka-kanuka-whauwhaupaku-kamahi-ti kouka/blackberry-rank exotic grasses forest

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats		
02	01	Wattle treeland 01 Silver wattle treeland		
	02	Radiata pine-dominant treeland		
	03	Pohutukawa-dominant treeland 01 Pohutukawa/exotic grasses treeland		
	04	Tree fern-dominant treeland		
	05	Mixed exotic treeland 01 Eucalyptus/mingimingi-manuka/mown lawn-nonvegetated raw-soilfield treeland 02 (Alder)-(bamboo)/manuka- <i>Histiopteris incisa</i> treeland		
	06	Silver birch-dominant treeland 01 Silver birch/narrow-leaved carpet grass treeland		
	07	Eucalyptus treeland 01 Eucalyptus/nonvegetated raw-soilfield treeland		
	08	Grey willow/mixed sedge treeland 01 Grey willow/ <i>Baumea juncea</i> -harakeke- <i>Coprosma propinqua</i> treeland ↔ manuka-harakeke shrubland		
03	01	Japanese honeysuckle-dominant vineland 01 Japanese honeysuckle- <i>Paesia scaberula</i> vineland		
	02	Grape vine -dominant vineland 01 Grape vineland		
	03	Mixed exotic vineland 01 Pohue-Japanese honeysuckle-blackberry vineland		
04	01	Prostrate kanuka-dominant scrub 01 Prostrate kanuka scrub 02 Prostrate kanuka-mingimingi scrub 03 Prostrate kanuka-mingimingi-manuka scrub 04 (Pohutukawa)/prostrate kanuka scrub 05 Prostrate kanuka-manuka-mingimingi scrub 06 (Dead pohutukawa x northern rata)/prostrate kanuka-mingimingi scrub 07 Tasmanian blackwood/prostrate kanuka scrub 08 Exotic pine/prostrate kanuka scrub 09 Manuka/prostrate kanuka scrub 10 Prostrate kanuka-manuka-Chinese privet scrub 11 Maritime pine/prostrate kanuka-blackberry scrub		
		02	Mingimingi-dominant scrub 01 Mingimingi-manuka scrub 02 Mingimingi-manuka-kanuka scrub 03 Mingimingi-prostrate kanuka-manuka scrub ↔ <i>Histiopteris incisa</i> fernland ↔ <i>Hypolepis distans</i> fernland ↔ gorse scrub. 04 Mingimingi-kanuka scrub 05 Mingimingi-kanuka-prostrate kanuka scrub 06 Mingimingi-bracken-manuka scrub 07 Dead pohutukawa x northern rata/manuka-mingimingi scrub 08 (Dead pohutukawa x northern rata)-(wheki)/mingimingi- <i>Histiopteris incisa</i> - <i>Gahnia setifolia</i> -gorse scrub 09 Black wattle/mingimingi-manuka scrub 10 Mingimingi- <i>Histiopteris incisa</i> shrubland 11 Mingimingi scrub ↔ manuka scrub 12 Mingimingi scrub 13 Exotic pine/mingimingi scrub 14 (Radiata pine)/mingimingi-prostrate kanuka scrub 15 Mingimingi-kanuka-manuka-karamu/bracken scrub 16 Mingimingi-manuka-prostrate kanuka scrub 12 Tasmanian blackwood/mingimingi scrub 13 Mingimingi-manuka-blackberry-indigenous broadleaved species scrub 14 Mingimingi-blackberry-manuka-prostrate kanuka scrub	
			03	Manuka-dominant scrub 01 Manuka scrub 02 Manuka-mingimingi scrub 03 Eucalyptus/manuka-mingimingi scrub 04 Manuka-kanuka/mingimingi scrub

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
		05 (Grey willow)-(ti kouka)/manuka scrub 06 Black wattle/manuka scrub 07 Grey willow/manuka scrub 08 Manuka mingimingi-broom scrub 09 Manuka-Spanish heath scrub 10 Manuka-kanuka-Spanish heath scrub 11 Manuka-prostrate kanuka scrub 12 Manuka-mingimingi scrub ⇔ prostrate kanuka shrubland 13 Exotic pine/manuka-mingimingi scrub 14 Manuka-mingimingi scrub ⇔exotic pine/karamu-wheki-mamaku scrub 15 (Scattered radiata pines)/manuka-mingimingi scrub 16 Manuka-mingimingi scrub ⇔radiata pine-maritime pine/karamu-wheki-mamaku scrub 17 Manuka-prostrate kanuka-Chinese privet scrub 18 Manuka-mingimingi-blackberry-bracken scrub
	04	Kanuka-dominant scrub 01 Kanuka scrub 02 Kanuka/mingimingi scrub 03 Kanuka-mahoe scrub 04 Kanuka/prostrate kanuka scrub 05 Eucalyptus/manuka mingimingi scrub 06 Kanuka-kohuhu/koromiko-blackberry scrub 07 (Silver birch)/kanuka-mingimingi scrub 08 Kanuka/narrow-leaved carpet grass scrub 09 Kanuka-pohutukawa-black wattle scrub
	05	Indigenous mixed shrubs-dominant communities 01 Mingimingi-manuka-blackberry-indigenous broadleaved species scrub 02 Whauwhaupaku scrub 03 Whauwhaupaku-kanuka/mingimingi scrub
	06	Gorse-dominant scrub 01 Gorse scrub
	07	Exotic and indigenous plantings scrub
	08	Blackberry-dominant scrub 01 Blackberry scrub 02 Blackberry-Himalayan honeysuckle-pohue scrub 03 Silver birch-Chinese privet/blackberry scrub 04 (Silver birch)/blackberry-manuka-prostrate kanuka scrub 05 (Silver birch)/blackberry-prostrate kanuka scrub
	09	Exotic-dominant scrub 01 Barberry/blackberry scrub 02 Radiata pine-maritime pine/broom-manuka-mingimingi scrub
	10	Buddleia-dominant scrub 01 Buddleia scrub
	11	Chinese privet-dominant scrub 01 Chinese privet scrub
	12	Monoao-dominant scrub 01 Monoao scrub
05	01	Prostrate kanuka-dominant shrubland 01 Prostrate kanuka shrubland 02 Prostrate kanuka-mingimingi shrubland 03 (Kanuka)/prostrate kanuka-mingimingi- <i>Carex secta</i> shrubland 04 (Kanuka)/prostrate kanuka-rank grasses shrubland 05 Prostrate kanuka-manuka-bracken shrubland 06 Prostrate kanuka-mingimingi-monoao-toru shrubland 07 Prostrate kanuka/narrow-leaved carpet grass shrubland 08 Prostrate kanuka-manuka shrubland 09 Prostrate kanuka- <i>Hypolepis ambigua</i> shrubland 10 Prostrate kanuka/sweet vernal shrubland 11 Prostrate kanuka/nonvegetated raw-soilfield 12 Wilding pine/prostrate kanuka-mingimingi shrubland 13 Prostrate kanuka-broom-blackberry shrubland 14 Wilding pine/prostrate kanuka shrubland

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
		15 Prostrate kanuka-mingimingi-manuka shrubland 16 Prostrate kanuka/ exotic grass shrubland 17 Wilding pine/prostrate kanuka-mingimingi shrubland 18 Wilding pine/prostrate kanuka-mingimingi-manuka shrubland 19 Prostrate kanuka-kamahi-wheki-whauwhaupaku/blackberry shrubland
	02	Mingimingi-dominant shrubland 01 Mingimingi- <i>Histiopteris incisa</i> -bracken shrubland 02 Mingimingi-manuka shrubland 03 Mingimingi-prostrate kanuka shrubland 04 Mingimingi- <i>Hypolepis distans</i> -turutu shrubland ⇔ <i>Hypolepis distans</i> -turutu-bracken fernland ⇔ prostrate kanuka scrub 05 Exotic pine/mingimingi-prostrate kanuka shrubland 06 Mingimingi shrubland
	03	Manuka-dominant shrubland 01 Manuka shrubland 02 Manuka-(kamahi) shrubland 03 (Emergent mixed exotic trees)/manuka-kanuka-mixed exotic species shrubland 04 Manuka-mingimingi shrubland 05 Manuka-kanuka-mingimingi shrubland 06 Manuka-prostrate kanuka shrubland 07 Manuka/bracken shrubland 08 Manuka/narrow-leaved carpet grass shrubland 09 (Silver birch)/manuka/ <i>Cyperus ustulatus</i> - <i>Hypolepis distans</i> shrubland 10 Manuka-prostrate kanuka/ <i>Lycopodiella cernua</i> shrubland 11 Manuka/gorse-creeping bent/nonvegetated raw-soilfield shrubland 12 Manuka-kanuka/ <i>Histiopteris incisa</i> shrubland 13 (Manuka)-(monoao)-(<i>Gaultheria paniculata</i>)-(prostrate kanuka)/ <i>Racomitrium sanuginosum</i> shrubland 14 Manuka/ <i>Baumea rubiginosa</i> shrubland 15 Manuka-wheki/ <i>Histiopteris incisa</i> - <i>Hypolepis ambigua</i> shrubland 16 Manuka-mingimingi-monoao shrubland 17 Manuka/Spanish heath-exotic grasses shrubland 18 Manuka-mingimingi- <i>Histiopteris incisa</i> -bracken shrubland 19 Manuka-mingimingi-broom shrubland 20 Manuka shrubland↔raupo- <i>Carex secta</i> - <i>Cyperus ustulatus</i> reedland 21 Manuka-harakeke shrubland 22 Manuka-pampas shrubland 23 Black wattle/manuka-blackberry-bracken shrubland 24 Manuka/bracken-broom shrubland ↔broom-bracken-blackberry shrubland↔prostrate kanuka scrub 25 (Maritime pine)/manuka-broom-blackberry-Himalayan honeysuckle shrubland 26 Manuka-harakeke- <i>Cyperus ustulatus</i> shrubland 27 Manuka/ <i>Histiopteris incisa</i> - <i>Carex secta</i> shrubland 28 Maritime pine/manuka-pampas shrubland 29 Manuka-prostrate kanuka-mingimingi shrubland
	04	Kanuka-dominant shrubland 01 Kanuka-mingimingi shrubland 02 (Kanuka)/prostrate kanuka-rank grasses shrubland 03 Kanuka/Mercer grass shrubland 04 Kanuka-mingimingi-bracken shrubland 05 Kanuka/Mercer grass-narrow-leaved carpet grass shrubland 06 Kanuka shrubland 07 Kanuka-manuka/oioi shrubland 08 Wilding pine/prostrate kanuka shrubland 09 Wilding pine/kanuka-mingimingi-manuka shrubland
	05	Pohutukawa-dominant shrubland 01 Pohutukawa shrubland
	06	Gorse-dominant shrubland 01 Gorse shrubland

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
	07	Planted indigenous shrubland 01 Planted indigenous shrubland and manuka-mingimingi shrubland 02 (Harakeke)-(kohuhu) shrubland/nonvegetated ground
	08	Mixed indigenous shrubland 01 Kanuka/prostrate kanuka-blackberry-mingimingi- <i>Carex virgata</i> shrubland 02 Rewarewa-kamahi-(toru)/prostrate kanuka-monoao shrubland 03 Mixed indigenous shrubs/mixed fern species shrubland 04 (Maritime pine)/kiokio-blackberry-bracken-buddleia shrubland
	09	Exotic planted shrubland 01 Cultivar manuka-mingimingi-flowering cherry-red hot poker-harakeke (and other garden plants) shrubland.
	10	Mixed indigenous-exotic shrubland 01 (Mingimingi)-(arrow bamboo)-(manuka)-(broom)-(silver birch)/narrow-leaved carpet grass-Mercer grass/raw-soilfield shrubland 02 (Wheki-kohuhu-ti kouka)/wheki-kiokio-blackberry shrubland
	11	Mixed-exotic shrubland 01 Gorse-blackberry/Yorkshire fog- <i>Hypolepis ambigua</i> - <i>Histiopteris incisa</i> shrubland
	12	Monoao dominant shrubland 01 Monoao-manuka-prostrate kanuka-mingimingi shrubland
	13	Blackberry-dominant shrubland 01 (Grey willow)/blackberry- <i>Carex geminata</i> shrubland 02 Exotic pine/blackberry-prostrate kanuka shrubland 03 (Indigenous species)/blackberry-bracken-kiokio shrubland 04 Blackberry (dead) shrubland 05 Blackberry-broom/Yorkshire fog shrubland 06 Blackberry- <i>Cyclosorus interruptus</i> shrubland 07 Blackberry shrubland 08 Blackberry-mingimingi- <i>Nephrolepis flexuosa</i> shrubland
	14	Ti kouka-dominant shrubland 01 Ti kouka-kanuka shrubland
	15	Monoao dominant shrubland 01 Monoao-manuka-prostrate kanuka-mingimingi shrubland
06	01	Pampas tussockland
	02	Mixed pampas tussockland
07	01	<i>Dicranopteris</i>-dominant fernland 01 <i>Dicranopteris linearis</i> fernland 02 <i>Dicranopteris linearis</i> -narrow-leaved carpet grass fernland
	02	<i>Hypolepis dicksonioides</i>-dominant fernland
	03	Bracken-dominant fernland 01 Bracken fernland 02 Wheki/bracken fernland 03 Bracken-Japanese honeysuckle-Himalayan honeysuckle fernland 04 (Dead manuka)bracken-mingimingi-gorse fernland 05 Bracken-mingimingi-blackberry fernland
	04	<i>Histiopteris incisa</i>-dominant fernland 01 <i>Histiopteris incisa</i> fernland 02 <i>Histiopteris incisa</i> -narrow-leaved carpet grass-gorse fernland 03 <i>Histiopteris incisa</i> -mingimingi fernland
	05	Mixed fernland 01 <i>Histiopteris incisa</i> -bracken-mingimingi fernland 02 Dead manuka/bracken-turutu- <i>Histiopteris incisa</i> -mingimingi fernland 03 <i>Histiopteris incisa</i> -bracken-mingimingi-Mercer grass-Yorkshire fog fernland 04 <i>Histiopteris incisa</i> -mingimingi-bracken fernland 05 <i>Hypolepis ambigua</i> - <i>Histiopteris incisa</i> fernland 06 <i>Dicranopteris linearis</i> - <i>Christella</i> aff. <i>dentata</i> ("thermal")- <i>Nephrolepis flexuosa</i> fernland 07 <i>Histiopteris incisa</i> -gorse- <i>Hypolepis ambigua</i> - <i>Carex virgata</i> fernland 08 Bracken-kiokio-blackberry-wheki- <i>Paesia scaberula</i> fernland 09 <i>Histiopteris incisa</i> - <i>Cyperus ustulatus</i> fernland 10 <i>Paesia scaberula</i> -exotic grasses fernland

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
		11 <i>Histiopteris incisa</i> -bracken-wheki fernland 12 <i>Hypolepis distans</i> - <i>Gleichenia microphylla</i> - <i>Hypolepis ambigua</i> fernland 13 Bracken- <i>Cyclosorus interruptus</i> -blackberry-pampas/nonvegetated raw-soilfield fernland 14 <i>Dicranopteris linearis</i> - <i>Histiopteris incisa</i> fernland 15 Mixed fernland 16 Manuka-(makomako)/ <i>Hypolepis ambigua</i> fernland 17 Bracken- <i>Baumea rubiginosa</i> -mixed fern sedgeland
	06	Christella aff. dentata ("thermal")-dominant fernland 01 <i>Christella</i> aff. <i>dentata</i> ("thermal")-fernland 02 <i>Christella</i> aff. <i>dentata</i> ("thermal")-blackberry-rank exotic grasses fernland 03 <i>Christella</i> aff. <i>dentata</i> ("thermal")- <i>Nephrolepis flexuosa</i> -blackberry fernland
	07	Lycopodiella-dominant fernland 01 <i>Lycopodiella cernua</i> fernland
	08	Nephrolepis flexuosa-dominant fernland 01 <i>Nephrolepis flexuosa</i> fernland 02 <i>Nephrolepis flexuosa</i> - <i>Dicranopteris linearis</i> fernland 03 <i>Nephrolepis flexuosa</i> -bracken- <i>Christella</i> aff. <i>dentata</i> ("thermal")-blackberry fernland
	09	Hypolepis ambigua-dominant fernland 01 <i>Hypolepis ambigua</i> - <i>Histiopteris incisa</i> fernland
	10	Nephrolepis cordifolia-dominant fernland 01 <i>Nephrolepis cordifolia</i> fernland
	11	Paesia scaberula-dominant fernland 01 <i>Paesia scaberula</i> fernland
	12	Deparia-dominant fernland 01 <i>Deparia</i> fernland
	13	Cheilanthes-dominant fernland 01 <i>Cheilanthes sieberi</i> -Mercer grass fernland 02 <i>Cheilanthes sieberi</i> -buffalo grass fernland
	14	Cyclosorus-dominant fernland 01 <i>Cyclosorus interruptus</i> fernland
08	01	Yorkshire fog-dominant grassland 01 Yorkshire fog grassland 02 Prostrate kanuka/Yorkshire fog grassland 03 Manuka/Yorkshire fog grassland
	02	Narrow-leaved carpet grass-dominant grassland 01 Narrow-leaved carpet grassland 02 Mosaic of narrow-leaved carpet grassland, manuka-mingimingi shrubland, and nonvegetated raw-soilfield 03 Narrow-leaved carpet grass-exotic garden plants grassland 04 (Manuka)-(prostrate kanuka)/narrow-leaved carpet grassland 05 Narrow-leaved carpet grass-wild serradella grassland
	03	Creeping bent grassland
	04	Mercer grass-dominant grassland 01 Mercer grass- <i>Paesia scaberula</i> grassland 02 Mercer grass-narrow-leaved carpet grassland 03 Mercer grass grassland 04 Mercer grass- <i>Cyclosorus interruptus</i> - <i>Hypolepis ambigua</i> grassland
	05	Kikuyu grassland
	06	Mixed exotic-dominant grassland 01 Mercer grass-creeping bent- <i>Microlaena stipoides</i> grassland. 02 Sweet vernal-browntop grassland 03 Mown and rank exotic grassland 04 (Prostrate kanuka)/rank exotic grasses grassland 05 (<i>Baumea anthrophylla</i>)/mixed exotic grasses-raw-soilfield grassland
	07	Indian doab-dominant grassland 01 Indian doab grassland
	08	Reed sweet grass-dominant grassland 01 Reed sweet grassland 02 Reed sweet grass-raupo- <i>Schoenoplectus tabernaemontani</i> grassland

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
		03 Raupo/reed sweetgrass- <i>Schoenoplectus tabernaemontani</i> -swamp millet grassland
09	01	Carex geminata-dominant sedgeland 01 <i>Carex geminata</i> sedgeland
	02	Cyperus ustulatus-dominant sedgeland 01 <i>Cyperus ustulatus</i> sedgeland 02 <i>Cyperus ustulatus-Cortaderia fulvida-Juncus edgarae-Histiopteris incisa</i> sedgeland 03 <i>Cyperus ustulatus-Cortaderia fulvida</i> -blackberry sedgeland 04 Dead kanuka/ <i>Cyperus ustulatus</i> -pampas sedgeland 05 Wheki-ponga/ <i>Cyperus ustulatus-Cyclosorus interruptus</i> sedgeland 06 <i>Cyperus ustulatus</i> -raupo sedgeland
	03	Carex virgata-dominant sedgeland 01 <i>Carex virgata-Nephrolepis flexuosa</i> sedgeland 02 Gorse- <i>Carex virgata-Cyperus ustulatus</i> sedgeland
	04	Baumea rubiginosa-dominant sedgeland 01 <i>Baumea rubiginosa</i> sedgeland 02 Wheki/ <i>Baumea rubiginosa</i> -kiokio sedgeland
	05	Mixed sedgeland 01 <i>Carex virgata-Carex secta-Cyperus ustulatus-Baumea articulata</i> sedgeland 02 Grey willow/ <i>Carex secta</i> -raupo- <i>Schoenoplectus tabernaemontani</i> sedgeland
	06	Carex secta-dominant sedgeland 01 <i>Carex secta</i> -raupo sedgeland 02 (Kanuka)/ <i>Carex secta</i> sedgeland
	07	Isolepis distigmata-dominant sedgeland 01 <i>Isolepis distigmata</i> sedgeland
	08	Oioi-dominant sedgeland 01 Oioi sedgeland
10	01	Juncus prismatocarpus-dominant rushland 01 <i>Juncus prismatocarpus-Carex geminata</i> rushland
11	01	Raupo-dominant reedland 01 Raupo reedland 02 (Ti kouka)-(grey willow)/raupo-harakeke-manuka/ <i>Juncus effusus-Isolepis distigmata</i> reedland 03 Raupo- <i>Cyperus ustulatus</i> reedland 04 (Grey willow)-raupo- <i>Carex secta-Schoenoplectus tabernaemontani</i> reedland ↔ raupo-pohuehue- <i>Schoenoplectus tabernaemontani</i> reedland 05 (Grey willow)-raupo- <i>Schoenoplectus tabernaemontani-Carex secta</i> -reedland 06 Raupo- <i>Schoenoplectus tabernaemontani-Carex secta</i> reedland 07 (Alder)/raupo reedland 08 Raupo- <i>Schoenoplectus tabernaemontani</i> -Japanese honeysuckle reedland 09 Raupo/ <i>Carex virgata</i> reedland 10 (Grey willow)-(silver birch)-(ti kouka)/raupo-blackberry reedland 11 Raupo-blackberry reedland 12 Raupo- <i>Schoenoplectus tabernaemontani-Carex secta-Baumea rubiginosa</i> reedland 13 (Crack willow)/raupo reedland 14 (Ti kouka)-(manuka)/raupo- <i>Cyperus ustulatus-Schoenoplectus tabernaemontani</i> reedland 15 Grey willow/raupo reedland 16 Raupo-harakeke reedland ↔ <i>Carex secta-Baumea rubiginosa-Baumea juncea</i> sedgeland
	02	Baumea articulata-dominant reedland 01 <i>Baumea articulata</i> reedland
	03	Baumea arthropylla-dominant sedgeland 01 <i>Baumea arthropylla</i> sedgeland
	04	Mixed Baumea sedgeland

Vegetation Structural Class	Broad Vegetation Type	Detailed Vegetation Types and Habitats
12	06	Baumea rubiginosa-dominant sedgeland 01 (Manuka)-(wheki)/ <i>Baumea rubiginosa</i> sedgeland
		Cushionfield
13	01	Herbfield 01 <i>Polygonum maculosa</i> herbfield 02 Arrow grass herbfield
14	01	Racomitrium-dominant Mossfield 01 <i>Racomitrium sanuginosum</i> mossfield
	02	Campylopus-dominant mossfield 01 <i>Campylopus capillaceus</i> mossfield 02 <i>Campylopus</i> sp. mossfield
15		Lichenfield
16		Rockland
17	01	(Sparse vegetation)/boulderfield 01 (Prostrate kanuka)/boulderfield
18		Stonefield/gravelfield
19		Sandfield 01 Geothermally heated sandfield
20		Loamfield/Peatfield
21		Flaxland
22	01	Geothermal water 01 Geothermal water 02 Mud pools 03 Geothermal sands and hot springs 04 Geothermal springs, mud pools, geothermal stream and sinter.
23	01	Wheki-dominant treefernland 01 Wheki/gorse- <i>Histiopteris incisa</i> treefernland 02 (Dead pohutukawa × northern rata)/wheki- <i>Gahnia setifolia</i> treefernland 03 (Dead pohutukawa × northern rata)/wheki-kamahahi treefernland 04 Wheki treefernland
24		Mudfield
25		Cliffland
26		Turf
27		Algalfield
28	01	Nonvegetated raw-soilfield 01 Nonvegetated raw-soilfield 02 Nonvegetated raw-soilfield (mining operations) 03 Geothermal sand 04 Nonvegetated raw-soil field (geothermal and landslide debris) 05 Bare ground 06 Prostrate kanuka/nonvegetated raw-soilfield shrubland
	02	(Prostrate kanuka)/raw-soilfield 01 (Prostrate kanuka)/nonvegetated raw-soilfield
	03	(Sparse indigenous vegetation)/raw-soilfield 01 (Kanuka)-(pohutukawa)-(mingimingi)-(silver birch)/ nonvegetated raw-soilfield 02 (Pohutukawa)-(manuka)-(Mercer grass)/ nonvegetated raw-soilfield 03 (Manuka)-(<i>Cyperus ustulatus</i>)/ nonvegetated raw-soilfield 04 (Prostrate kanuka)-(manuka)/ nonvegetated raw-soilfield 05 (Manuka)/ nonvegetated raw-soilfield 06 (<i>Juncus edgarae</i>)-(<i>Carex virgata</i>)-(<i>Morelotia affinis</i>)-(mixed exotic grasses)/ nonvegetated raw-soilfield 07 (<i>Cyperus ustulatus</i>)-(kanuka)-(<i>Cortaderia fulvida</i>)/nonvegetated raw-soilfield
	04	Exotic grasses/ nonvegetated raw-soilfield 01 Dead kikuyu-dead narrow-leaved carpet grass/ nonvegetated raw-soilfield.
29	01	Residential development-scattered geothermal vegetation 01 Residential development-scattered geothermal vegetation
30	01	Bamboo-dominant bambooland 01 Arrow bambooland

3.6 Threats/modification/vulnerability

For each site, current threats, modification and vulnerability were evaluated under four categories:

- invasive exotic plant species
- human threats
- grazing
- adjoining land use

Invasive exotic plant species were assessed in terms of their abundance. A cover class index based on Allen (1992) (see Table 3) was used to indicate the relative abundance of weeds at each site.

Table 3: Cover class index (from Allen 1992).

Percentage Cover	Cover Class
<1	1
1-5	2
6-25	3
26-50	4
51-75	5
76-100	6

3.7 Site mapping

Vegetation type boundaries for each site were digitised in ArcView (V.9.3) (on the 2007 WRAPs) at a scale of 1:5,000 with the following data fields; Site Name, ECOSIG2003, BOTRANK 96, new site number, NZTM Eastings and Northings, Vegetation Code, Broad Vegetation Class, Vegetation description, Ecological District, Ecological Significance Ranking, Geothermal Field, Hydroclass, Territorial Local Authority, Structural Class Code, Broad Class Code, and Area (ha).

3.8 Historical site changes

Historical site changes were undertaken by examining aerial photographs held by Waikato Regional Council from the 1940s-1960s to determine the extent of change of geothermal sites. Due to the nature of the historic aerial photos (differing scales/black and white), interpretation of change was subjectively carried out by an ecologist familiar with geothermal vegetation and the individual sites. A literature search was also carried out to provide supplementary information on historic site condition. Where possible change was quantified in terms of broad percent ranges of hectare lost or gained.

3.9 Assessment of botanical significance by Given (1996)

Given (1996) applied four ranking systems that had been defined in earlier reports - Given's 1995 geothermal survey - full set of criteria; Given's 1995 geothermal survey - biodiversity criteria only; the criteria outlined in Whaley *et al.* 1995; and the 'Waimakariri system' (Meurk *et al.* 1993). Each site was ranked using each ranking system and a final assessment was then made by combining the four separate

assessments. The sites were grouped into four categories (A-D), where 'A' is the highest rank and 'D' is the lowest. These are listed in the notes section for each site.

3.10 Ecological evaluation

The relative significance of each geothermal site (see Figure 1) was assessed as part of the current study using the criteria specified in Environment Waikato Regional Policy Statement (2002). This has recently been updated to reflect more recent changes to the New Zealand Threat Classification Lists (refer to Appendices 10 and 11). Using these criteria, each site was assigned to one of four levels of relative significance: Internationally Significant, Nationally Significant, Regionally Significant, or Locally Significant. The rankings were completed in the pre-formatted Excel spreadsheet provided by the Council.

3.11 Data analysis data

Data was generated from analyses of mapped vegetation for each site. The extent of each geothermal vegetation type (as per Table 2) in each site was calculated. The extent of geothermal vegetation in each ecological district, geothermal field, and in each administrative district was also calculated (see Tables 5, 9, 10, and 11). These totals exclude geothermal water. A total is given for geothermal water, and terrestrial and emergent geothermal wetland habitats, at each site.

Vegetation mosaics have been included in the site descriptions and accompanying maps for more accurate descriptions, however for GIS data compilation, the mosaics were assigned to the vegetation type dominant in a mosaic, thereby providing a scale appropriate for analysis at a regional level.

3.12 Presentation of results

Geothermal Fields

Site information is presented in order of geothermal field, generally following a North to South alignment, and then a West to East alignment.

The following information is presented for each geothermal field within the Waikato Region.

1. A list of geothermal sites within the Waikato Region.
2. A separate data sheet for each geothermal site (see Table 4 below).
3. Maps
 - Topographic maps showing the location of each geothermal site (scale 1:20,000).
 - Vegetation maps of sites overlain on aerial photographs (vegetation map scales vary from 1:2,000 to 1:15,000 depending on the size of the site).
4. All geothermal sites are listed in Table 5, within relevant geothermal fields and ecological districts. The area (ha) of geothermal vegetation at each site and the significance ranking assigned to the site are provided in Table 6 (see Section 5).

Table 4: Format and categories for presentation of information on geothermal sites.

SITE NAME

- Site Number:**
- Grid Reference:**
- GPS Reference:**
- Local Authority:**
- Ecological District:**
- Geothermal Field:**
- Bioclimatic Zone:**
- Tenure:**
- Altitude:**
- Extent of Geothermal Habitat:**
- Extent of Geothermal Vegetation:**
- Date of Field Survey:**

Code	Type	Landform	Extent

- Geophysical Assessment:¹**
- Indigenous Flora:**
- Fauna:**
- Current Condition (Year of Most Recent Assessment):**
- Threats/Modification/ Vulnerability:**
 - Invasive pest plants (Year of most recent Assessment):*
 - Human impacts (Year of most recent Assessment):*
 - Grazing (Year of most recent Assessment):*
 - Adjoining land use (Year of most recent Assessment):*
- Site Change:**
 - Recent Change:*
 - Historical:*
- Management Requirements:**
- Significance Level:**
- Significance Justification:**
- Notes:**
- References:**

¹ Selected sites only.

Explanatory Notes for the Site Summary Sheet

Explanatory notes for the site summary sheet are provided below:

Site Number: Number assigned to a site during the current survey. These have all been updated since the Wildland Consultants (2004) report, and previous site numbers are provided in a footnote for cross reference.

Grid Reference: Central grid reference of the site from the relevant NZTopo50 topographic map. The 2004 to 2007 reports were based on NZMS260, which are no longer being used.

GPS Reference: The grid reference is also provided as a GPS reference in NZTM (New Zealand Transverse Mercator).

Local Authority: Local authority with jurisdiction over the area.

Ecological District: Ecological district within which the site lies. Ecological districts each have distinctive characteristics of climate, geology, landform, soils and biological features (Myers *et al.* 1987). Three ecological districts in the Waikato Region contain sites with geothermal vegetation.

Geothermal Field: Name of the geothermal field within which the site lies. Geothermal surface features are supplied with mineralised hot water or steam from underlying geothermal reservoirs, and one field may supply many discrete geothermal sites. Geothermal field names and the assignment of each site to a geothermal field were undertaken by the Waikato Regional Council.

Bioclimatic Zone: Bioclimatic zones follow Leathwick *et al.* (1995), and are defined in Appendix 5.

Tenure: Tenure is shown as either protected or unprotected private land, or both if applicable. If the area is protected, the type of protection (e.g. reserve, covenant) is shown.

Altitude: Altitude of the site given in metres, determined from topographical maps. For larger sites a range is given.

Extent of Geothermal Habitat: Total area of geothermal habitat. This includes geothermal water and geothermal vegetation in hectares (see geothermal vegetation below).

Extent of Geothermal Vegetation: Total area of geothermal vegetation (see Table 2). This excludes geothermal water, but includes nonvegetated raw-soilfield in hectares.

Date of Field Survey: Date of the most recent field survey.

Vegetation Code: A numeric code based on structural class, broad vegetation type, and detailed vegetation type following Wildland Consultants (2005) Contract Reports 1056 and 1072, and additional types included in Table 2.

Vegetation Type: A vegetation classification using predefined structural classes and a protocol for assigning type names based on the dominant plant species, as described in Atkinson (1985), Wildland Consultants Contract Report No. 757, and additional types observed during the current field survey (see Table 2).

Landform: Describes the physical landform on which a vegetation type occurs.

Geophysical Assessment: Describes the unique geothermal physical aspects of the site (note that this assessment has only been carried out on selected sites and at some larger sites, only parts of the geophysical aspects were assessed).

Indigenous Flora: Any species characteristic of geothermal sites, and nationally threatened or uncommon species (as per de Lange *et al.* 2009) are listed. Relevant information may also be provided about plant distribution (for more detail refer to Appendix 4).

Fauna: A list of fauna known to occur at the site. Previous reports focussed on indigenous species only, but all fauna information has been included in this report where possible. A literature review was undertaken for each site, although for most sites, no further information was found.

Current Condition: Comments on the overall current condition of the site as determined from field reconnaissance and existing information. May include comment on features related to the character and history of the site which have influenced vegetation composition.

Threats/Modification/Vulnerability: Any current or potential threats to the indigenous vegetation and integrity of the geothermal ecosystem, particularly the occurrence and abundance of invasive exotic plants, potential and current human threats, and threats from domestic stock or pest animals, and adjoining landuse.

Site Change Recent Change: Any changes to the site since the last field visit (and general comments about change in the last ten years) were noted, and any changes evident in the 2007 aerial photographs compared with recent earlier surveys. Changes that are not a real change, but simply a result of better quality aerial photographs were noted.

Site Change Historical: Historical changes determined from 1940s to 1960s aerial photographs and relevant literature. Aerial photograph codes recorded as follows, for example a site with the code SN 172 Run 1176 Photos 5-6, 1946: SN = survey run number, Run = flight path number, Photos = number of photo(s) into the flight path, 1946 = year of photograph.

Management Requirements: Recommendations for action necessary to prevent, minimise or remedy any known threats or modification to the site.

Significance Level: The significance level assigned to the site from the ecological evaluation criteria based on Waikato Regional Council Technical Report TR2002/15 (Environment Waikato and Wildland Consultants 2002). Areas of Significant Indigenous Vegetation and Habitats of Indigenous Fauna in the Waikato Region: Guidelines to apply Regional Criteria and Determine Level of Significance (refer to Appendix 11).

Significance/Justification: A brief explanation of why a site was assigned to a particular significance level.

Notes: Any further comments including and previous rankings of geothermal vegetation (e.g. Given 1995).

References: References which are of direct relevance to the site.

An index by site and page number has been prepared to make information in this report more readily accessible (presented at the end of the report).

Location Map

Figure 1 (scale c.1:300,000) shows the location of each geothermal site with its significance level(s).

Table 5: Breakdown of broad geothermal hydroclass and vegetation groups within each site ordered by geothermal field and ranked by area of geothermal vegetation, Waikato Region.

Site Name	Site Number	Ecological District	Hydroclass/Vegetation Grouping				Total Geothermal Vegetation (ha)	Total Site Area (Geothermal Vegetation and Geothermal Water) (ha)	Size Rank for Extent of Geothermal Vegetation within the Waikato Region (by Geothermal Field)
			Geothermal Water (ha)	Geothermal Vegetation					
				Nonvegetated Raw-Soilfield (ha)	Terrestrial Vegetation (ha)	Emergent Wetland (ha)			
<i>Horooho Geothermal Field</i>									
Horooho	HHV01	Atiamuri	<0.1		<0.1		<0.1	<0.1	<0.1 ha
		Total	<0.1		<0.1		<0.1	<0.1	
<i>Waikite Geothermal Field</i>									
Waikite Valley	WAV01	Atiamuri	1.2	0.3	18.6	5.6	24.6	25.8	7
Northern Paeroa Range	WAV02	Atiamuri		0.3			0.3	0.3	
		Total	1.2	0.6	18.6	5.6	24.9	26.1	
<i>Waiotapu Geothermal Field</i>									
Maungaongaonga	WTV01	Atiamuri		0.7	8.4		9.1	9.1	1
Ngapouri	WTV02	Atiamuri	0.5	<0.1	3.1		3.1	3.6	
Waiotapu North	WTV03	Atiamuri	2.9	4.6	41.3		45.8	48.8	
Maungakakamea (Rainbow Mountain)	WTV04	Atiamuri/ Rotorua Lakes	3.4	4.3	46.2		50.6	54.0	
Waiotapu South	WTV05	Atiamuri	20.6	8.4	77.8	26.3	112.4	133.0	
		Total	27.4	18.0	176.7	26.3	221.0	248.4	
<i>Mokai Geothermal Field</i>									
Whakamaru	MKV01	Atiamuri		<0.1			<0.1	<0.1	10
Waipapa Stream	MKV02	Atiamuri			1.1		1.1	1.1	
Tirohanga Road	MKV03	Atiamuri	0.3	<0.1	0.1		0.2	0.5	
Paerata Road	MKV04	Atiamuri	0.2	0.4	1.3		1.7	1.8	
		Total	0.5	0.4	2.5		2.9	3.4	
<i>Atiamuri Geothermal Field</i>									
Upper Atiamuri West	ATV01	Atiamuri			<0.1		<0.1	<0.1	12
Whangapoa Springs	ATV02	Atiamuri	<0.1	<0.1	<0.1		0.1	0.1	
Matapan Road	ATV03	Atiamuri			<0.1		<0.1	<0.1	
		Total	<0.1	<0.1	<0.1		0.1	0.2	
<i>Te Kopia Geothermal Field</i>									
Te Kopia	TKV01	Atiamuri	1.1	5.5	48.9	4.4	58.8	59.9	5
Murphy's Springs	TKV02	Atiamuri			0.2		0.2	0.2	
Te Kopia Northwest	TKV03	Atiamuri		<0.1			<0.1	<0.1	
Te Kopia West Mud Pools	TKV04	Atiamuri			<0.1		<0.1	<0.1	
Te Kopia Red Stream	TKV05	Atiamuri			0.2		0.2	0.2	

Site Name	Site Number	Ecological District	Hydroclass/Vegetation Grouping					Total Site Area (Geothermal Vegetation and Geothermal Water) (ha)	Size Rank for Extent of Geothermal Vegetation within the Waikato Region (by Geothermal Field)
			Geothermal Water (ha)	Geothermal Vegetation			Total Geothermal Vegetation (ha)		
				Nonvegetated Raw-Soilfield (ha)	Terrestrial Vegetation (ha)	Emergent Wetland (ha)			
Mangamingi Station	TKV06	Atiamuri		0.1	0.4		0.5	0.5	
		Total	1.1	5.6	49.8	4.4	59.8	60.9	
Orakeikorako Geothermal Field									
Waihunuhunu	OKV01	Atiamuri	2.3		0.3	2.7	3.0	5.3	
Akatārewa Stream	OKV02	Atiamuri			1.4		1.4	1.4	
Orakeikorako	OKV03	Atiamuri	<0.1	2.1	40.3		42.4	42.4	6
Red Hills	OKV04	Atiamuri	0.1	0.3	11.1		11.4	11.5	
Akatārewa East	OKV05	Atiamuri		<0.1	<0.1		<0.1	<0.1	
		Total	2.5	2.3	53.2	2.7	58.2	60.7	
Ngatamariki Geothermal Field									
Waikato River Springs	NMV01	Atiamuri	0.2	<0.1		0.4	0.4	0.6	
Ngatamariki	NMV02	Atiamuri	0.2	0.4	1.0	<0.1	1.5	1.7	11
		Total	0.4	0.4	1.0	0.4	1.9	2.3	
Whangairorohea Geothermal Field									
Whangairorohea	WGV01	Atiamuri	<0.1		<0.1		<0.1	<0.1	<0.1 ha
		Total	<0.1		<0.1		<0.1	<0.1	
Reporoa Geothermal Field									
Longview Road	RPV01	Atiamuri	0.2	1.5	1.9		3.4	3.6	
Wharepapa Road	RPV02	Atiamuri	0.2	1.2	2.2		3.3	3.5	9
Golden Springs	RPV03	Atiamuri	<0.1		0.1	0.3	0.5	0.5	
		Total	0.4	2.6	4.4	0.3	7.2	7.6	
Ohaaki Geothermal Field									
Ohaaki Steamfield West	OHV01	Atiamuri	0.1	2.2	9.5		11.7	11.8	
Ohaaki Steamfield East	OHV02	Atiamuri		3.1	3.7		6.8	6.8	8
		Total	0.1	5.3	13.2		18.5	18.6	
Wairakei-Tauhara Geothermal Field									
Otumuheke Stream	THV01	Atiamuri			2.3		2.3	2.3	
Spa Thermal Park	THV03	Atiamuri		<0.1	0.1		0.1	0.1	
Broadlands Road	THV04	Atiamuri	<0.1	4.6	25.2		29.8	29.8	
Crown Park	THV05	Taupo		0.1	0.6		0.7	0.7	
Crown Road	THV06	Taupo/Atiamuri		3.7	13.8		17.5	17.5	2
Waipahihi Valley	THV07	Taupo			0.3		0.3	0.3	
Te Rautehuia	WKV01	Atiamuri		0.5	7.2		7.7	7.7	
Te Rautehuia Stream	WKV02	Atiamuri		0.5	1.6		2.1	2.1	
Upper Wairakei Stream	WKV03	Atiamuri		0.2	4.5		4.7	4.7	

Site Name	Site Number	Ecological District	Hydroclass/Vegetation Grouping				Total Geothermal Vegetation (ha)	Total Site Area (Geothermal Vegetation and Geothermal Water) (ha)	Size Rank for Extent of Geothermal Vegetation within the Waikato Region (by Geothermal Field)
			Geothermal Water (ha)	Geothermal Vegetation					
				Nonvegetated Raw-Soilfield (ha)	Terrestrial Vegetation (ha)	Emergent Wetland (ha)			
(Geyser Valley)									
Wairakei Borefield	WKV04	Atiamuri			<0.1		<0.1	<0.1	
Te Kiri O Hine Kai Stream Catchment/Wairoa Hill	WKV05	Atiamuri	0.2	3.3	36.8		40.1	40.3	
Lower Wairakei Stream	WKV06	Atiamuri	<0.1		<0.1		<0.1	<0.1	
Karapiti Forest	WKV07	Atiamuri			0.6		0.6	0.6	
Hall of Fame Stream	WKV08	Atiamuri			0.1		0.1	0.1	
Waipouwerawera Stream/Tukairangi	WKV09	Atiamuri			0.1		0.1	0.1	
Craters of the Moon	WKV10	Atiamuri		1.5	43.1		44.6	44.6	
		Total	0.3	14.4	136.3		150.7	151.0	
Rotokawa Geothermal Field									
Rotokawa North	RKV01	Atiamuri	<0.1	3.3	31.1		34.3	34.4	3
Lake Rotokawa	RKV02	Atiamuri	67.9	13.1	56.2		69.4	137.3	
		Total	68.0	16.4	87.3		103.7	171.7	
Tokaanu-Waihi-Hipaua Geothermal Field									
Hipaua	TOV02	Tongariro		0.4	11.0		11.3	11.3	4
Tokaanu Lake Shore Wetland	TOV05	Taupo/ Tongariro	3.3			39.1	39.1	42.4	
Maunganamu West	TOV07	Taupo/ Tongariro				0.6	0.6	0.6	
Tokaanu Thermal Park	TOV08	Tongariro	0.2	0.1	6.7	0.8	7.6	7.8	
Tokaanu Urupa Mud Pools	TOV09	Taupo			<0.1		<0.1	<0.1	
Maunganamu East	TOV10	Taupo				<0.1	<0.1	<0.1	
Maunganamu North Wetland	TOV11	Taupo				0.9	0.9	0.9	
Tokaanu Tailrace Canal	TOV14	Tongariro				<0.1	<0.1	<0.1	
		Total	3.5	0.5	17.7	41.4	59.5	63.0	
Tongariro Geothermal Field									
Te Maari Craters	TGV01	Tongariro		4.9			4.9	4.9	8
Ketetahi	TGV02	Tongariro		8.2			8.2	8.2	
Emerald Lakes	TGV03	Tongariro	0.8	11.3			11.3	12.1	
Red Crater	TGV04	Tongariro		0.7			0.7	0.7	
		Total	0.8	25.1			25.1	25.9	
Grand Total			106.2	91.8	560.7	81.1	733.6	839.88	

4. DEFINITION OF GEOTHERMALLY INFLUENCED VEGETATION

Geothermally influenced terrestrial and emergent wetland vegetation are plant communities that have compositional, structural, and/or growth rate characteristics determined by current or former inputs of geothermally-derived energy (heat) or material (solid, fluid, or gas).

Merrett & Clarkson 1999

Compositional, structural, and/or growth rate characteristics of geothermally influenced terrestrial and emergent wetland vegetation include the unexpected presence of species found elsewhere in warmer climates or at lower altitudes or latitudes (disjunct populations), prostrate or stunted growth forms, and reduced growth rates. Merrett & Clarkson (1999) classified geothermal habitats into four broad categories:

- heated ground
- geothermal wetlands
- cooled hydrothermally altered soils
- atmospheric influence from regular toxic gas emissions, or warm micro-climates created by hot-springs discharge.

Refer to Appendix 6 for explanations of these terms. This was accompanied by a hierarchical classification of geothermally influenced terrestrial and emergent wetland vegetation, of which detailed vegetation types and habitats are included in site reports.

4.1 Basis of summarising extent of geothermal habitat, geothermal vegetation, and open water

The broad summaries of geothermal vegetation and habitats in this report include all mapped geothermal habitat that includes vegetation dominated by vascular plants, non-vascular plants, nonvegetated raw-soilfield (which often contain scattered patches of non-vascular and vascular plants), and emergent wetland vegetation. It does not include open geothermal water. Geothermal water was mapped if it was an integral part of a geothermal site. Open water is included in “extent of geothermal habitat” in site reports, but not in “extent of geothermal vegetation”.

4.2 Geothermal wetland vegetation

Adapted from Wildland Consultant 2005 (Report No. 1072).

The definition of geothermal wetland for this study follows Clarkson *et al.* (2002) and Johnson (2004).

“A wetland hydrosystem where the dominant function is **geothermally heated water**. The RMA91 specifies geothermal waters as those heated by natural phenomena to 30 degrees C or above. Geothermal wetlands may have water temperatures below this, but must be considered geothermal due to the chemical composition of the water. Geothermal wetlands are permanently or intermittently wet areas, shallow water, or land water margins that support a natural ecosystem of plants that have compositional,

structural, and/or growth rate characteristics determined by current or former inputs of geothermally derived water.” (Clarkson *et al.* 1992)

“A hydrosystem where volcanic activity produces hot surface waters, or heated soils (30°C or more) or where geothermal chemistry affects wetland habitats.” (Johnson 2004)

Wetlands habitats have been mapped as best as possible within limitations of time, difficulty of safe access and issues of very small scales. Many wetland vegetation types cover a very small area and are too small to be mapped.

Examples where limitations of a single site visit approach and scale of mapping exists to determine geothermal wetland boundaries include:

- heated wet air (steam) from fumaroles and hot pools can extend for either small distances, or quite considerable distances from the surface geothermal activity, and are generally difficult to map.
- heated water flowing over waterfalls produces graduations of habitats affected by water flow, splash, spray (Johnson 2004) and through seepages and associated increased air and soil temperatures providing habitat for plant species typical of geothermal activity.
- the presence of surface geothermal activity can fluctuate at a particular location and across a landscape.

Access to all parts of a geothermally active area is difficult in some locations, particularly in geothermal wetlands where isolated geothermal seepages and immediate geothermal plants can be surrounded by cold water species (e.g. raupo (*Typha orientalis*) wetland). In this situation the vegetation is mapped as one broad class. Generally the water present will have geothermal derived chemical inputs.

Wetlands are quite varied both within and between geothermal sites, for example at Waiotapu South, there are extensive areas of wetland manuka (*Leptospermum scoparium*) scrub, with additional areas of raupo reedland, and *Baumea juncea* sedgeland, while at Te Kopia Wetland areas are dominated by *Baumea rubiginosa*. In the Tokaanu Lakeshore Wetland, there are extensive areas of raupo reedland, with small areas of oioi (*Apodasmia similis*) rushland present at Tokaanu Thermal Park. Geothermal wetlands provide habitat for threatened fern species such as *Thelypteris confluens* at Waikite and *Cyclosorus interruptus* at Waiotapu South.

4.3 Nonvegetated raw-soilfield (Source: Merrett & Clarkson 1999)

Areas that are bare of vegetation that are (i) too hot to support plant life, (ii) are cooled but hydrothermally altered, sinter pavements, or (iii) are subjected to regular mud ejection or gas emission that prevent colonisation and established plants. These areas are often small scale, and may not be visible on aerial photographs.

Very hot soils are often associated with steam vents and/or boiling mud craters, and soil temperatures at 10 cm depth are usually >90°C.

Vigorously boiling mud pools and craters that regularly eject hot mud around margins effectively prevent plant colonisation. Where toxic gas is emitted, vegetation is either absent, or if present, killed.

Hydrothermally altered soils often occur where geothermal expression has ceased, e.g. dried mud craters, which result in soils with unusual chemical composition.

4.3.1 Basis of mapping of nonvegetated raw-soilfield for this study

This study is based on both field survey and interpretation of vegetation cover based on aerial photographs. At many sites, particularly large ones, not all units of vegetation and habitats could be viewed in the field, nor was it safe to do so. Occasional scattered vascular and non-vascular plants are included in mapping, particularly in areas that appear as bare ground on aerial photographs, and in areas that could not be viewed by field survey. On this basis, nonvegetated raw-soilfield is included in tallies of terrestrial geothermal vegetation in the summary of vegetation types by geothermal field.

Large areas with open water and abundant mud pools were mapped as open geothermal water, while small mud pools amongst nonvegetated raw-soilfield have been mapped as nonvegetated raw-soilfield. Open water areas containing abundant mud pools were given a separate vegetation code (22.01.02).

5. GEOTHERMAL SITES IN THE WAIKATO REGION

A total of 64 sites have been described in Appendix 1 and are listed in Table 5. The only known major exception is the hill slopes above Tokaanu, which are likely to contain some sites with significant examples of geothermal vegetation. Landowner permission was not received to enable survey of these sites, so these sites were not surveyed or mapped. While these sites are considered to be relatively small, field survey of them should be a high priority if access can be arranged. Details of the vegetation, condition, and significance of each site are presented in Appendix 1, together with vegetation type maps on an aerial photograph backdrop, and topographic maps showing site boundaries. Each of the 64 sites meets one or more of the criteria for ecological significance in the Waikato Regional Policy Statement (refer to Appendix 10). Therefore, each site was assigned a relative significance level; International, National, Regional, or Local following the assessment method in Appendix 11. Four sites were identified as being of International significance (Te Kopia, Te Maari Craters, Emerald Lakes and Red Crater) and part of another site (Waiotapu South), encompassing *c.*205 ha or 24% of geothermal habitat in the Waikato Region (see Table 6). Eight sites were of National significance, with two sites being partly of National significance and partly of Local significance, encompassing *c.*382 ha or 46% of geothermal habitat in the Waikato Region. Twenty-three sites were identified as being of Regional significance, with an additional two sites being partly of Regional and partly of Local significance. Parts of Waiotapu South were identified as being of International, Regional and Local significance. In total, *c.*242 ha or 29% of geothermal habitat in the Waikato Region was identified as being Regionally significant. The remainder of the sites (25) were

identified as being of Local significance. The total area of geothermal habitat of Local significance in the Waikato Region was c.11 ha or c.1%.

Table 6: Ecological significance ranking of geothermal sites ordered by geothermal field, Waikato Region.

Site Name (Site Number)	Ecological District	Area (ha) of Site According to Ecological Significance Ranking			
		International	National	Regional	Local
Horohoro Geothermal Field					
Horohoro (HHV01)	Atiamuri				<0.1
	Total				<0.1
Waikite Geothermal Field					
Waikite Valley (WAV01)	Atiamuri		25.8		
Northern Paeroa Range (WAV02)	Atiamuri				0.3
	Total		25.8		0.3
Waiootapu Geothermal Field					
Maungaongaonga (WTV01)	Atiamuri		9.1		
Ngapouri (WTV02)	Atiamuri			0.8	2.8
Waiootapu North (WTV03)	Atiamuri			48.8	
Maungakakaramea (Rainbow Mountain) (WTV04)	Atiamuri/Rotorua Lakes		54.0		
Waiootapu South (WTV05)	Atiamuri	127.2		5.3	0.5
	Total	127.2	63.1	54.9	3.3
Mokai Geothermal Field					
Whakamaru (MKV01)	Atiamuri				<0.1
Waipapa Stream (MKV02)	Atiamuri		0.8		0.3
Tirohanga Road (MKV03)	Atiamuri				0.5
Paerata Road (MKV04)	Atiamuri				1.8
	Total		0.8		2.6
Atiamuri Geothermal Field					
Upper Atiamuri West (ATV01)	Atiamuri				<0.1
Whangapoa Springs (ATV02)	Atiamuri				0.1
Matapan Road (ATV03)	Atiamuri				<0.1
	Total				0.1
Te Kopia Geothermal Field					
Te Kopia (TKV01)	Atiamuri	59.9			
Murphy's Springs (TKV02)	Atiamuri			0.2	
Te Kopia Northwest (TKV03)	Atiamuri				<0.1
Te Kopia West Mud Pools (TKV04)	Atiamuri				<0.1
Te Kopia Red Stream (TKV05)	Atiamuri				0.2
Mangamingi Station (TKV06)	Atiamuri				0.5
	Total	59.9		0.2	0.8
Orakeikorako Geothermal Field					
Waihunuhunu (OKV01)	Atiamuri		5.3		
Akatarewa Stream (OKV02)	Atiamuri			1.4	
Orakeikorako (OKV03)	Atiamuri		42.4		
Red Hills (OKV04)	Atiamuri		11.5		
Akatarewa East (OKV05)	Atiamuri				<0.1
	Total		59.2	1.4	<0.1

Site Name (Site Number)	Ecological District	Area (ha) of Site According to Ecological Significance Ranking			
		International	National	Regional	Local
Ngatamariki Geothermal Field					
Waikato River Springs (NMV01)	Atiamuri			0.6	
Ngatamariki (NMV02)	Atiamuri			1.7	
	Total			2.3	
Whangairorohea Geothermal Field					
Whangairorohea (WGV01)	Atiamuri				<0.1
	Total				<0.1
Reporoa Geothermal Field					
Longview Road (RPV01)	Atiamuri			3.6	
Wharepapa Road (RPV02)	Atiamuri			3.2	0.3
Golden Springs (RPV03)	Atiamuri			0.5	<0.1
	Total			7.3	0.3
Ohaaki Geothermal Field					
Ohaaki Steamfield West (OHV01)	Atiamuri			11.8	
Ohaaki Steamfield East (OHV02)	Atiamuri			6.8	
	Total			18.6	
Wairakei-Tauhara Geothermal Field					
Otumuheke Stream (THV01)	Atiamuri		1.8		0.4
Spa Thermal Park (THV03)	Atiamuri				0.1
Broadlands Road (THV04)	Atiamuri			29.8	
Crown Park (THV05)	Taupo				0.7
Crown Road (THV06)	Taupo/ Atiamuri			17.5	
Waipahihi Valley (THV07)	Taupo			0.3	
Te Rautehuia (WKV01)	Atiamuri			7.7	
Te Rautehuia Stream (WKV02)	Atiamuri			2.1	
Upper Wairakei Stream (Geyser Valley) (WKV03)	Atiamuri			4.7	
Wairakei Borefield (WKV04)	Atiamuri				
Te Kiri O Hine Kai Stream Catchment/ Wairoa Hill (WKV05)	Atiamuri			40.3	
Lower Wairakei Stream (WKV06)	Atiamuri			<0.1	
Karapiti Forest (WKV07)	Atiamuri				0.6
Hall of Fame Stream (WKV08)	Atiamuri			0.1	
Waipouwerawera Stream/Tukairangi (WKV09)	Atiamuri				0.1
Craters of the Moon (WKV10)	Atiamuri		44.6		
	Total		46.4	102.7	2.0
Rotokawa Geothermal Field					
Rotokawa North (RKV01)	Atiamuri			34.4	
Lake Rotokawa (RKV02)	Atiamuri		137.3		
	Total		137.3	34.4	
Tokaanu-Waihi-Hipaua Geothermal Field					
Hipaua (TOV02)	Tongariro			11.3	
Tokaanu Lake Shore Wetland (TOV05)	Taupo/ Tongariro		42.4		

Site Name (Site Number)	Ecological District	Area (ha) of Site According to Ecological Significance Ranking			
		International	National	Regional	Local
Maunganamu West (TOV07)	Taupo/ Tongariro			0.6	
Tokaanu Thermal Park (TOV08)	Tongariro/ Taupo			7.8	<0.1
Tokaanu Urupa Mud Pools (TOV09)	Tongariro			<0.1	
Maunganamu East (TOV10)	Taupo				<0.1
Maunganamu North Wetland (TOV11)	Taupo				0.9
Tokaanu Tailrace Canal (TOV14)	Tongariro/ Taupo				<0.1
	Total		42.4	19.7	0.9
Tongariro Geothermal Field					
Te Maari Craters (TGV01)	Tongariro	4.9			
Ketetahi (TGV02)	Tongariro		8.2		
Emerald Lakes (TGV03)	Tongariro	12.1			
Red Crater (TGV04)	Tongariro	0.7			
	Total	17.7	8.2		
Grand Total		205	382	242	11

Changes in the number of sites identified at each significance level from the Wildland Consultants (2004) report are the result of several factors. The increase in the number of Internationally Significant sites is largely due to the addition to the study of three sites within Tongariro National Park which are ranked as Internationally Significant due to their location within a World Heritage Site and their unmodified nature. Only three sites were previously identified as Locally significant, compared to the 25 full and five parts of sites identified as Local in this report. These are mostly sites that were not described or assessed in Wildland Consultants (2004) (for two sites additional areas were added to those sites which were subsequently ranked at a different level than the parts of the site which were identified in 2007 (i.e. Paerata Road and Otumuheke Stream). The classification of 10 previously ranked sites has been revised since 2004, due to one or more of the following factors: the updated ranking criteria, the revision of the threatened status of all New Zealand plant species by de Lange *et al.* (2009)¹, and additional information which has been collected for each site (Table 7). These latter sites are generally small sites with moderate-sized populations (on a nationwide basis) of an „At Risk’ species. These changes in rankings are described in Table 7.

¹ This review changed the threat status of many of the species that occur in geothermal sites that were ranked as threatened and at risk in de Lange *et al.* (2004).

Table 7: Geothermal sites for which the level of significance has been revised between 2007 and 2011.

Site No.	Site Name	Assessments of Relative Significance		Reason for Change of Significance Ranking
		Previous Assessment (2004-2007)	2011 Assessment	
MKV03	Tirohanga Road	Regional	Local	An 'At Risk' species, prostrate kanuka (<i>Kunzea ericoides</i> var. <i>microflora</i>), is present, but the population is small. A number of sites have larger areas of vegetation dominated by this species.
MKV04	Paerata Road	Regional (part) Local (part)	Local	An 'At Risk' species, prostrate kanuka, is present, but the site is not an important habitat for the conservation of this species.
OKV02	Akatarewa Stream	National	Regional	Reclassification* of the threat status of <i>Christella</i> aff. <i>dentata</i> ("thermal").
NMV02	Ngatamariki	National (part) Regional (part)	Regional	Reclassification* of the threat status of <i>Cyclosorus interruptus</i> .
RKV02	Lake Rotokawa	Regional	National	Based on ongoing improvements to the condition of the site, size, the wide diversity of geothermal habitats present, and the presence of a large and important population of <i>Calochilus robertsonii</i> , an 'At Risk' species.
NMV01	Waikato River Springs	National	Regional	Reclassification* of the threat status of <i>Christella</i> aff. <i>dentata</i> ("thermal").
THV05	Crown Park	Regional	Local	An 'At Risk' species, prostrate kanuka, is present, but the population is small. A number of sites have larger areas of vegetation dominated by this species.
WKV04	Wairakei Borefield	Regional	Local	An 'At Risk' species, prostrate kanuka, is present, but the population is small. A number of sites have larger areas of vegetation dominated by this species.
WKV06	Lower Wairakei Stream	National	Regional	Reclassification* of the threat status of <i>Christella</i> aff. <i>dentata</i> ("thermal").
WKV07	Karapiti Forest	Regional	Local	An 'At Risk' species, prostrate kanuka, is present, but the population is small. A number of sites have larger areas of vegetation dominated by this species.

* In 2009, the threat classification of the New Zealand's vascular flora was revised and updated (de Lange *et al.* 2009). The ranking for many species was revised including several species present in geothermal areas: *Cyclosorus interruptus*, *Christella* aff. *dentata* ("thermal") and prostrate kanuka were revised from 'Chronically Threatened' (de Lange *et al.* 2004) to 'At Risk' (de Lange *et al.* 2009). These revised rankings resulted in the significance level for some sites being revised downward. See Appendix 4 for details of 2009 threat rankings for plant species typical of geothermal areas.

6. GEOTHERMAL VEGETATION OF THE WAIKATO REGION - AN OVERVIEW

A total of *c.*734 ha of geothermal vegetation (including raw-soilfield) was mapped in the Waikato Region in this study, with an additional 106 ha of open water mapped. This is an increase of *c.*21% to the area mapped in Wildland Consultants (2004), where *c.*579 ha was mapped. The increase reflects an increase to the scope of the project rather than a real increase in the extent of geothermal vegetation and habitats. This is discussed in full in Section 8 below. Most of this change can be accounted for by the addition of existing sites to this project in Wildland Consultants 2006, 2007a, 2007b, and the current study. Additional parts of sites were also found, most notably at Waioapu South where additional areas of geothermal wetland were found.

6.1 Assessment by geothermal field

Horohoro Geothermal Field

The geothermal features of this field (an overflowing pool and a seepage) is mapped in this report as one site; Horohoro (HHV01). The site is currently surrounded by pasture, and values could be enhanced if the site were fenced to exclude stock. Species typical of geothermal habitat recorded in 2004 were *Lycopodiella cernua*, mingimingi (*Leucopogon fasciculatus*), and *Gleichenia microphylla*. *Nephrolepis flexuosa* has been recorded from this site in the past (Given 1995), but is presumed extinct at this site (Bycroft and Beadel 2007). This field has <1 ha of geothermal vegetation, surrounding hot springs. The Horohoro Geothermal Field is classified as a „Development Geothermal System’ by Waikato Regional Council¹.

Waikite Geothermal Field

The geothermal features of this site are mapped within two sites; Waikite Valley (WAV01) and Northern Paeroa Range (WAV02). The Northern Paeroa Range site was included for the first time in this report.

A total of *c.*24.9 ha of geothermal vegetation has been mapped in the Waikite Geothermal Field, most of it in the Waikite Valley site. This comprises about 3.4% of the geothermal vegetation in the Waikato Region, and is made up of *c.*5 ha of geothermal wetland, *c.*0.6 ha of nonvegetated raw-soilfield and *c.*18.6 ha of terrestrial geothermal vegetation. In addition to the above, *c.*0.2 ha of geothermal water has also been mapped in this field. A total of *c.*6.0 ha of this field was mapped as indigenous scrub and shrubland, and of this 4.9 ha was mapped as being dominated by prostrate kanuka (*c.*1.3 % of the area of vegetation dominated by this species in the Waikato Region).

Most of the vegetation mapped (24.5 ha) is contained within the Waikite Valley site and includes several disjunct areas of geothermal activity near several small bodies of open water to the north of the site, and hot springs, heated soils, sinter pavements, geothermal wetlands, and plants present on the margins of heated geothermal streams.

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

Surface water draw-off to supply a public swimming pool is the only extractive use of the geothermal resource. Extensive areas to the north of the Waikite Swimming Baths are farmed, and areas that were previously wetlands have been drained for farming purposes. Vegetation along most stream margins, and geothermal wetlands has been subjected to grazing by both cattle and stock in the past. Most of the wetlands are now fenced to exclude stock. Work is underway to restore a large geothermal wetland in the part of the site that is on the Waikite Landcorp Farm. The stream below the Corbett Road Bridge is dominated by weed species, and the geothermal areas on the Waikite Scarp are surrounded by dense areas of blackberry (*Rubus fruticosus* agg.) scrub. The site contains important habitat for a number of „At Risk’ plant species including the second largest population of *Christella* aff. *dentata* (“thermal”) in New Zealand. Five other „At Risk’ species (as per de Lange *et al.* 2009) are known from this site; prostrate kanuka, *Cyclosorus interruptus*, *Thelypteris confluens*, *Nephrolepis flexuosa*, *Dicranopteris linearis*, and *Hypolepis dicksonioides*.

The Waikite Geothermal Field is classified as a „Protected Geothermal System’ by Waikato Regional Council¹.

Waiotapu Geothermal Field

The Waiotapu Geothermal Field contains the largest area of surface geothermal activity in New Zealand (Cave *et al.* 1993). The vegetation of this field is mapped over five sites, although the boundaries of these sites are somewhat arbitrary, with geothermal vegetation being almost continuous between these five sites. A total of c.221.0 ha of geothermal vegetation was mapped, which comprises almost a third (c.30.1%) of the geothermal vegetation of the Waikato Region. As the sites are currently mapped, Waiotapu South is the largest of the sites in this field comprising c.112.4 ha of geothermal vegetation, followed by Maungakakamea (Rainbow Mountain) (c.50.6 ha), Waiotapu North (c.45.8 ha), Maungaongaonga (c.9.06 ha), and Ngapouri (c.3.1 ha). Most or all of Maungakakamea (Rainbow Mountain), Maungaongaonga, and Waiotapu South are protected and administered by the Department of Conservation. A small part of Ngapouri Station is also protected as a Covenant. Other sites and parts of these sites are in private ownership and are surrounded by farmland and plantation forests.

The area mapped in the Waiotapu Geothermal Field comprises 176.7 ha of terrestrial vegetation, c.18.0 ha of nonvegetated raw-soilfield, and c.26.3 ha of geothermal wetland. All of the area mapped as geothermal wetland was in the southern part of the geothermal field in part of the area mapped as Waiotapu South. This is the best geothermal wetland vegetation in the Waikato Region with the wetland extending beyond the area mapped into non-geothermal wetland. The geothermal portion of this wetland comprises c.32.4% of the geothermal wetland vegetation of the Waikato Region. While the wetlands present at Tokaanu are larger, they do not contain the diversity of habitat types, or the diversity of geothermal features of the Orutu Wetland at Waiotapu. The areas mapped as nonvegetated raw-soilfield (c.18% of this type in the Waikato Region) include some of the largest area of sinter terraces remaining in

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

New Zealand, as well as extensive areas of geothermally heated bare ground. The site contains *c.*176.3 ha (*c.*31.4%) of the terrestrial geothermal vegetation in the Waikato Region. The field includes *c.*198.6 ha of indigenous geothermal scrub and shrubland (which includes some extensive areas of geothermal wetland mapped as manuka scrub). Of this, 146.94 ha is dominated by prostrate kanuka scrub and shrubland (38.7% of the area dominated by this species in the Waikato Region), making this the most important field for this species and vegetation type in the Waikato Region.

Taxa present in this geothermal field classed as „At Risk’ in de Lange *et al.* (2009) are prostrate kanuka, *Cyclosorus interruptus*, *Schizaea dichotoma* (sparse), *Nephrolepis flexuosa*, *Dicranopteris linearis*, *Calochilus paludosus*, *C. robertsonii*, *Petalochilus alatus*, *Stegostyla atradenia*, and *Korthalsella salicornioides*. The population of *Cyclosorus interruptus* in Orutu Wetland is the largest population of this species present at any geothermal site in New Zealand. Other species of interest are *Lycopodiella cernua*, *S. fistulosa* and *S. bifida*, *Psilotum nudum*, *Caladenia atradenia*, *Thelymitra carnea*, *T. decora*, and *T. ixioides*.

This geothermal field, particularly the parts protected in Scenic Reserves at Maungaongaonga, Maungakakamea (Rainbow Mountains), and the Waiotapu South site contains the greatest area of habitat of any geothermal field in New Zealand. Management of pest plants, particularly wilding pines is a priority in protected areas, and some control of these species has been undertaken by land managers and the Department of Conservation recently. Extensive damage by pigs through trampling and making tracks throughout the geothermal wetland vegetation was observed in the Orutu Wetland of Waiotapu South during the current study. The Waiotapu Geothermal Field is classified as a „Protected Geothermal System’ by Waikato Regional Council¹.

Parts of the geothermal vegetation and habitats that are not protected are subject to grazing and extensive areas are dominated by pest plants. These unprotected areas are important linkages between the protected areas of geothermal habitat, and regular management of pest plants, particularly wilding trees should be undertaken. These areas should be regularly monitored for management issues and formal protection and a restoration plan for these areas would enhance and/or protect the highly significant ecological values of this field.

Mangakino Geothermal Field

At least one boiling spring was known at Mangakino but was drowned during the formation of Lake Maraetai (Cave *et al.* 1993) and is not included in the current study. No terrestrial geothermal vegetation is known to be present within this geothermal field. The Mangakino Geothermal Field is classified as a „Development Geothermal System’ by Waikato Regional Council¹.

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

Mokai Geothermal Field

Four sites within the Mokai Geothermal Field were described in this study. These comprise small areas of steam-heated activity and a small area (c.2.9 ha) of associated geothermal vegetation. This is c.0.4% of the geothermal vegetation in the Waikato Region. An additional area of c.0.4 ha was mapped as geothermal water. The northern part of the Waipapa Stream site includes the third largest population of the fern, *Christella* aff. *dentata* (“thermal”) (ranked as At Risk-Declining in de Lange *et al.* 2009) in New Zealand. Prostrate kanuka (another „At Risk’ species) was recorded from Paerata Road and Tirohanga Road. Other plants characteristic of geothermal sites include *Psilotum nudum* which is uncommon in the Waikato Region, (formally an „at risk’ species classed as „RRange Restricted’ in de Lange *et al.* 2004, but now no longer considered threatened), *Doodia australis*, *Lycopodiella cernua*, and *Campylopus capillaceus*.

A geothermal power plant began producing electricity at the Mokai Geothermal Field by drawing off geothermal fluid in November 1999 and now generates 96 MW (<http://www.mightyriverpower.co.nz/Generation/AboutUs/Geothermal/Mokai.aspx> accessed 4 July 2011). All geothermal fluid is being re-injected 4 km from the site (Stretch 2000 in Merrett & Fitzgerald 2004). Monitoring is recommended to assess the impacts of energy extraction on geothermal features in this field. This field is classified as a „Development Geothermal System’ by Waikato Regional Council¹.

Other key management issues include:

- Some geothermal features at Paerata Road are grazed by stock, and values would be enhanced by fencing. Fences should be checked regularly at Tirohanga Road to ensure stock are excluded from the site.
- Wildling pines are an issue at Waipapa Stream. Future plantation pine planting at the site should allow a buffer between the plantation and geothermal features, and any wildling trees should be regularly removed from the site.

Atiamuri Geothermal Field

Several hot springs and pools occur at the Whangapoa Springs and the Matapan Road Geothermal sites, and several other surface expressions of geothermal activity are present at Upper Atiamuri West. There is evidence from past records that the area once had hotter temperatures (Cave *et al.* 1993), and two pools are known to have been submerged by Lake Atiamuri. There are similarities between the Atiamuri and Horohoro Geothermal Fields and the two fields may be connected (Cave *et al.* 1993). A small population of *Nephrolepis flexuosa* is present by one hot pool at Whangapoa Springs. This and the neighbouring pool at Whangapoa Springs have been fenced, and considerable weed control and planting of indigenous tree species has taken place at this site since the 2004 study. The other two sites are within farmland, or in fenced gullies adjacent to farmland, with no significant ecological values found. This field

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

contains c.0.1 ha of geothermal vegetation and is classified as a „Limited Development Geothermal System’ by Waikato Regional Council¹.

Te Kopia Geothermal Field

Geothermal vegetation at Te Kopia Geothermal Field (c.59.21 ha) comprises c.8.2% of the geothermal vegetation of Waikato Region, which is the fifth largest area of geothermal vegetation within a geothermal field in the Waikato Region. This vegetation has been mapped over six geothermal sites, with most of the vegetation being present at Te Kopia (TKV01); c.58.8 ha. Most of this site is within the Te Kopia Scenic Reserve and is surrounded by a large area of indigenous vegetation; mainly forest within the Te Kopia Scenic Reserve. The geothermal vegetation of Te Kopia (TKV01) is in good condition, and this site was identified as being of International significance. The geothermal activity of this area is thought to result from steam boiling off deep chloride water. All the features result from steam heating, although chloride springs are thought to have occurred here in the past (Cave *et al.* 1993).

The vegetation at Te Kopia Geothermal Field is made up of 49.8 ha of terrestrial geothermal vegetation, c.5.6 ha of nonvegetated raw-soilfield, and c.4.4 ha of emergent wetland. An additional one hectare was mapped as geothermal water. The field has c.5% of the geothermal wetland and 8.8% of the geothermal terrestrial vegetation in the Waikato Region. Approximately 44 ha was mapped as indigenous scrub or shrubland, and c.20.5 ha of this was mapped as prostrate kanuka scrub and shrubland, which is about 5% of the total area of prostrate kanuka in the Waikato Region.

This site contains very high quality examples of geothermal vegetation. One of the largest populations in New Zealand of the fern *Dicranopteris linearis* (classed as „At Risk’ in de Lange *et al.* 2009) occurs here. *D. linearis* is known from c.24 sites in New Zealand. Murphy’s Springs contains a good sized population of *Christella* aff. *dentata* (“thermal”) (also classed as „At Risk’) with about 100 plants present. Other „At Risk’ species known from this field include *Schizaea dichotoma*, *Calochilus paludosus*, *C. robertsonii*, *Korthalsella salicornioides*, and *Nephrolepis flexuosa*.

Key management issues in Te Kopia Geothermal Field include fencing of geothermal habitat where stock may have access to „At Risk’ fern populations outside Te Kopia Scenic Reserve (e.g. Mangamingi Station and Murphy’s Springs). Pest plants should continue to be monitored and controlled in Te Kopia Scenic Reserve, particularly wilding pines. Formal protection (e.g. Covenant) should be considered for geothermal areas outside of the Te Kopia Scenic Reserve. The Te Kopia Geothermal Field is classified as a „Protected Geothermal System’ by Waikato Regional Council¹.

Orakeikorako Geothermal Field

Geothermal vegetation at Orakeikorako Geothermal Field (c.58.2 ha) comprises c.7.9% of the geothermal vegetation of Waikato Region, and is the sixth largest area

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

of geothermal vegetation in the Waikato Region. An additional 2.5 ha was mapped as geothermal water. The vegetation has been mapped over five sites with the largest areas of geothermal vegetation present at two sites; Orakeikorako (c.42.4 ha) and Red Hills (c.11.4 ha). This includes c.2.3 ha of nonvegetated raw-soilfield, c.2.7 ha of wetland, and the remainder as terrestrial geothermal vegetation. In this field, a total of c.52.6 ha of vegetation has been mapped as indigenous scrub and shrubland, with c.10.4 ha being mapped as scrub and shrubland dominated by prostrate kanuka - this is about 2.7% of the prostrate kanuka dominated vegetation in the Waikato Region.

Present day geothermal features and vegetation represent only part of what was once a spectacular geyser field (Cave *et al.* 1993). About three quarters of the geothermal features were lost when the Waikato River was dammed and Lake Ohakuri was created in 1961 (Cave *et al.* 1993). Cave *et al.* (1993) note that any development for exploitation of the Te Kopia and Ngatamariki fields would need to be investigated to establish the nature and extent of possible connections with Orakeikorako. Te Kopia is classed as a „Protected Geothermal Systems’ by Waikato Regional Council¹. Ngatamariki is a „Development Geothermal System’ and Mighty River Power has consent to develop it, however early warning monitoring wells are being drilled between Ngatamariki and Orakeikorako which will be monitored for pressure changes with protocols to ensure there is no effect on Orakeikorako (K. Luketina pers. comm.).

The two largest sites in the Orakeikorako Geothermal Field, Red Hills and Orakeikorako, contain large areas of good quality geothermal vegetation, are nationally significant sites, and are notable for a large population of the „At Risk’ fern, *Dicranopteris linearis* (classed as „At Risk’ in de Lange *et al.* 2009). As well as *D. linearis*, there are a relatively high number of other at risk species including good populations of several at risk ferns; *Christella* aff. *dentata* (thermal), *Schizaea dichotoma*, *Nephrolepis flexuosa*, *Thelypteris confluens*, and *Cyclosorus interruptus*; and the orchids *Calochilus robertsonii* and *Prasophyllum pumilum* (Given 1989). Other notable geothermal species present, include *Lycopodiella cernua*, arrow grass (*Triglochin striata*), *Schizaea bifida*, sea rush (*Juncus kraussii* var. *australiensis*), *Psilotum nudum*, and the moss *Campylopus capillaceus*.

The key management issue in this field is the management of pest plants, particularly wilding pines, Chinese privet (*Ligustrum sinense*), and black wattle (*Acacia mearnsii*). Blackberry should be controlled where present in the eastern side of Lake Whakamaru where it is currently rare. Recent control work of wilding pines at Orakeikorako has improved the long-term viability of this site. Pampas (*Cortaderia selloana*) should be controlled around any geothermal features, and royal fern in wetlands. Willows should be controlled in the geothermal wetland at Orakeikorako. Geothermal vegetation at Akatarewa East should be fenced to exclude stock.

Ngatamariki Geothermal Field

There is c.1.9 ha of geothermal vegetation in the Ngatamariki Geothermal Field containing small areas of nonvegetated raw-soilfield and geothermal wetland. The

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

vegetation has been mapped over two sites. A high proportion of Ngatamariki (NMV02) is surrounded by pine plantation. The key geothermal features at this site are the Orakonui hot springs, which are mostly protected in a DOC reserve. The Waikato River Springs are a series of springs located on each side of the Waikato River along c.200 m of river.

About 30 plants of *Cyclosorus interruptus* (a Chronically Threatened species classed as „At Risk-Declining’ in de Lange *et al.* 2009) are present at this site. Other species characteristic of geothermal sites include prostrate kanuka, *Campylopus*, arrow grass, and *Lycopodiella cernua*. *Psilotum nudum* has also been recorded here (Ecroyd 1979b). A small population of *Christella* aff. *dentata* (“thermal”) was recorded from Waikato River Springs in 2006 (Wildland Consultants 2006).

The Ngatamariki Geothermal Field is classified as a „Development Geothermal System’ by Waikato Regional Council¹. An 82 MW electricity generating development is planned in the Ngatamariki Geothermal Field possibly to be constructed by the end of 2013².

Other key management issues in this geothermal field are the monitoring and control of pest plants, and good practice in the management of surrounding pine plantations.

Whangairorohea Geothermal Field

This geothermal field has a 10 × 15 m wide geothermal spring surrounded by sedges, reeds and exotic terrestrial vegetation, the site being about 0.1 ha in size. The few pest plants surrounding the pool should be removed (e.g. poplars (*Populus* sp.), Spanish heath (*Erica lusitanica*), blackberry, and buddleia (*Buddleja davidii*)).

Reporoa Geothermal Field

Reporoa Geothermal Field contains c.7.4 ha of geothermal vegetation spread over three sites. Several unmapped areas of surface activity are also present in this field (e.g. Butchers’ Pool), but are not thought to contain any geothermal vegetation. The mapped vegetation is made up of c.4.4 ha of terrestrial vegetation, c.0.3 ha of emergent wetland, and c.2.6 ha of nonvegetated raw-soilfield.

The atmospheric influence of the Golden Springs enables the occurrence of the fern *Christella* aff. *dentata* (“thermal”) (classed as „At Risk’ in de Lange *et al.* 2009), which occurs only 14 geothermal sites in New Zealand. There is also a small population of prostrate kanuka (classed as „At Risk’ in de Lange *et al.* 2009) and some *Campylopus capillaceus*, as well as areas of manuka/mingimingi shrubland, and arrow grass herbfield.

Parts of the site at Golden Springs and Wharepapa Road are unfenced and grazed by stock, and values of the sites would improve if the sites were fenced. Geothermal features have been impacted by drainage at all sites. It is recommended that no

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

² http://www.nzgeothermal.org.nz/elec_geo.html: Accessed 24 July 2011.

further drainage of geothermal wetlands and features is undertaken at any of these sites. The Reporoa Geothermal Field is classified as a „Research Geothermal System’ by Waikato Regional Council¹.

Ohaaki Geothermal Field

The Ohaaki Geothermal Field has about 18.5 ha of geothermal vegetation which is c.2.5% of the geothermal vegetation in the Waikato Region. The vegetation here comprises c.5.3 ha of nonvegetated raw-soilfield, and c.13.16 of terrestrial geothermal vegetation. About 10.0 ha is dominated by prostrate kanuka scrub and shrubland, c.2.6% of the prostrate kanuka dominant vegetation of the Waikato Region. The vegetation has been mapped over two sites on each side of the Waikato River.

The Ohaaki Geothermal Field is classified as a „Development Geothermal System’ by Waikato Regional Council¹. From 1989, Ohaaki Geothermal Power Station supplied electricity to the national grid, and this exploitation has affected the geothermal features of both sites examined in the current survey. All geothermally influenced pools in this area are now dry and ground temperatures have decreased in places; however, in others they have increased resulting in an overall increase in the extent of geothermal vegetation (Merrett & Burns 1998a). However Merrett *et al.* (2003) found no apparent evidence of any negative impact of geothermal fluid extraction on geothermal vegetation overlying the Ohaaki Geothermal field between December 1997 and July 2003.

Other threats to geothermal vegetation in this field include the ongoing subsidence of land and subsequent inundation of existing geothermal vegetation, and the spread of wilding pines from surrounding plantation into geothermal sites. Overall the values of these sites could be enhanced through restoration including pest plant control and appropriate planting to enhance and maintain the ecological values present.

Small areas of relatively undisturbed geothermal vegetation dominated by prostrate kanuka are present. Scattered areas of monoao (*Dracophyllum subulatum*) is a feature of this geothermal field. Other species typical of geothermal habitat include *Lycopodiella cernua*, *Campylopus capillaceus* (a moss), and *Dicranopteris linearis* (known from c.24 sites in New Zealand). Arrow grass (Burns 1997a) and *Psiloum nudum* (Merrett *et al.* 2003) have been recorded in this geothermal field.

Wairakei-Tauhara Geothermal Field

The Wairakei-Tauhara Geothermal contains c.150.7 ha of geothermal vegetation, which is c.20.5% of the geothermal vegetation in the Waikato Region. The vegetation has been mapped over 16 sites with the largest sites being Craters of the Moon (44.5 ha), Te Kiri O Hine Kai Stream Catchment/Wairoa Hill (40.09 ha), Broadlands Road (29.76 ha) and Crown Road (17.48 ha). A total of c.136.3 ha was mapped as terrestrial geothermal vegetation and c.14.42 ha of nonvegetated raw-soilfield. An area of c.122.2 ha was mapped as scrub and shrubland dominated by prostrate kanuka,

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

which represents 29.0% of the prostrate kanuka dominant vegetation of the Waikato Region.

Geothermal features associated with the Wairakei-Tauhara Geothermal Field occur in both the Atiamuri and Taupo Ecological Districts. This field is classified as a Development Geothermal System by Waikato Regional Council¹. Exploitation from the Wairakei Geothermal Power Station has resulted in the decline of chloride water springs and geysers, and in shallow aquifers and hot ground. The result of this is that some sites are cooling, while others are becoming hotter, affecting the vegetation growing on the sites (Cave *et al.* 1993). The extent, distribution and composition of the geothermal vegetation of this field is continuing to change. Geothermal vegetation had decreased and/or declined in quality at most sites (e.g. Upper Wairakei Stream (Geyser Valley)), however this has been partly compensated by an increase of geothermal vegetation at the Broadlands Road site (Burns *et al.* 1995). This reflects a similar increase at Craters of the Moon, which has occurred due to draw-off from the power station (Burns 1996).

Other key threats to geothermal sites in the Wairakei Geothermal field are:

- The recent loss of vegetation to both road and industrial development, particularly sites near Taupo Township at Crown Road and Broadlands Road. The sites near Taupo are also particularly vulnerable to fire, with a fire at Crown Road in 2002.
- Grazing occurs at several sites in Wairakei Geothermal Field (e.g. parts of Te Rautehuia, and Te Rautehuia Stream). It is recommended that these areas are fenced to exclude stock.
- Pine plantation is present to the margins of many sites in this field. These provide a source of wilding pines, so all sites should be monitored for their spread. Pines should be felled away from geothermal areas when harvesting, and a buffer of at least 10 m should be established around geothermal sites. Other pest plants should be controlled in geothermal sites, e.g. pampas at Otumuheke Stream and grape (*Vitis vinifera*) vine at Upper Wairakei Stream (Geyser Valley).

At Broadlands Road, Craters of the Moon, Te Kiri O Hine Kai Stream Catchment/Wairoa Hill, and Crown Road there are relatively large areas of prostrate kanuka (classed as „At Risk’ in de Lange *et al.* 2009). Good populations of two ferns, *Cyclosorus interruptus* (a chronically threatened species classed as „At Risk-Declining’ in de Lange *et al.* 2009) and *Christella* aff. *dentata* (“thermal”) (classed as „At Risk’ in de Lange *et al.* 2009) are present at Otumuheke Stream. A small population of *Christella* aff. *dentata* (“thermal”) is also known from Hall of Fame Stream, and a small population of *Cyclosorus interruptus* is present at Waipahihi Valley. Relatively large populations of *Nephrolepis flexuosa* and *Dicranopteris linearis* are present between Te Kiri O Hine Kai Stream Catchment/Wairoa Hill, Te Rautehuia Stream, and Craters of the Moon. Other taxa present in the Wairakei-

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

Tauhara Geothermal field include *Hypolepis dicksonioides*, *Campylopus capillaceus*, *Psilotum nudum*, *Lycopodiella cernua*, and rock fern (*Cheilanthes sieberi*). *Asplenium flabellifolium* and *Fimbristylis velata* have also been recorded from the site in the past (Given 1989a), but not in recent surveys.

Rotokawa Geothermal Field

The Rotokawa Geothermal Field contains c.103.7 ha of geothermal vegetation and habitats, which is c.23.4% of the geothermal vegetation in the Waikato Region. An additional 67.9 ha has been mapped as geothermal water; specifically Lake Rotokawa. Of the c.103.7 ha, c.16.4 ha of this field was mapped as nonvegetated raw-soilfield; the extent of this type may reduce over time as the site recovers from past disturbances. The vegetation has been mapped over two sites; Lake Rotokawa (69.4 ha) and Rotokawa North (34.3 ha). The vegetation between parts of the two sites is continuous with the boundaries between them being somewhat arbitrary. Most of the Lake Rotokawa site is administered by the Department of Conservation as Lake Rotokawa Conservation Area. An area of c.64.9 ha was mapped as scrub and shrubland dominated by prostrate kanuka, which represents 17.1% of the prostrate kanuka dominant vegetation of the Waikato Region.

This field is characterised by collapse pits and eruption craters, one of which is filled by Lake Rotokawa. Large deposits of sulphur lie under and around the edge of the lake, and the surrounding area has been modified by sulphur mining. Further modification has occurred from harvesting operations in the surrounding pine plantations which dominate the northern end of this field (Cave *et al.* 1993). Considerable control of pest plants has been undertaken by the Department of Conservation in the Lake Rotokawa Conservation Area in recent years. Ongoing control of pest plants in this reserve is recommended.

The large area of prostrate kanuka scrub and shrubland is a key feature of the geothermal field. Large areas of manuka scrub and shrubland are also present. Small populations of *Nephrolepis flexuosa* and *Dicanopteris linearis* were recorded near one spring in 2004. A relatively large population of *Calochilus robertsonii* was recorded from the Lake Rotokawa site in November 2006 (Bycroft 2007). Within Lake Rotokawa, two species of flagellate algae (*Euglena anabaena* and *Chlamydomonas* sp.), a leech (*Helobdella* sp.), and larvae of *Chironomus zealandicus*, a chironomid have been recorded (Burns 2007). The blue-green alga *Cyanidium caldarum* has been recorded in and around hot springs and their outflows around the lake and the Parariki Stream, and, associated with this, larvae of the thermal mosquito, *Culex rotoruae* and the thermal fly, *Ephydrella thermarum* (Burns 2007).

This field is classified as a Development Geothermal System by Waikato Regional Council¹. The 29 MW Rotokawa power station was commissioned in 1997 (and subsequently expanded to 35 MW in 2003). Further development of the Rotokawa field has since taken place with commissioning of the 140 MW Nga Awa Purua power station in 2010, which includes the largest single geothermal turbine in the

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems>: Accessed 24 July 2011.

world¹. The impacts of this energy extraction on the vegetation and features in this geothermal field should be monitored to assist with future management of this field.

Horomatangi Geothermal Field

This geothermal field occurs on the bed of Lake Taupo. It comprises sinter-depositing springs on the bed of the lake, sinter tubes and associated specialised ecosystems². The Horomatangi Geothermal Field is classified as a „Protected Geothermal System’ by the Waikato Regional Council¹. As this Geothermal Field is under Lake Taupo, no terrestrial or emergent wetland geothermal vegetation will be present in this geothermal field, and no sites are mapped and described in this report and analysis.

Tokaanu-Waihi-Hipaua Geothermal Field

The Tokaanu-Waihi-Hipaua Geothermal Field contains *c.*59.5 ha of geothermal vegetation, which is *c.*8.1% of the geothermal vegetation in the Waikato Region. An additional *c.*3.5 ha has been mapped as geothermal water. This field contains an estimated 41.4 ha of geothermal wetland habitat; about 50% of the geothermal wetland vegetation in the Waikato Region. The boundaries of geothermal wetlands are somewhat difficult to map, so the boundaries identified in this report may require updating in the future if more information becomes available. Regardless of the exact size of the geothermal wetland it is of considerable ecological significance. Most of the area mapped as geothermal wetland was present at Tokaanu Lakeshore Wetland (*c.*39.1 ha). A small area was mapped as nonvegetated raw-soilfield (0.4 ha). About 10.8 ha was mapped as prostrate kanuka dominant scrub and shrubland, which is about 2.8% of this vegetation type in the Waikato Region.

Geothermal activity at Tokaanu has changed and, historically, this site was more extensive and spectacular than it is now. The cause of this decrease in activity is unknown, but may have been related to changes in the water level of Lake Taupo (Cave *et al.* 1993).

The geothermal vegetation, most of which has developed during the last few decades, is of relatively good quality, with few weeds. A moderate-sized population of the naturally uncommon, semi-parasitic mistletoe, *Korthalsella salicornioides* (an „At Risk’ species in de Lange *et al.* 2009), occurs at this site. *Schizaea dichotoma* (an „At Risk’ species in de Lange *et al.* 2009) is also present and there are historical records of the fern *Christella* aff. *dentata* (“thermal”) and *Nephrolepis flexuosa* (both classed as „At Risk’ in de Lange *et al.* 2009) from the site (Given 1995, de Lange *et al.* 2005). Oioi occurs at site Tokaanu Thermal Park, outside its normal coastal distribution. Tokaanu Lakeshore Wetland contains an extensive area of wetland, with steam seen rising through raupo at regular intervals throughout much of the mapped site. Most of the prostrate kanuka dominant vegetation occurs at Hipaua, however while it is presumed to be of high quality, there has been no botanical survey here since 1996

¹ http://www.nzgeothermal.org.nz/nz_geo_fields.html#Rotokawa: Accessed 24 July 2011.

http://www.nzgeothermal.org.nz/elec_geo.html

² <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems/> accessed 24 July 2011.

(Given 1996). Hipaua was ranked highly by Given due to a high diversity of edaphic factors, and for the overall integrity and maintenance of processes.

Tongariro Geothermal Field

Mt Tongariro has four areas of geothermal vegetation covering *c.*25.1 ha, or 3.4% of the geothermal vegetation in the Waikato Region. One site was not surveyed in this study (Ketetahi) and its analysis was based on aerial photographs and descriptions of Given (1995). The other three sites (Red Crater, Emerald Lakes, and Te Maari Craters) were included in this project for the first time. An estimated *c.*25.1 ha of geothermal vegetation occurs in this geothermal field, the only subalpine geothermal vegetation mapped in this study. The three sites in Tongariro National Park (Te Maari, Emerald Lakes and Red Crater) are protected, and Ketetahi is protected by the Māori owners as private land. Most of the geothermal sites are bare ground, with scattered *Rytidosperma setifolium* in cooler areas. A small population of *Lycopodiella cernua* was found in Te Maari Crater. The nearest known population of this species is at Tokaanu Thermal Park.

6.2 Assessment by Local Authority District

Geothermal vegetation in the Waikato Region is distributed relatively evenly between the Rotorua and Taupo Districts with *c.*51.1% in the Rotorua District and 48.9% in the Taupo District (see Table 8).

Table 8: Area of geothermal vegetation (includes terrestrial vegetation, nonvegetated raw-soilfield and wetland, but not geothermal water) in the Waikato Region in the Rotorua and Taupo Districts.

Administrative District	Area (ha)¹	Area (%)
Rotorua	374.9	51.1
Taupo	358.6	48.9
Total	733.5	100

6.3 Assessment by Ecological District

The majority (85.9%) of geothermal vegetation in the Waikato Region occurs in the Atiamuri Ecological District (see Table 9). Taupo Ecological District and Tongariro Ecological District contain *c.*8.9% and 5.4% of the vegetation in the region respectively.

¹ All areas (ha) given refer to the area of geothermal vegetation, not the area of the site.

Table 9: Area of geothermal vegetation (includes terrestrial vegetation, nonvegetated raw-soilfield and wetland, but not geothermal water) and geothermal water in the Waikato Region of the Atiamuri, Rotorua Lakes, Taupō, and Tongariro Ecological Districts.

Ecological District	Hydroclass/Vegetation Grouping					Total (ha)
	Geothermal Water (ha)	Geothermal Vegetation			Total Geothermal Vegetation (ha)	
		Nonvegetated Raw-Soilfield (ha)	Terrestrial Vegetation (ha)	Emergent Wetland (ha)		
Atiamuri	101.4	62.5	528.1	39.7	630.6	731.8
Rotorua Lakes	0.5	0.5	0.1	0.0	0.6	1.0
Taupo	3.5	3.3	21.1	41.3	65.7	69.2
Tongariro	0.9	25.5	11.2	0.1	36.7	37.6
Grand Total	106.2	91.8	560.5	81.1	733.66	839.7

The change in extent of geothermal vegetation from the time of European settlement to the present day was estimated for each Ecological District. Estimations are based on existing data and anecdotal evidence, and are only a rough indication of the changes that have occurred. Within Atiamuri Ecological District, an overall loss of *c.*30% of the geothermal vegetation has been estimated, compared with an estimated gain of *c.*4% within the Taupo Ecological District (Wildland Consultants 2004). There has probably been little change in the extent of geothermal vegetation in the Tongariro Ecological District.

7. CHANGES IN EXTENT OF GEOTHERMAL SITES BETWEEN 1940s/1950s AND 2007

Historical photos of 52 sites held by the Waikato Regional Council library were studied. Photos for 12 sites were not able to be located. Of the 52 sites studied, photographs for 15 sites were not clear enough to determine any site change due to uncertainty of the surrounding landscape identification or cloud cover on the historical photograph or were simply too small to identify any changes in extent. Where possible, existing literature was used to fill information gaps. Using a combination of historical photos and existing literature, the extent of geothermal vegetation has decreased in 23 out of the 37 sites able to be assessed (Table 10). In six sites, the extent of geothermal vegetation has increased compared to what was historically present, and eight sites have no discernable vegetation change.

Many of the historical photographs showed large light coloured patches, often not present in 2007 aerials. These light coloured patches may be bare ground, but could also be short-statured vegetation (reflecting light), or open water. Bare ground can be indicative of heated soils resulting in less vegetation cover. It is possible that many sites have cooled over the last 60 years as a result of geothermal extraction, resulting in a corresponding increase in vegetation cover. Causes of a reduction in geothermal vegetation cover include an increase in ground temperature beyond the capacity to support vegetation, vegetation clearance for e.g. roading, pasture, and spread of weeds.

Table 10: Summary changes in extent and composition of geothermal vegetation and habitats between historical photos and 2007 aerial photographs.¹

Site Name	Site Number	Type of Change
Horooho	HHV01	Too small to assess.
Waikite Valley	WAV01	Decrease.
Northern Paeroa Range	WAV02	No historical photos.
Maungaongaonga	WTV01	No significant change could be detected.
Ngapouri	WTV02	Decrease.
Waiotapu North	WTV03	Decrease.
Maungakakamea (Rainbow Mountain)	WTV04	Decrease.
Waiotapu South	WTV05	Decrease.
Whakamaru	MKV01	Too small to assess.
Waipapa Stream	MKV02	No historical photos.
Tirohanga Road	MKV03	No historical photos.
Paerata Road	MKV04	No historical photos.
Upper Atiamuri West	ATV01	No historical photos.
Whangapoa Springs	ATV02	No historical photos.
Matapan Road	ATV03	No historical photos.
Te Kopia	TKV01	No significant change could be detected.
Murphy's Springs	TKV02	No historical photos.
Te Kopia Northwest	TKV03	No historical photos.
Te Kopia West Mud Pools	TKV04	No historical photos.
Te Kopia Red Stream	TKV05	No historical photos.
Mangamingi Station	TKV06	No historical photos.
Waihunuhunu	OKV01	Decrease.
Akaterewa Stream	OKV02	Decrease.
Orakeikorako	OKV03	Decrease.
Red Hills	OKV04	Decrease.
Akaterewa East	OKV05	Too small to assess.
Waikato River Springs	NMV01	Too small to assess.
Ngatamariki	NMV02	Increase.
Whangairorohea	WGV01	No significant change could be detected.
Longview Road	RPV01	Decrease.
Wharepapa Road	RPV02	Decrease.
Golden Springs	RPV03	Too small to assess.
Ohaaki Steamfield West	OHV01	Increase.
Ohaaki Steamfield East	OHV02	Increase.
Otumuheke	THV01	Too small to assess.
Spa Thermal Park	THV03	Decrease.
Broadlands Road	THV04	Increase.
Crown Park	THV05	Decrease.
Crown Road	THV06	Decrease.
Waipahihi Valley	THV07	Decrease.
Te Rautehuia	WKV01	Decrease.
Te Rautehuia Stream	WKV01	Decrease.
Upper Wairakei Stream (Geyser Valley)	WKV03	Decrease.
Wairakei Borefield	WKV04	Too small to assess.
Te Kiri O Hine Kai Stream Catchment/ Wairoa Hill	WKV05	Decrease.
Lower Wairakei Stream	WKV06	Too small to assess.
Karapiti Forest	WKV07	Decrease.
Hall of Fame Stream	WKV08	Too small to assess.

¹ Ordered by geothermal field.

Site Name	Site Number	Type of Change
Waipouwerawera Stream/Tukairangi	WKV09	Increase.
Craters of the Moon	WKV10	Increase.
Rotokawa North	RKV01	No significant change could be detected.
Lake Rotokawa	RKV02	Decrease.
Hipaua	TOV02	No significant change could be detected.
Tokaanu Lakeshore Wetland	TOV03/ TOV04/ TOV05/TOV06	No significant change could be detected.
Maunganamu West	TOV07	Too small to assess.
Tokaanu Thermal Park	TOV08	Decrease.
Tokaanu Urupa Mud Pools	TOV09	Too small to assess.
Maunganamu East	TOV10	Decrease.
Maunganamu North Wetland	TOV11	Too small to assess.
Tokaanu Tailrace Canal	TOV14	No significant change could be detected.
Te Maari Craters	TGV01	Too small to assess.
Ketetahi	TGV02	No significant change could be detected.
Emerald Lakes	TGV03	Could not assess geothermal features.
Red Crater	TGV04	Too small to assess.

8. CHANGES IN EXTENT OF GEOTHERMAL SITES (2002 AND 2007 AERIAL PHOTOS)

The mapped extent of geothermal vegetation at 37 sites changed by less than 1 ha as a result of better quality aerial photographs and field survey. Sites where real changes to the extent and quality of vegetation were anticipated since the last field visit were re-visited in the field where possible. Also, additions to sites were made based on new information about areas of geothermal vegetation at particular sites. Sites in this category are Waio tapu South, Waio tapu North, Maungakakaramaea (Rainbow Mountain), and Waipapa Stream. The changes in extent of mapped geothermal vegetation at Orakeikorako and Te Kopia were largely as a result of better quality aerial photographs.

There was a real increase in extent of geothermal vegetation at one site (Waikite Valley) while there was a real decline in the extent of geothermal vegetation at another (Crown Road). Restoration works undertaken in one of the geothermal wetlands at Waikite Valley included increasing water table levels in this wetland and its surrounds (drains previously dug through this wetland had resulted in a lowered water table in this wetland). Recent restoration has resulted in a significant increase in the area of geothermal habitat at this site, which is now *c.*7 ha larger than the 2004 study. At Crown Road *c.*1.5 ha of geothermal vegetation was destroyed during land development for industrial use, and roading developments. Reasons for changes to the extent of geothermal vegetation are provided in Table 1, with more detailed notes for each site in Appendix 1.

Table 11: Changes in extent of each site between 2002 and 2007 aerial photos (as mapped in Wildland Consultants 2004, 2006, 2007a & b and current report). Reasons for change are noted in comments column. Other observed changes that have occurred at these sites since 2000 are also noted.

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Horohoro Geothermal Field						
Horohoro	HHV01	Atiamuri	<0.1 (Wildland Consultants 2004)	<0.1	No change	Not resurveyed in 2011, assessment based on 2004 study and viewing 2007 aerial photographs. No change likely.
		Total	<0.1	<0.1		
Waikite Geothermal Field						
Waikite Valley	WAV01	Atiamuri	17.6 (Wildland Consultants 2007b)	24.6	Increase	Restoration works have taken place in one of the geothermal wetlands at this site. This included increasing water table levels in this wetland and its surrounds. Drains dug through this wetland had lowered the water table in this wetland in the past. This has significantly increased the area of geothermal habitat at this site.
Northern Paeroa Range	WAV02	Atiamuri	Not surveyed	0.3	Unlikely	Not previously included in study. Significant change unlikely.
		Total		24.9		
Waiotapu Geothermal Field						
Maungaongaonga	WTV01	Atiamuri	9.1 (Wildland Consultants 2004)	9.1	No change	No field work was undertaken for this site in 2010-11. Site appeared similar in 2007 aerial photographs to the area mapped in Wildland Consultants 2004.
Ngapouri	WTV02	Atiamuri	3.1 (Wildland Consultants 2004)	3.1	No change	No field work was undertaken for this site in 2010-11. Site appeared similar in 2007 aerial photographs to the area mapped in Wildland Consultants 2004.
Waiotapu North	WTV03	Atiamuri	40.7 (Wildland Consultants 2004)	45.8	No change	Change related to additional areas of geothermal habitat discovered in 2010 survey, not a real change in the extent of geothermal vegetation and habitat at this site between the 2004 and 2010-11 studies.
Maungakakamea (Rainbow Mountain)	WTV04	Atiamuri/ Rotorua Lakes	41.7 (Wildland Consultants 2004)	50.6	No change	Change related to boundaries being better defined on better quality 2007 aerial photographs, and new geothermal habitat found during field survey. The authors do not consider that the extent of geothermal vegetation has increased at this site between the 2004 and 2011 surveys.

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Waiotapu South	WTV05	Atiamuri	69.5 (Wildland Consultants 2004)	112.4	No change	Extensive areas of geothermal wetland vegetation were identified in the 2010-11 survey and added to this site. Additional areas of geothermal vegetation were discovered near stream margins. However, the authors of this report do not consider that the overall extent of vegetation at this site has increased between the 2004 and 2010-11 studies.
		Total	164.1	221.0		
Mokai Geothermal Field						
Whakamaru	MKV01	Atiamuri	Not surveyed	<0.1	Unlikely	Not previously included in study. Significant change unlikely.
Waipapa Stream	MKV02	Atiamuri	0.7 (Wildland Consultants 2004a)	1.1	No change	An additional area of geothermal vegetation was identified in the 2011 field survey. The authors of this report do not consider that the overall extent of vegetation at this site has increased between the 2004 and 2010-11 studies.
Tirohanga Road	MKV03	Atiamuri	0.4 (Wildland Consultants 2007a)	0.2	Decrease	There has been some vegetation clearance and adjustment of boundaries based on better quality aerial photographs.
Paerata Road	MKV04	Atiamuri	1.3 (Wildland Consultants 2004)	1.7	No change.	Change related to boundaries being better defined on 2007 aerial photographs, not a real change in vegetation extent.
		Total	3.4	2.9		
Atiamuri Geothermal Field						
Upper Atiamuri West	ATV01	Atiamuri	<0.1 (Wildland Consultants 2007a)	<0.1	No change	No field assessment in 2010-11. No change likely.
Whangapoa Springs	ATV02	Atiamuri	0.1 (Wildland Consultants 2004)	0.1	No change	While the vegetation surrounding the site has improved in quality, it has not changed in overall extent.
Matapan Road	ATV03	Atiamuri	Not surveyed	<0.1	Unlikely	Not previously included in study. Significant change unlikely.
		Total	0.1	0.1		
Te Kopia Geothermal Field						
Te Kopia	TKV01	Atiamuri	56.4 (Wildland Consultants 2004)	58.8	No change	Site not field surveyed for 2010-11 study. Slight change in hectares is based on remapping of vegetation boundaries, which are more clearly identified on 2007 aerial photographs, than those used in Wildland Consultants 2004.

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Murphy's Springs	TKV02	Atiamuri	Not surveyed	0.2	Unlikely	Not previously included in study. Significant change unlikely.
Te Kopia Northwest	TKV03	Atiamuri	Not surveyed	<0.1	Unlikely	Not previously included in study. Significant change unlikely.
Te Kopia West Mud Pools	TKV04	Atiamuri	Not surveyed	<0.1	Unlikely	Not previously included in study. Significant change unlikely.
Te Kopia Red Stream	TKV05	Atiamuri	Not surveyed	0.2	Unlikely	Not previously included in study. Significant change unlikely.
Mangamingi Station	TKV06	Atiamuri	Not surveyed	0.5	Unlikely	Not previously included in study. Significant change unlikely.
		Total	56.4	59.8		
Orakeikorako Geothermal Field						
Waihunuhunu	OKV01	Atiamuri	3.0 (Wildland Consultants 2007b)	3.0	No change	Not resurveyed in 2011. Assessment based on Wildland Consultants 2007b and revising the site boundaries using 2007 aerial photographs. No change likely.
Akaterewa Stream	OKV02	Atiamuri	1.4 (Wildland Consultants 2007b)	1.4	No change	Not resurveyed in 2011. Assessment based on Wildland Consultants 2007b and revising the site boundaries using 2007 aerial photographs. No change likely.
Orakeikorako	OKV03	Atiamuri	39.2 (Wildland Consultants 2007b)	42.4	No change	Additional vegetation identified based on better detail on 2007 aerial photographs, and some additional geothermal vegetation found in 2010-11 field survey. The authors do not consider that there has been any change in the extent of geothermal vegetation and habitat at this site between 2004 and 2011.
Red Hills	OKV04	Atiamuri	11.5 (Wildland Consultants 2007b)	11.4	No change	No field survey undertaken in 2010-11. Slight refinement of boundaries based on 2007 aerial photographs.
Akaterewa East	OKV05	Atiamuri	Not surveyed	<0.1	Unlikely	Not previously included in study. Significant change unlikely.
		Total	57.4	58.2		
Ngatamariki Geothermal Field						
Waikato River Springs	NMV01	Atiamuri	<0.1 (Wildland Consultants 2006)	0.4	No change	Additional geothermal vegetation and habitat found in 2011 field survey. The authors do not consider this to be an increase in the extent of geothermal vegetation and habitat at this site. Additional areas may be found in the future when lower river levels permit full access to the site.
Ngatamariki	NMV02	Atiamuri	1.4 (Wildland Consultants 2007b)	1.5	No change	Minor change in boundaries based on remapping of site boundaries based on 2007 aerial photographs and field survey in 2011. Overall the authors consider that there has been no change in the extent of geothermal vegetation and habitat at this site.
		Total	1.4	1.9		

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Whangairorohea Geothermal Field						
Whangairorohea	WGV01	Atiamuri	Not surveyed	<0.1	Unlikely	Not previously included in study. Significant change unlikely.
		Total	<0.1	<0.1		
Reporoa Geothermal Field						
Longview Road	RPV01	Atiamuri	3.4 (Wildland Consultants 2004)	3.4	No change	Site assessment based on 2007 aerial photographs, site not field surveyed between 2010-2011.
Wharepapa Road	RPV02	Atiamuri	3.4 (Wildland Consultants 2004)	3.3	No change	Not resurveyed in 2011, assessment based on 2004 study and viewing 2007 aerial photographs. No change likely. Slight boundary changes are based on remapping site boundaries, but are not considered as real change in extent of geothermal vegetation.
Golden Springs	RPV03	Atiamuri	0.5 (Wildland Consultants 2007b)	0.5	No change	Not resurveyed in 2011, assessment based on Wildland Consultants 2007b and viewing 2007 aerial photographs. No change likely.
		Total	7.3	7.4		
Ohaaki Geothermal Field						
Ohaaki Steamfield West	OHV01	Atiamuri	10.5 (Wildland Consultants 2004)	11.7	No change	Slight change to site size is related to more accurate mapping of site boundaries on better quality 2007 aerial photographs, compared to aerials available for Wildland Consultants 2004 study.
Ohaaki Steamfield East	OHV02	Atiamuri	6.0 (Wildland Consultants 2004)	6.8	No change	Slight change to site size is related to more accurate mapping of site boundaries on better quality 2007 aerial photographs, compared to aerials available for Wildland Consultants 2004 study.
		Total	16.5	18.5		
Wairakei-Tauhara Geothermal Field						
Otumuheke Stream	THV01	Atiamuri	2.0 (Wildland Consultants 2004)	2.3	No change	Slight change to site based on remapping site boundaries, and a small additional area of geothermal vegetation and habitat found in the 2010 field survey. The authors do not consider this to be real change in the extent of geothermal vegetation and habitat at this site.
Spa Thermal Park	THV03	Atiamuri	0.1 (Wildland Consultants 2006)	0.1	No change	Slight change to site based on remapping site boundaries, not a real change in the extent of geothermal vegetation and habitat at this site.

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Broadlands Road	THV04	Atiamuri	30.3 (Wildland Consultants 2006)	29.8	No change	Slight change to site based on remapping site boundaries, not a real change in the extent of geothermal vegetation and habitat at this site.
Crown Park	THV05	Taupo	0.7 (Wildland Consultants 2006)	0.7	No change	Not resurveyed in 2011, assessment based on Wildland Consultants 2006 and viewing 2007 aerial photographs.
Crown Road	THV06	Taupo	19.0 (Wildland Consultants 2004)	17.5	Decrease	Vegetation has decreased following land development for industrial use, and roading developments.
Waipahihi Valley	THV07	Taupo	0.2 (Wildland Consultants 2004)	0.3	No change	Minor changes vegetation boundaries following restoration works, and easier access to parts of site. Overall no change in extent of geothermal vegetation and habitats at this site over these timeframes.
Te Rautehuia	WKV01	Atiamuri	7 (Wildland Consultants 2006)	7.7	No change	Slight change to site based on remapping site boundaries, not a real change in the extent of geothermal vegetation and habitat at this site.
Te Rautehuia Stream	WKV02	Atiamuri	2.2 (Wildland Consultants 2006)	2.1	No change	Slight change to site based on remapping site boundaries, not a real change in the extent of geothermal vegetation and habitat at this site.
Upper Wairakei Stream (Geyser Valley)	WKV03	Atiamuri	4.6 (Wildland Consultants 2004)	4.7	No change	Slight change to site based on remapping site boundaries, not a real change in the extent of geothermal vegetation and habitat at this site.
Wairakei Borefield	WKV04	Atiamuri	<0.1 (Wildland Consultants 2007a)	<0.1	No change	Not resurveyed in 2011, assessment based on Wildland Consultants 2007a study and viewing 2007 aerial photographs. Very small site.
Te Kiri O Hine Kai Stream Catchment/ Wairoa Hill	WKV05	Atiamuri	40.0 (Wildland Consultants 2007b)	40.1	No change	Slight change to site based on remapping site boundaries, not a real change in extent of geothermal vegetation at this site.

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Lower Wairakei Stream	WKV06	Atiamuri	<0.1 (Wildland Consultants 2007a)	<0.1	No change	Not resurveyed in 2011, assessment based on Wildland Consultants 2007b and viewing 2007 aerial photographs. No change likely.
Karapiti Forest	WKV07	Atiamuri	0.4 (Wildland Consultants 2004)	0.6	No change	Not resurveyed in 2011, assessment based on 2011 field survey and viewing 2007 aerial photographs. Minor change is based on remapping site rather than real site change.
Hall of Fame Stream	WKV08	Atiamuri	0.1 (Wildland Consultants 2004)	0.1	Unlikely	Not resurveyed in 2011, assessment based on Wildland Consultants 2007b and viewing 2007 aerial photographs. No change likely.
Waipouwerawera Stream/Tukairangi	WKV09	Atiamuri	0.7 (Wildland Consultants 2004)	0.1	No change	Minor changes to site boundaries are based on both field survey and better quality aerial photographs. No real change to the extent of the site between field surveys.
Craters of the Moon	WKV10	Atiamuri	45.7 (Wildland Consultants 2004)	44.6	No change	Changes based on viewing 2007 aerial photographs, are the result of boundaries being better defined on better quality aerial photographs, rather than any real change in the extent of geothermal vegetation at these sites.
Total			153.0	150.7		
Rotokawa Geothermal Field						
Rotokawa North	RKV01	Atiamuri	33.8 (Wildland Consultants 2004)	34.3	No change	Small units were added to the site from the authors' knowledge of the site, and based on better quality aerial 2007 aerial photographs. No real change identified in extent of geothermal vegetation of this site based on a desktop exercise.
Lake Rotokawa	RKV02	Atiamuri	68.7 (Wildland Consultants 2004)	69.4	No change	Site change based on realigning boundaries on better quality aerial photographs, rather than real site change in the extent of geothermal vegetation. Change assessed on basis of analysis of aerial photograph, not onfield assessment.
Total			102.5	103.7		
Tokaanu-Waihi-Hipaua Geothermal Field						
Hipaua	TOV02	Tongariro	8.7 (Wildland Consultants 2004)	11.3	No change	Site not field assessed in 2004-7, or 2010-11. Site boundary changes are based on better quality site photographs, rather than real site change.
Tokaanu Lake Shore Wetland	TOV05	Tongariro/Taupo	Not surveyed	39.1	No change	Not previously included in study, no real change considered likely.

Site Name	Site Number	Ecological District	Area of Geothermal Vegetation Mapped (ha)		Overall Real Change	Comments
			2004-2007	2011		
Maunganamu West	TOV07	Tongariro/ Taupo	0.6 (Wildland Consultants 2007a)	0.6	No change	Not reassessed in 2010-11. No evidence of real change.
Tokaanu Thermal Park	TOV08	Tongariro	7.8 (Wildland Consultants 2007a)	7.6	No change	Change related to better delineation on better quality aerial photographs. No field survey undertaken for 2010-11 study.
Tokaanu Urupa Mud Pools	TOV09	Taupo	<0.1 (Wildland Consultants 2007a)	<0.1	No change	Not resurveyed in 2011, assessment based on 2007a study and viewing 2007 aerial photographs. No change likely. Very small site.
Maunganamu East	TOV10	Taupo	<0.1 (Wildland Consultants 2007a)	<0.1	No change	Not resurveyed in 2011, assessment based on 2007a study and viewing 2007 aerial photographs. No change likely. Very small site.
Maunganamu North Wetland	TOV11	Taupo	Not surveyed	0.9	No change	Not previously included in study, but no change is considered likely.
Tokaanu Tailrace Canal	TOV14	Tongariro	<0.1 (Wildland Consultants 2007a)	<0.1	No change	Not resurveyed in 2011, assessment based on 2007a study and viewing 2007 aerial photographs. No change likely. Very small site.
		Total	17.1	59.5		
Tongariro Geothermal Field						
Te Maari Craters	TGV01	Tongariro	Not surveyed	4.9	Unlikely	Not previously included in study. Significant change unlikely.
Ketetahi	TGV02	Tongariro	Not surveyed	8.2	Unlikely	Not previously included in study. Significant change unlikely.
Emerald Lakes	TGV03	Tongariro	Not surveyed	11.3	Unlikely	Not previously included in study. Significant change unlikely.
Red Crater	TGV04	Tongariro	Not surveyed	0.7	Unlikely	Not previously included in study. Significant change unlikely.
		Total	N/A	25.1		
Grand Total			510	734		

9. NATURAL DYNAMICS

Many geothermal sites are very active and dynamic, and their habitats are therefore somewhat unstable. Changes in geothermal activity tend to be reflected in changes in the extent and composition of geothermal vegetation. Local increases in heat, steam production, and eruptions of mud and hot water often damage or kill surrounding vegetation, or cooling ground may lead to increased weed invasion and the decline of heat tolerant species. These changes are an integral part of the natural dynamics of geothermal sites.

10. HUMAN DISTURBANCE AND ASSOCIATED THREATS

Human disturbance and associated threats to the geothermal vegetation in the Waikato Region include a range of activities, as set out below:

- *Exploitation of geothermal fields for energy production.* This is one of the greatest threats to the viability and sustainability of geothermal vegetation and associated flora. Exploitation can cause changes to the underground geothermal system that can have the potential to change both the character of geothermal sites, and the distribution of species within them. Exploitation can result in increases in temperature (e.g. Karapiti), or decreases in temperature which result in the disappearance of species. Extraction of energy can have the potential to alter underground geothermal systems, and can both change the quality of these systems and the distribution and composition of species in vegetation of surface geothermal manifestations. For example, exploitation of the Wairakei-Tauhara Geothermal Field for electricity generation has resulted in a lowering of the water table and consequent loss of hot springs and geysers. Past collections indicate that Geyser Valley at Wairakei supported colonies of nearly all the tropical ferns and fern allies associated with thermal areas in New Zealand (Given 1989b). Most are now either completely absent or much reduced in abundance and distribution here. The cooler ground has also allowed the invasion of adventive weeds. However, in nearby Karapiti, a ten-fold increase in heat output has occurred following development of the Wairakei field (Huser 1989); botanical values for some species have been enhanced with considerable development of geothermal vegetation and large populations of plants characteristic of geothermal sites (Given 1989b).
- Large scale energy development has been undertaken in the following fields; Wairakei-Tauhara, Mokai, Ohaaki, Ngatamariki, and Rotokawa Geothermal fields. These fields have been classified as Development Geothermal systems by Waikato Regional Council¹. The Waikato Regional Council allows large-scale uses as long as they are undertaken in a sustainable and environmentally responsible manner. Horohoro and Mangakino Geothermal Fields are also classified as Development Geothermal Systems, but no large scale developments have been undertaken in these geothermal resources to date. A

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems/>: Accessed 25 July 2011.

total of c.277.7 ha of geothermal vegetation was mapped in Development Fields, comprising c.38% of the mapped geothermal in the Waikato Region.

- Two geothermal fields (Atiamuri and Tokaanu-Waihi-Hipaua) are classified as Limited Development Geothermal Systems. The Waikato Regional Council allows takes that will not damage surface features¹. A total of c.59.6 ha of geothermal vegetation was mapped in Limited Development Geothermal Systems, comprising c.8% of the geothermal vegetation in the Waikato Region.
- The Reporoa Geothermal Field is classified as a Research Geothermal System, because the Waikato Regional Council considers that not enough is known about the system 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 allowed¹. A total of 7.3 ha of geothermal vegetation was mapped in this Geothermal Field, which represents c.1% of the geothermal vegetation in the Waikato Region.
- Six Geothermal Fields are protected from development and classified as protected geothermal systems by Waikato Regional Council. These are Horomatangi, Orakeikorako, Te Kopia, Tongariro, Waikite and Waiotapu Geothermal Fields. These fields 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. A total of c.389.0 ha of geothermal vegetation was mapped in Protected Geothermal Systems, representing c.53% of the geothermal vegetation in the Waikato Region.
- *Tourism and Recreation.* Considerable damage can result from the construction of facilities such as tracks, roads and buildings, and from the combined effects of large numbers of visitors, especially to popular tourist sites such as Waiotapu, Wairakei, and Maungakakamea (Rainbow Mountain), Craters of the Moon, and Upper Wairakei Stream (Geyser Valley, and Orakeikorako). Some sites such as Craters of the Moon have produced a plan to reduce the impacts of tourists to these sites, by discouraging visitors from walking off formed tracks. Geothermal sites are particularly vulnerable to trampling damage, particularly populations of threatened ferns, and prostrate kanuka dominant vegetation.

Attempts to „tidy’ or otherwise „enhance’ areas for tourism and recreation can also degrade the geothermal vegetation. Mowing or slashing geothermal vegetation, the indiscriminate use of herbicides for weed control, replacement of „scruffy’ geothermal vegetation with grass or other introduced plants and the application of fertiliser to promote growth of non-thermal vegetation all threaten the viability of geothermal vegetation.

Vegetation and features at Crown Road have been destroyed for motorcross track construction.

¹ <http://www.waikatoregion.govt.nz/environmental-information/Geothermal-resources/Classifying-geothermal-systems/>: Accessed 25 July 2011.

Mountain bikers should be discouraged from riding in vegetation and features at Craters of the Moon and other Wairakei sites. This should also be the case if a mountain bike track is constructed at Maungakakamea (Rainbow Mountain).

- *Dumping of Rubbish.* Dumping of garden refuse leads to the establishment of garden escapes and other weeds. Dumping of other rubbish is a problem at some sites, e.g. Wharepapa Road, Crown Park, Otumuheke, and Ngapouri, and it threatens the viability of geothermal vegetation, as well as being unsightly.
- *Pest Plants.* Adventive plants, particularly blackberry and wilding pines, are the most obvious threat to most sites. While weeds will generally not survive on hotter sites, species such as blackberry, wilding pines, silver birch (*Betula pendula*), buffalo grass (*Stenotaphrum secundatum*), Montpellier broom (*Teline monspessulana*), tree lucerne (*Chamaecytisus palmensis*), Himalayan honeysuckle (*Leycesteria formosa*), broom (*Cytisus scoparius*), Spanish heath, *Cotoneaster glaucophyllus*, and pampas (mainly *Cortaderia selloana*) readily invade cooler ground around the margins of geothermal sites, e.g. Maungakakamea (Rainbow Mountain), Te Kopia, Lake Rotokawa, and Waiotapu. Some pest plants are site specific and require urgent management, for example *Cyperus involucratus* and ivy (*Hedera helix*) are a significant threat to populations of *Nephrolepis flexuosa* and geothermal vegetation at Waikite. Weed control methods need to avoid or minimise risk to geothermal vegetation. The protection of any rare and threatened species present is important, e.g. *Christella* aff. *dentata* (“thermal”) at Waikite Valley. Each site larger than 10 hectares (apart from those in Tongariro National Park) ideally should have a management plan for pest plants to monitor and control pest plants at these sites.
- *Domestic Livestock Damage.* Where livestock have access to geothermal vegetation they are a major threat to its viability, and stock-proof fencing is a high priority, e.g. the north-east area of Waikite Valley. Livestock cause damage to vegetation by grazing, trampling and pugging of the ground surface and open up sites for weed invasion. Stock can cause considerable damage to sites by congregating in the warm areas during cold weather. Deer were noted to have caused considerable damage to some units by trampling in prostrate kanuka shrubland at Te Rautehuia Stream in 2006.
- *Plantation Forestry and Shelterbelts.* A number of geothermal sites in the Waikato Region are adjacent to plantation forest and wilding pines are invading the geothermal vegetation, particularly around the margins. For example seven species of wilding pines are known from Maungakakamea (Rainbow Mountain), and earlier reports noted it covering 6-20% of the geothermal vegetation. However considerable pine control work has been undertaken at this site by the Department of Conservation. Pine control has also taken place at neighbouring Waiotapu, Te Kopia, Orakeikorako and several Wairakei sites. Where geothermal areas adjoin plantations, management and harvesting operations need to be undertaken with care to avoid damaging the geothermal vegetation or associated buffer vegetation. Such damage can allow weed invasion and wind access, and threaten the viability of geothermal vegetation. The adverse effects of plantation forestry on geothermal sites needs to be addressed, as recommended by Given

(1995), who emphasised the importance of buffer zones for indigenous vegetation, of which there are currently few.

Some sites (e.g. Northern Paeroa Range) are surrounded by shelter belts. These should be managed to ensure that trees are not felled into geothermal sites.

- *Introduced Pest Animals.* Animal pests such as possums, deer and pigs can threaten the viability of indigenous vegetation associated with geothermal sites. Control is required where pest animals are causing problems. Significant damage by pigs was noted at Waitapu South in Orutu Wetland. This is the best quality geothermal wetland in New Zealand, and control of pigs should be undertaken to reduce their impacts on this site.
- *Fire.* Geothermal vegetation is frequently dominated by flammable species such as prostrate kanuka and monoao and great care needs to be taken with fire in the vicinity of geothermal sites. Fire has been a problem at several sites in the Waikato Region including Crown Road. Smoking should be discouraged from all geothermal sites.
- *Genetic Pollution.* The planting of indigenous species around geothermal areas using plants sourced from other parts of New Zealand can result in genetic mixing of different ecotypes (e.g. see Wassilief and Timmins 1984, Simpson 1992). Only locally-sourced plants should be used, say from within the same ecological region or district.
- *Wetland Infilling and Drainage.* Some geothermal activity is associated with freshwater wetlands, and these sites are vulnerable to infilling and drainage, which are common threats to wetlands. Wetlands have been much reduced in the Waikato Region and remaining wetlands deserve a high level of protection.
- *Industrial/Residential/Roading Development:* Sites near urban areas have been destroyed by replacing vegetation for industrial, residential and roading developments. This has been particularly noted at sites near Taupo where the new State Highway 1 bypass around Taupo has passed through the Crown Road site, and areas to the south of the site have recently been converted to industrial land use.

11. FUTURE MANAGEMENT

11.1 Regulatory controls

All areas of geothermal vegetation ranked as being significant are worthy of formal protection and management to protect them from the threats listed above. Some sites that have been assessed as locally significant, or regionally significant may improve in condition over time if protected, and could warrant a higher ranking in the future.

11.2 Buffers and connections

Protective buffers enhance the viability of natural areas and are an important management issue. They buffer sensitive ecosystems from external modifying influences such as wind and weed invasion. Geothermal habitats were previously surrounded by larger areas of non-geothermal indigenous vegetation, which also previously provided connective links or corridors to other geothermal sites. Connections need to be protected or enhanced wherever possible. Many geothermal sites are relatively small and currently have inadequate buffers.

The presence of surface geothermal activity can fluctuate at a particular location and across the landscape. A good sized buffer is desirable around many geothermal sites to allow for this variability.

11.3 Land status and protection

Private Land

Many sites containing geothermal vegetation with significant conservation values are located on private land. Formal legal protection (e.g. by covenant) would be warranted for these sites. The current management of some privately-owned sites is ecologically unsustainable, and land management agencies need to consider opportunities to promote and fund physical protection and restoration works (e.g. fencing) for geothermal features in private ownership.

Protected Sites

Some legally protected sites (e.g. reserves administered by District Councils or the Department of Conservation) require physical protection works, e.g. control of wilding pines. Some reserves (or parts of them) may also warrant an upgraded classification to reflect their relative significance for nature conservation.

11.4 Ecological restoration

Ecological restoration of degraded geothermal sites would enhance the conservation values and viability of many areas - particularly the smaller areas.

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