Waikato Regional Council Technical Report 2022/34

Restoring and protecting karst lands in the Waikato

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

Prepared by:
PW Williams (The University of Auckland), E Overdyck (Waikato Regional Council) and I Millar (New Zealand Speleological Society)

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

Cover Photo courtesy of B Hayward

March 2023

Document #: 24195112

Peer reviewed by:
Bruce Clarkson Date February 2023

Approved for release by:
Mike Scarsbrook Date March 2023

Acknowledgement

The authors would like to acknowledge the valuable contributions of Bruce Clarkson and Bruce Hayward in preparing this document. An initial draft was reviewed by Bruce McAuliffe, Mike Scarsbrook & Yanbin Deng. Bruce Clarkson has provided a final peer review.

Table of Contents

Abstract

This document contributes to Waikato Regional Council's karst management programme by providing information for landowners, land managers and communities on the value, uniqueness and protection of karst features. Karst ecosystems are naturally uncommon and are considered significant natural areas for biodiversity protection (Waikato Regional Policy Statement 2016). Many rare and specialised species are associated with this habitat including several plant and animal species unique to Waikato karst. Historic vegetation loss and landuse change across the region has altered many karst ecosystems and natural karst processes. Ecological values, both above ground and below ground, are threatened by ongoing land use change and inappropriate management practices. Unique karst hydrology requires consideration of landuse practice beyond surface catchment boundaries due to the subsurface processes occurring and the potential for underground stream connection between catchments.

Much of Waikato's karst is on privately owned land and knowledge of the physical karst landscape and ecosystem processes will empower land managers to protect their karst features and associated biodiversity values. Fencing off, revegetation, pest control and eliminating the practice of dumping rubbish in karst sinkholes are some of the most important measures land managers can take to protect the karst landscape. A raised awareness of opportunities for action and support will improve the resilience of karst ecosystems in the region.

1 Introduction

Over the last three decades Waikato Regional Council (the council) has been developing a programme to support the protection of karst lands across the region. Over the same period the Department of Conservation has sought to address more effective management of karst across New Zealand, particularly on public conservation land (Urich 2002, Department of Conservation 1999). Many karst sites meet the criteria for protection under the Resource Management Act (1991), Section 6, as being nationally important (b) outstanding natural features and landscapes, and (c) significant indigenous vegetation and significant habitats of indigenous fauna. The natural scarcity of karst ecosystems meets the criteria to be considered as significant natural areas (SNA) for indigenous biodiversity protection in the Waikato region (Criteria 5 Table 11-1, Waikato Regional Policy Statement 2016).

The identification and assessment of Waikato's karst areas for biodiversity management (Floyd and Clarkson 2009) has enabled the prioritisation of sites based on ecological and geomorphological values (Clark et al. 2017). A workshop of local karst experts and follow up information gathering (Lewis 2018) has provided further input on priority karst sites in the Waikato region. These sites have now been mapped (Hayward 2022) and a methodology developed to rank karst sites for both ecological significance and management priority (Taylor-Smith et al. 2020).

Large areas of karst in the Waikato occur on land in private ownership. Consequently, during the assessment process a need was identified for karst-specific restoration guidelines and publicly available information promoting the protection, management and restoration of karst lands for landowners and land managers. The council has subsequently produced a public factsheet introducing Waikato's karst landscapes and promoting restoration management, which is available on the council website (https://waikatoregion.govt.nz/assets/WRC/6964Karstlandscapefactsheet.pdf). This technical report supports the factsheet and provides greater detail on the processes and values inherent in Waikato's karst landscapes. Recommendations include measures that can be taken by landowners, land managers and communities to support the protection of these unique landscapes.

2 Methodology

This report draws on technical knowledge of karst processes and ecosystems presented with reference to examples from the Waikato region. The authors bring together expertise on hydrology and geomorphology (PW), aboveground ecology and restoration (EO), and cave and subterranean fauna (IM). This has been supplemented by relevant literature and further expert input from Bruce Clarkson (aboveground ecology and restoration), Bruce Hayward (geology and geomorphology), Mike Scarsbrook (karst aquatic ecosystems) and Bruce McAuliffe (resource management policy).

Field visits ground-truthing the priority karst sites and council workshop discussions have contributed to examples and photographs presented.

3 The karst landscape

Karst is a limestone landscape with sinkholes, fluted rocky outcrops, disappearing streams, underground rivers, caves, natural bridges and springs. It develops because limestones and marble that are made of calcium carbonate ($CaC0_3$), once deposited on ancient ocean floors and then uplifted and exposed to erosional processes, are especially susceptible to solution by rainfall which dissolves the rock. But not all limestones are karstified, because some are too impure, containing clay and silt which clog up developing underground passages.

In the Waikato region, karst landscapes are particularly well developed on the pure limestones exposed around Te Kuiti, Waitomo and Piopio, but are also found near the west coast between Kawhia, Raglan and Port Waikato.

Karst landscapes develop through a complex interaction of many processes including climate, geology, ecology, geomorphology and hydrology. The underground parts of the karst landscape are strongly influenced by the environment on the surface.

3.1 Pseudokarst

Some other rocks like basalt are also slightly soluble, so sometimes display solution flutes on rocky outcrops, but although not soluble enough to have solution caves and sinkholes the solution flutes are karst features. Landforms such as deep fissures, rocky pillars and dry valleys are found on ignimbrite rocks in the Waikato, but these features are not the product of rock solution, so they are not karst landforms, but could be termed pseudokarst because they are karst-like.

3.2 Karst formation- karstification

The solubility of limestone encourages joints and faults in the bedrock to be widened and penetrated by surface runoff, and so over time this enables streams to sink underground and to develop caves (Figure 1). Because the rock is dissolved by rainwater, its removal is not obvious; yet every year in the Waikato region runoff carries away in solution about 70 cubic metres (around 186 tonnes) of limestone from every square kilometre of karst landscape. It is this dissolving of the bedrock that is responsible for the creation of most sinkholes, although some are also formed by the collapse of cave roofs. The process of turning limestone rock into terrain with caves and sinkholes is called karstification.

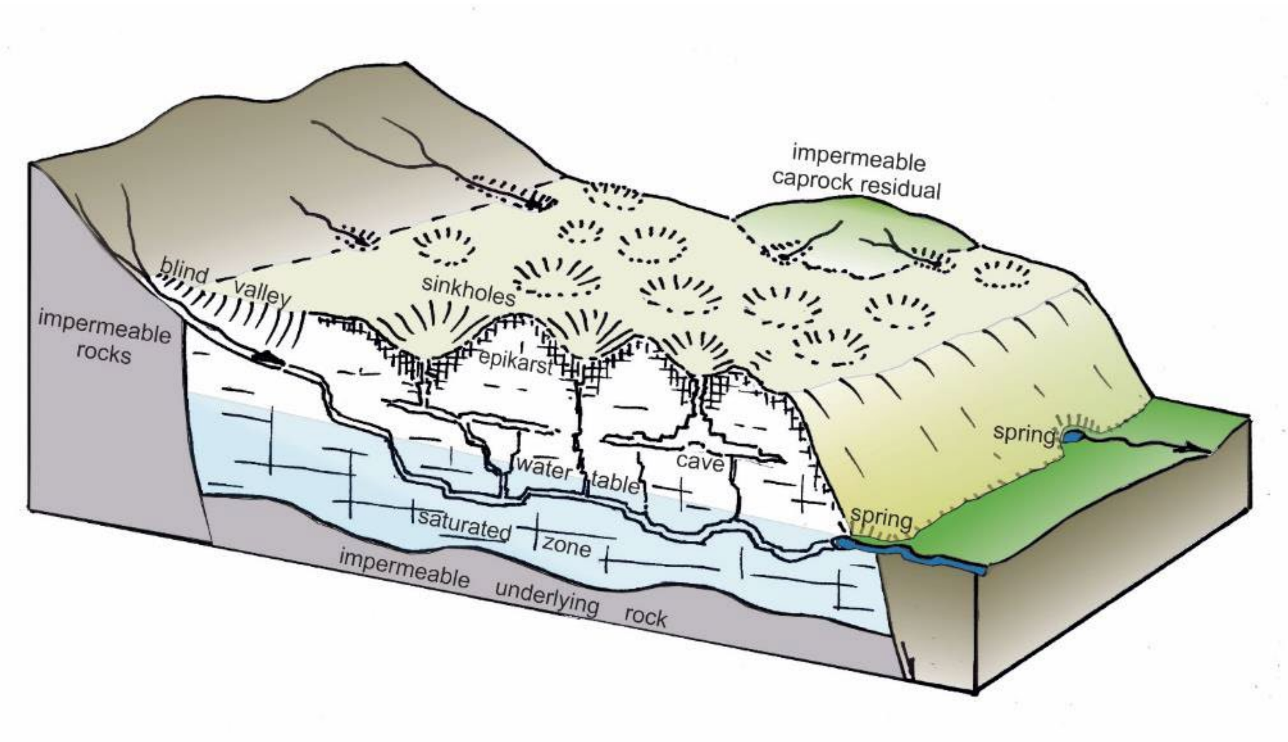

Figure 1. Schematic depiction of typical three-dimensional characteristics of a limestone landscape in the Waikato region, including its surface karst topography and its subsurface cave and groundwater system.

These natural processes have been going on in the Waikato region for more than a million years, so sinkholes and caves can be numerous and are intricately connected with underground streams, which can travel several kilometres before reappearing at the surface again.

3.3 Karst hydrology

The hallmark of karst country is the sinkhole (Figure 2). It provides the same natural service in the karst landscape as a valley in a normal landscape, i.e., it drains rainwater, in this case funnelling it underground. The karst surface in some places is intensely pocked with these crater-like depressions (Figure 3). They are packed closely together like a giant egg-tray, collect all the rainfall, and convey it underground. Near the Lost World Cave, for example, there are about 55 sinkholes per square kilometre. They average around 160 m in diameter and 60 m or so in depth, although their dimensions vary widely.

Every one of these sinkholes directs runoff downslope to a central low point from where it drains into caves, sometimes quickly if there is an open shaft, sometimes slowly if the bottom has a thick covering of soil or if the shaft is blocked with weathered debris (Figure 4). Where sinkhole country still has its natural bush cover, rainfall escapes underground more quickly, because the trees and their roots restrain soil movement and so permit natural rock fissures on the sinkhole floor to remain more open.

Figure 2. Karst sinkholes (dolines) on farmland near Waitomo. Photo: P. Williams

Figure 3. Oblique aerial view across a limestone landscape packed with sinkholes. Terrain of this type where neighbouring sinkholes occupy all the available space is sometimes known as polygonal karst, because the high ground around the sinkhole follows a polygonal pattern. Photo: P. Williams

Figure 4. Buried soil-filled shafts revealed in a limestone quarry near Te Kuiti. These old karst features were formed by collapse, but then later covered and hidden by volcanic deposits. Only a shallow basin at the surface would have indicated their presence prior to quarrying. Photo: P. Williams

Because drainage in karst regions is subterranean, the surface of the landscape has relatively few streams, but subsurface streams are plentiful. There they flow through cave passages like intricate storm-water sewer systems, receiving water that has seeped through from overlying sinkholes and conveying it towards a nearby spring. The flow rate in cave streams is about the same as in a surface river and there is little or no filtration; so, what comes in goes out, usually in a matter of hours to a few days. Although there may be the expectation that karst springs are pure, in the Waikato they are generally no cleaner than surface rivers.

When there is a saturated zone underground with water stored in flooded caves and fissures, it behaves hydrologically like an underground lake and so delays the outflow. Although some small springs may run dry, many larger karst springs persist as water sources through dry seasons, because they drain groundwater stored in a large volume of fissured bedrock. Karst water that sustains the flow of springs is a mixture of that which has flowed quickly through caves and that which has seeped more slowly through fissures and pores.

3.4 Karst land types

Dolines and tomos

Signature karst landforms are sinkholes (known scientifically as ‘dolines’). Most are funnel or bowl like enclosed basins formed by solution of the rock (‘solution dolines’), although some more cylindrical and steeper sided ones developed from collapse of an underlying cave (‘collapse dolines’) – the Lost World sinkhole with its 100 m abseil pitch is an excellent local example (Figure 5). A large area of closely packed dolines gives rise to terrain that resembles a huge egg-tray with hollows bounded by hilly ridges that have a honeycomb pattern and, because of the geometrical pattern of adjoining divides around the basins, the country is sometimes described as ‘polygonal karst’. When collapse occurs in a cave, it sometimes penetrates right through the rock from the cave roof up to the surface, where foundering of bedrock produces a collapse sink. But sometimes smaller collapses occur in voids not far beneath the soil surface, leading to a thick plug of soil dropping down into a cavity in the bedrock. These rupture the soil, but do not necessarily reveal the bedrock beneath (Figure 6). They are locally known as ‘tomo’, but internationally are referred to as ‘dropout dolines’.

Figure 5. ‘Lost World’ shaft was formed by the bottom of a sinkhole collapsing into a cave, in this case involving a 100 m direct drop to the underground Mangapu River west of Te Kuiti. Photo: P. Williams

Figure 6. Much of the Waikato karst country is thickly mantled by volcanic ash deposits. The roofs of shallow caves in the limestone sometimes stope upwards, causing soil cover to collapse into underlying voids. This produces dropout-dolines, locally known as 'tomo'. Photo: P. Williams

Figure 7. The upper Waitomo Stream, shortly after crossing onto limestone, disappears underground in a stream-sink (or swallow hole). Photo: P. Williams

Blind valleys

Another characteristic feature of karst landscape is sinking streams that terminate in 'blind valleys'. The drainage collects on higher ground composed of other rocks and then flows onto limestone, where it is absorbed underground in a stream-sink also sometimes called a submergence or swallow hole (Figure 7) or, when particularly big, a blind valley. The larger streams follow normal valleys that simply terminate abruptly against a cliff, at the foot of which the stream disappears into a cave. The most spectacular blind valley in the Waikato Region is at Lake Disappear, north of Aotea Harbour, where the Pakihi Stream ends in a deep valley (Figure 8). When the stream floods, its sink cannot absorb all the incoming water, so it back-floods the valley creating a temporary lake. Other examples of streams with blind valleys in the region are the Mangawhitikau and Mangapu to the west of Te Kuiti.

Figure 8. Lake Disappear is formed by the Pakihi stream in a blind valley where the stream flows underground into limestone in the foreground. Photo: B. Hayward

Fluted rock or karren

Smaller but widespread karst surface features include solutionally sculpted rocky outcrops (Figure 9). These go by the general name of 'karren' and are sometimes prized as curiously sculpted features for rock gardens. Karren can be recognised by their solutionally fluted surfaces where water has dissolved the rock into natural gutters. In fact, most of this sculpting originally occurred beneath mossy leaf litter within natural rain forest but has been exposed by land clearance. It also occurs around the edges of swamps where rock can acquire a gruyere appearance. Karren are found on limestone outcrops, sometimes on hilltop culminations between doline basins with residual bush amongst the rocks.

Figure 9. Outcrops of limestone are fluted vertically by solution runnels collectively termed karren. They were originally formed beneath native bush, where the rocks would have been draped with mosses, lichen and forest litter. This would have provided a damp sponge-like cover over the outcrops and a relatively acidic environment in which limestone solution was enhanced. Photo: P. Williams

The epikarst

The third dimension – the underworld of caves and its associated groundwater system and biota – is an especially important characteristic of karst landscapes. The link between the surface and the subterranean realm is a zone known as the epikarst, also termed the subcutaneous zone. It includes the highly weathered bedrock beneath the surface and any soil that may mantle it. Usually, it is about 10 m in thickness. The epikarst occurs because the rainwater that dissolves karst is a weak acid, carbonic acid, which is made by dissolving carbon dioxide gas in water (as in soft drinks). The gas comes from the atmosphere and rain dissolves it as it falls, but much more comes from the respiration and decomposition of organisms in the soil. Hence infiltrating rainwater acquires more carbon dioxide as it percolates through the soil. This acidified water then encounters limestone and starts to dissolve it, but its capacity to dissolve the rock diminishes with distance from the main source of carbon dioxide (the soil). So as water percolates downwards into and through the rock, its ability to further dissolve limestone gradually diminishes until it eventually loses its acidity, becoming saturated with calcium carbonate. The effect of this process is for bedrock to be most highly weathered just beneath the soil. Since water penetrates the rock by percolating into joints and fissures, those closest to the surface are most widened by solution, but the width of opened fissures tapers downwards. The joints close with depth so that when it rains water soaks into the surface quickly, trickles downwards but then tends to pond as the fissures reduce in width with depth. There is a bottleneck effect and incoming water gets detained in the epikarst. From dye tracing studies, water is known to disperse and mix laterally in the epikarst and can take several months to flow through. Importantly, it is the epikarst that catches unwanted spillages and infiltrating wastewater from the surface.

The epikarst not only provides important water storage, but also provides a habitat for rare stygobitic (aquatic) species and it is the water leaking from the epikarst zone that sustains the drips of stalactites in caves even through a long dry summer. Some terrestrial cave animals (troglobites) may also live in the epikarst above the water level.

Caves

Caves are absolutely typical of karst, because drainage is routed underground. Most of the biggest caves in the Waikato region are found downstream of stream-sinks such as the Glowworm Cave and Ruakuri with stream passages supporting tourist activities like glowworm viewing and blackwater rafting. Gardners Gut Cave is the longest system in the Waikato region with a total of 12.2 km of surveyed passages. Its underground streams follow a dendritic pattern (like veins in a leaf) similar to a normal surface river, with main stream and tributary passages.

In most respects cave streams behave like their surface counterparts in rocky channels, except that they flow in a tunnel. Caves also contain high level passages that were formed by ancient streams but were abandoned when the water found a lower route. These dry passages operate as important natural vaults, collecting and protecting evidence of past times such as moa skeletons, tuatara bones and those of other organisms that were once common in the region. Caves beneath country still covered by natural bush still operate as natural systems and support a surprisingly large underground fauna. Caves beneath farmland are modified both in their hydrology and ecosystems.

4 Contrasting karst with other landscapes

4.1 Unique karst landforms

Karst only occurs on rocks that are particularly soluble, like limestone, and the landforms produced are quite different from those found on normal landscapes made of relatively insoluble rocks and drained by surface rivers. Valleys in the normal landscape are replaced by internally draining basins (sinkholes) in the karst landscape that direct water underground. Subterranean streams flow through extensive networks of caves (that can be many kilometres long) and reappear again at springs around the margins of the karst. Rocky outcrops of limestone are dissolved by rainwater, producing solution flutes known as karren; joints are widened by solution into corridors; and horizontal discontinuities on outcrops are etched, resulting in exposures resembling ‘pancake’ rocks (Figure 10). Karren are sometimes also found on other rock types that are susceptible to solution, such as basalt, but are much better developed on limestone because it is even more soluble.

Figure 10. Remnant coastal scrub on fluted karren showing 'pancake' rock formation caused by horizontal solution of limestone, Rakaunui karst, Kawhia harbour. Photo: B. Hayward

4.2 Unique karst hydrology

Unlike in most other landscapes, karst drainage is mainly subterranean (Figure 11). Few surface rivers flow across limestone, because they sink subsurface. Drainage from sinkholes and stream-sinks disappears out of sight and it is difficult to predict where it goes. Runoff collects in caves that may lead off in unexpected directions, and there is no way of guessing the route from the surface topography, because karst water often crosses beneath surface watersheds (Figure 12).

When streams that have collected on other rocks drain onto limestone, they soon disappear and then flow in caves, later to reappear at springs. Some springs are large because they drain extensive catchments, but the water that emerges is often not as pure as one might expect, because there is little natural filtration in cave passages and surface runoff passes through the system quite quickly, not taking long enough or having the sunlight needed for pathogenic organisms to die off.

Rivers that have cut right through the limestone onto impervious rocks beneath follow gorges bounded by limestone cliffs. Some of these gorges were once caves that have been unroofed over time by progressive cave ceiling collapse (Figure 13). Natural bridges remain where some of the former cave passage persists.

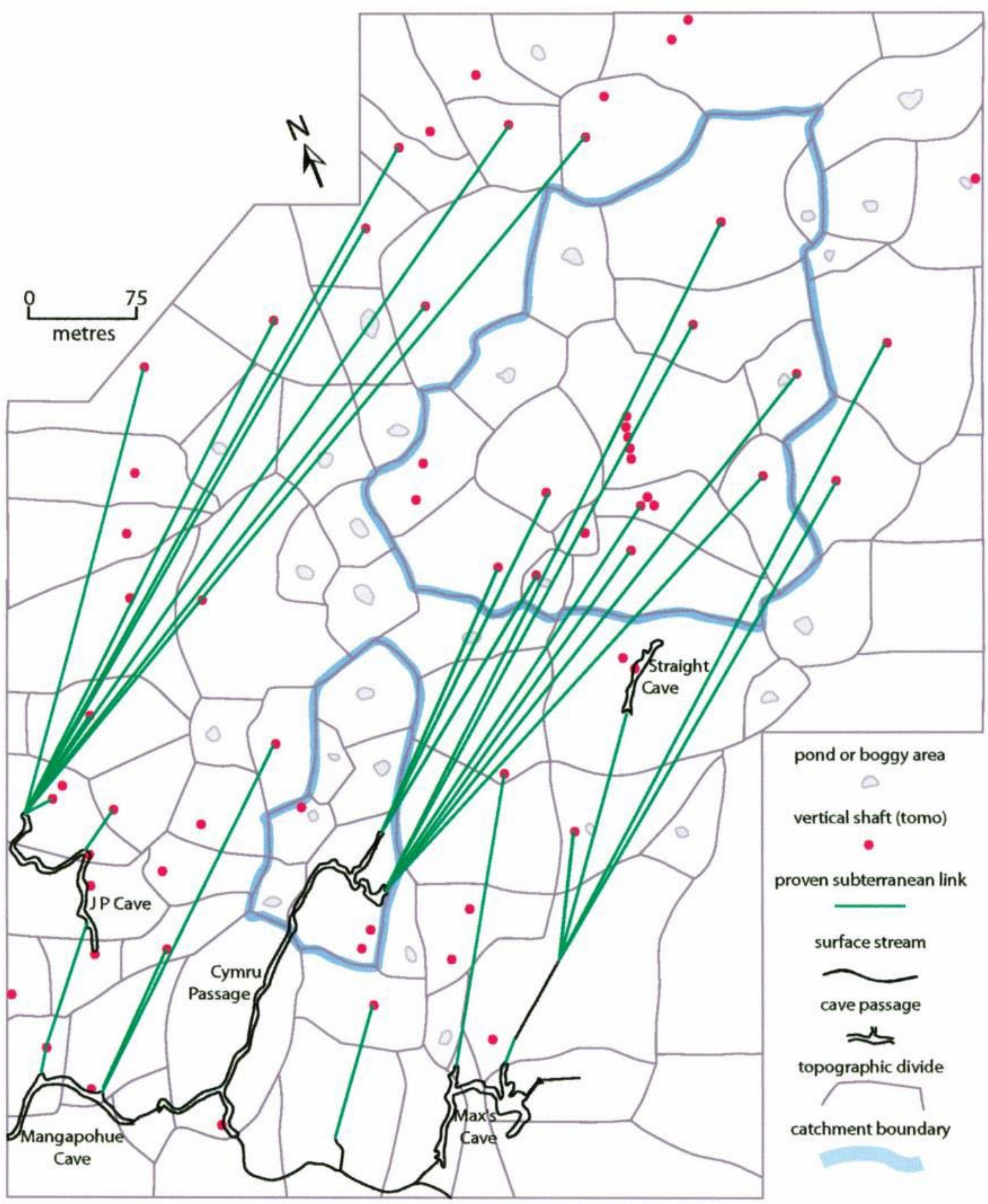

Figure 11. The map depicts an area of karst of about 0.4 square kilometres under QEII bush reserve at Awatiro. The polygonal mesh shows surveyed topographic divides around the perimeters of closed depressions. Near their base, some sinkholes have small open holes or shafts, whereas others have boggy areas of ponding. Part of the area is underlain by known stream caves, the location of their passages being shown, although there are other caves too small to map that also act as effective natural drains. Tracer dyes were placed in some of the sinkholes during rainy periods and detected later in cave passages. Straight lines (green) were drawn between dye input points and where reappearance was first detected. In this case we see that underground drainage is generally to the southwest, crossing beneath the surface divides of numerous karst depressions. Once reaching a cave stream, the tracer is carried to the nearest spring (from Gunn 1978).

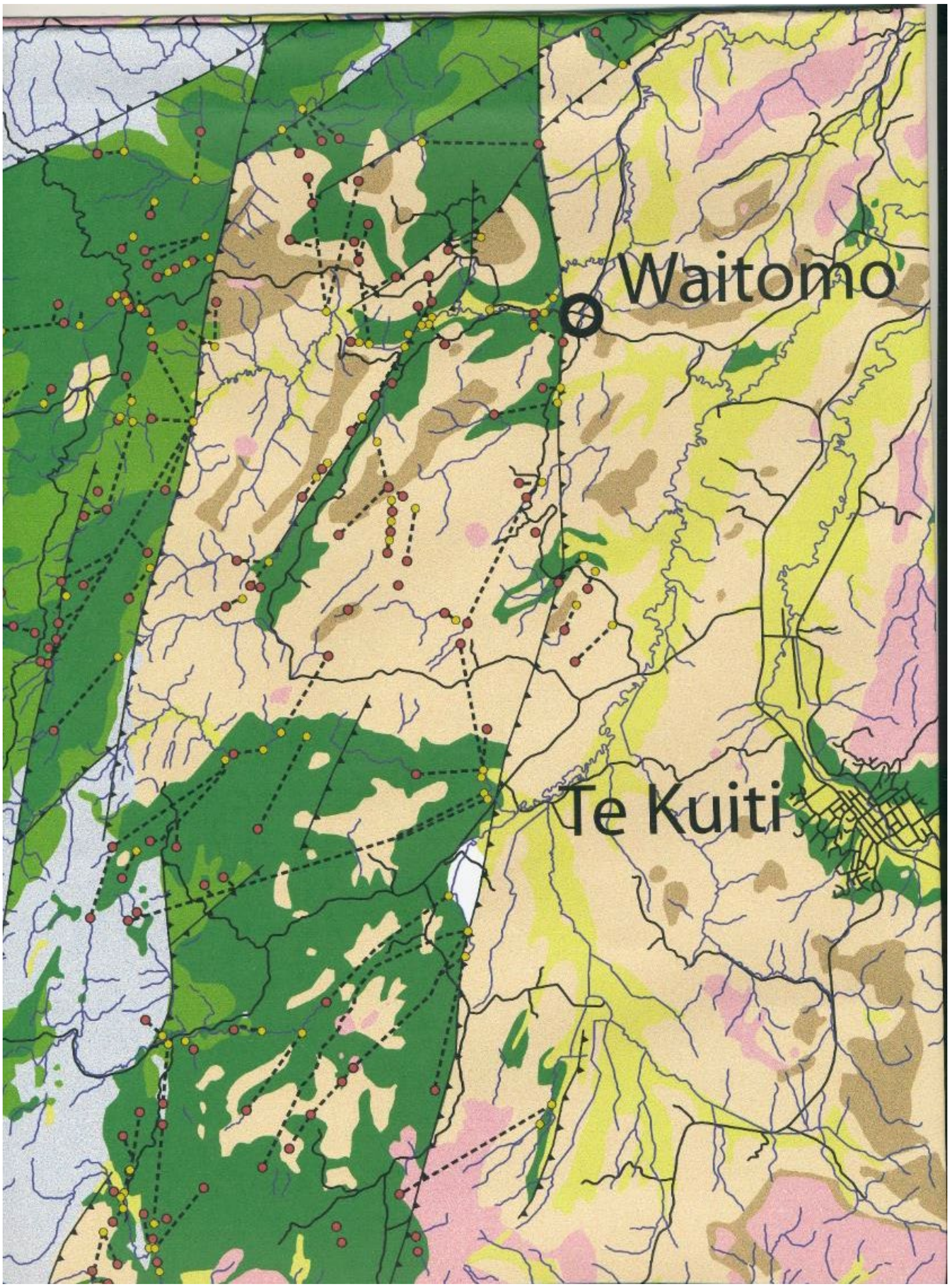

Figure 12. Part of the Waikato karst showing underground flow directions determined by water tracing. Mapped area shown is 14 km east to west. Red dots depict stream-sinks, dotted lines are traced underground routes, and yellow dots are karst springs. Some traced paths exceed 5 km. The map indicates that karstified limestones frequently underlie coverbeds of clastic rocks and volcanic deposits and that sinking streams can penetrate through thin coverbeds. Mesozoic basement rocks are represented in pale blue, overlying mudstones and sandstones are in pale green, main karst limestones in dark green, clastic coverbeds in ochre and brown, ignimbrite in pink, and alluvium in yellow. Black lines with flecks depict faults. (Compiled by P. Williams 2003 with cartography by J. Hägg).

Figure 13. A dry canyon in karst, almost certainly the remains of an unroofed cave. Part of Grand Canyon Cave, Puketiti Station. Photo: P. Williams

4.3 Global and national scale importance

Continuously exposed limestones and marble (carbonate rocks) cover about 10% of the surface of the Earth and discontinuously exposed (where limestone is interbedded with other rocks) more than 5%; thus around 15% of the ice-free continental surface is made up of carbonate rocks (Goldscheider et al. 2020), most of which are karstified. Groundwater from these rocks supplies drinking water to 678 million people (Stevanović 2019). In Europe, for example, about 21.8% of the continent consists of karst, and water from it (with appropriate treatment) sustains the supplies of numerous large cities. Limestone is also an important resource for cement, so conflicts can arise between extractive quarrying and protecting sustainable water supplies.

In New Zealand less than 3% of the country is covered by carbonate rocks; consequently, the relative rarity of karst accords it a special value. The evolution of karst landscapes in New Zealand is explained by Williams (2017), surveys of North Island caves are available in Crossley (2014) and New Zealand cave country is beautifully illustrated by Thomas and Silverwood (2017).

4.4 Special karst in the Waikato

The extensive, intensely pocked sinkhole country to the west of Te Kuiti is the best example of polygonal karst (the egg-tray style of landscape) in New Zealand, and in the Southern Hemisphere outside of the tropics. It is the kind of landscape most often seen in the humid tropics to sub-tropics (Papua New Guinea, Indonesia, Malaysia, Vietnam, Southern China); so is most unusual this far into the temperate latitudes. In our case, it developed under dense temperate rain forest not unlike that found in the highlands of Papua New Guinea. It has been evolving in the Waikato for two to three million years, although with occasional catastrophic interruptions from colossal volcanic super-eruptions.

4.5 Cultural and spiritual importance

Karst, and its caves, are of cultural and spiritual importance to tangata whenua. In Māori culture Papatuanuku is the earth mother and all land, including karst, provides a connection with Papatuanuku. People are nurtured by the shelter, warmth and protection provided by Papatuanuku. The specific significance of karst, and particularly caves, to Māori includes association with spiritual connections, as sacred burial sites, places of healing, the location of taonga cave writings or art, and being places of shelter (Department of Conservation 1999).

5 Karst systems

The karst system is an integrated surface and subsurface system comprising limestone (carbonate) rocks, karst landforms, caves, surface and subterranean streams, groundwater reservoirs (both in the epikarst and saturated zone), soil cover, vegetation and fauna (Figure 14). Through this system there are flows of energy from the sun, water and carbon dioxide that keep the cave ecosystem functioning. The karst system provides many natural services:

- Karst is a sink for atmospheric carbon dioxide because it is consumed in the solution of limestone
- Karstified limestones are major host rocks for groundwater resources, because of interconnected underground voids (caves, fissures and pores) that provide storage capacity for water
- Fissured rocks at the surface and cavities underground provide numerous protected habitats and refugia for rare and endangered species
- The alkaline environment provides specialised niches for calcicole (lime-loving) plants
- Caves act as nature’s vaults, being environments for speleothem growth (stalactites etc), and repositories for fossils, sediments and organic materials that record natural history events of the surrounding region, including earthquake history
- Karst landforms and caves offer numerous unusual tourist attractions and recreational opportunities
- Karst landscapes provide forest and agricultural resources
- Carbonate rocks provide essential resources for industry, e.g. cement
- Karst and caves are of cultural and spiritual significance to Māori, e.g. Ngāti Maniapoto in the South-western Waikato

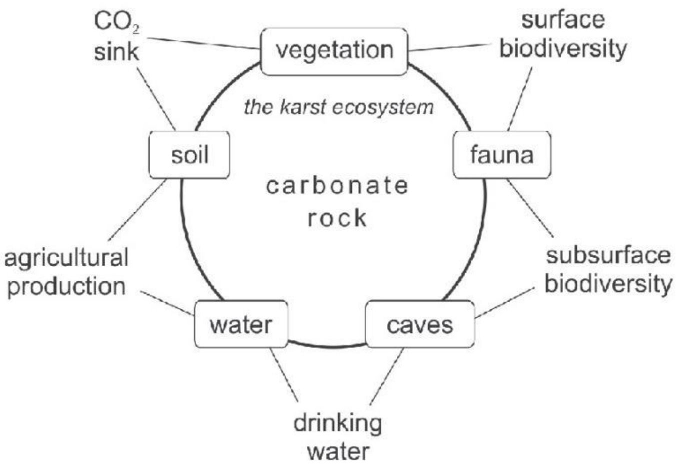

Figure 14. The karst ecosystem, showing main aspects of the karst environment and their inter-relationships (from Goldscheider 2019).

6 Life in karst

New Zealand's karst landscapes are associated with several naturally uncommon or historically rare ecosystem types as described by Williams et al. (2007) and are therefore prioritised for biodiversity protection on private land (Wiser et al. 2013, Holdaway et al. 2012, Ministry for the Environment 2007). There are five uncommon ecosystems including karst landforms that are present within the Waikato region: cave entrances, caves and cracks in karst, sinkholes, calcareous cliffs, scarps and tors, and calcareous coastal cliffs (see link in Section 9). Due to this natural scarcity, and often significant flora and fauna values present, karst ecosystems are considered Significant Natural Areas (SNA) for indigenous biodiversity protection in the Waikato region (Waikato Regional Policy Statement 2016).

Karst landscapes contribute significantly to the biological diversity of the Waikato region and support some unique animals and plant communities, several confined to this region. Highly fertile limestone soils can have diverse plant communities which in turn support high productivity ecosystems with rich animal assemblages and complex food webs. However, high nutrient vegetation can favour grazing or browsing by animals and fertile soils are exploited by exotic weeds following forest disturbance.

Plant and animal communities are influenced by the variety in habitat and microclimate found across Waikato's karst landscapes; from dark, cool caves with subterranean streams and associated shaded, moist cave entrances to sunny rock outcrops and salty windblown coastal cliffs.

6.1 Above ground biodiversity

Karst landscapes produce an alkaline soil environment through the weathering of limestone, and this favours plants with a tolerance of (facultative calcicoles) or even a preference for (obligate calcicoles) lime-rich soils. Of New Zealand's 145 documented calcicoles 95% are regionally specific; in Waikato four plant species are reported to occur predominantly or only on limestone substrate with one of these being found only in this region (Rogers et al. 2018). Some plant species which are most intimately associated with limestone substrate are classified as "threatened with" or "at risk of" extinction in Department of Conservation's threat classification system (Townsend et al. 2007) due to a combination of both the natural rarity and in many cases degradation of their favoured habitat.

Forest composition across Waikato's karst landscapes is diverse due to the combination of limestone with differing adjacent parent rock materials and climatic variation (BD Clarkson, in Clarkson et al. 2002). This variation in vegetation associated with karst spans from north to south e.g., Port Waikato to Mokau on the west coast, and from coast to inland e.g., Kawhia to Waitomo and over to Coromandel on the east coast.

6.2 Cave entrances

Plants found specifically around cave entrances in the Waikato include some characteristic ferns, mosses and liverworts. The focus here is the vascular native flora, as the non-vascular plants are less well known but just as important. Vascular species more or less confined to shaded, moist, calcareous rocks include the rare fern *Asplenium cimmeriorum* (Figure 15). Also found near, but not restricted to, forested cave entrances are the rare shrub *Teucrium parvifolium* and king fern (*Ptisana salicina*) and the rata vines *Metrosideros colensoi* and *M. carminea*. The distinctive, orange-flowered shrub *Rhabdothamnus solandri* and the shade-loving groundcover parataniwha (*Elatostema rugosum*) are also often associated with limestone gorges and cave entrances (Figure 16, 17).

Figure 15. Cave spleenwort (*Asplenium cimmeriorum*) a threatened fern growing in the karst environment. Photo: Glowing Adventures

Figure 16. The surface karst landscape on limestone bedrock in native lowland forest near the Waitomo Stream, Ruakuri Scenic Reserve. Groundcover vegetation includes parataniwha (*Elatostema rugosum*) and ferns with understorey tree species nikau (*Rhopalostylis sapida*) and pate (*Schefflera digitata*). Closest to the stream, where inundation is frequent, the potholed surface is draped with moss. Photo: P. Williams

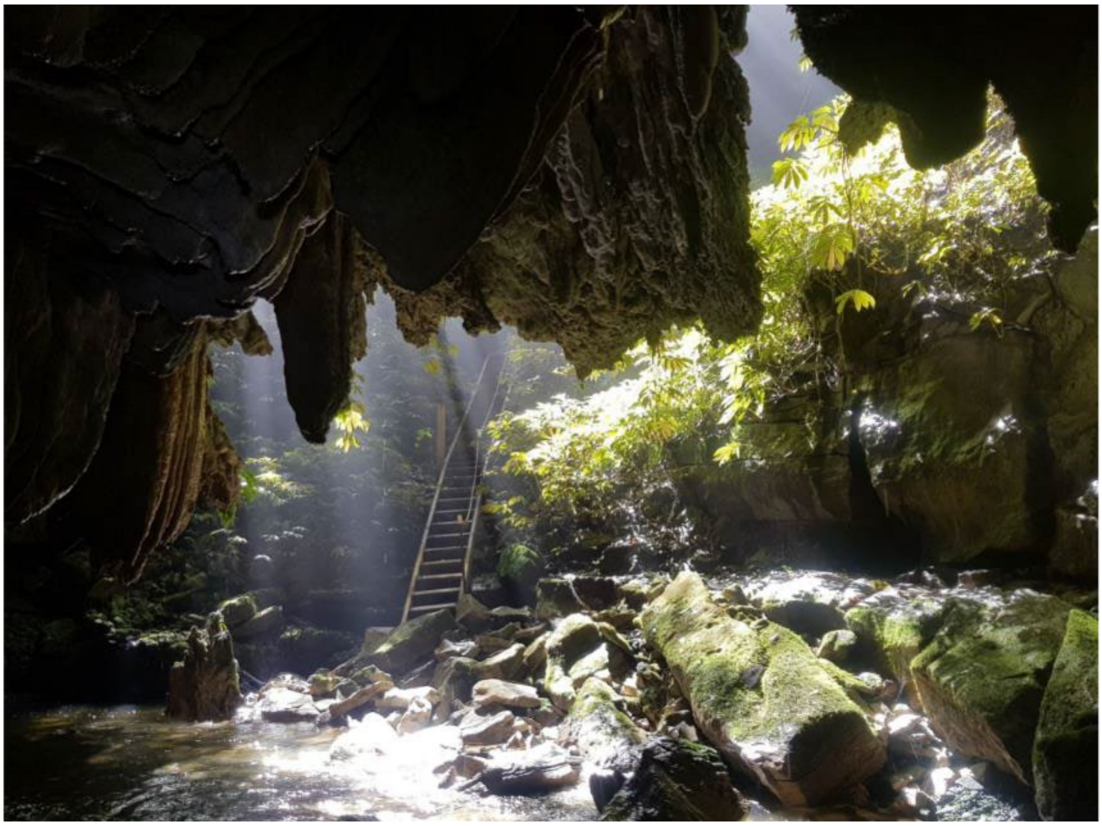

Figure 17. Cave entrance with moss and native groundcover vegetation of lush parataniwha (*Elatostema rugosum*). Mangapu Gorge and blind valley. Photo: Glowing Adventures

6.3 Rock outcrops

Limestone outcrops with cliffs and crevices support lime-loving plants and can provide refuge for native vegetation and animals from browsing or predation by pest animals and from land development. The ferns *Asplenium lyallii* and *A. trichomanes* are often associated with this habitat, as is the uncommon small tree *Pittosporum huttonianum* that does not occur south of the Waikato. A range-restricted cliff-dwelling species found only in the Waikato- the Awaroa hebe (*Veronica scopulorum*) is found on only a handful of rock outcrops in the partially forested karst landscape of the Awaroa Valley, inland from Kawhia (Figures 18, 19).

Figure 18. The rare Awaroa hebe (*Veronica scopulorum*) endemic to a few rocky outcrops in Waikato karst. Photo: B. D. Clarkson

Figure 19a and 19b. Awaroa hebe (*Veronica scopulorum*) on a rocky limestone outcrop inland from Kāwhia. Photos: T. Emmitt

6.4 Coastal cliffs

Near the coast *Scandia rosifolia* is a cliff-dwelling herb which is largely confined to coastal limestone around Raglan, Kawhia, Te Anga and further south of the region. At the southern edge of the Waikato region the cliff-dwelling daisy *Brachyglottis turneri* has been recorded on limestone in the Mohakatino catchment, apparently the northern limit for this naturally rare species. *Peperomia urvilleana* is a creeping, succulent groundcover herb often found on rocky limestone outcrops near the coast (Figures 20, 21) and extending inland around Waitomo.

Figure 20. Raglan coastal karst, on the northern coastline of Whaingaroa harbour. Photo: E. Overdyck

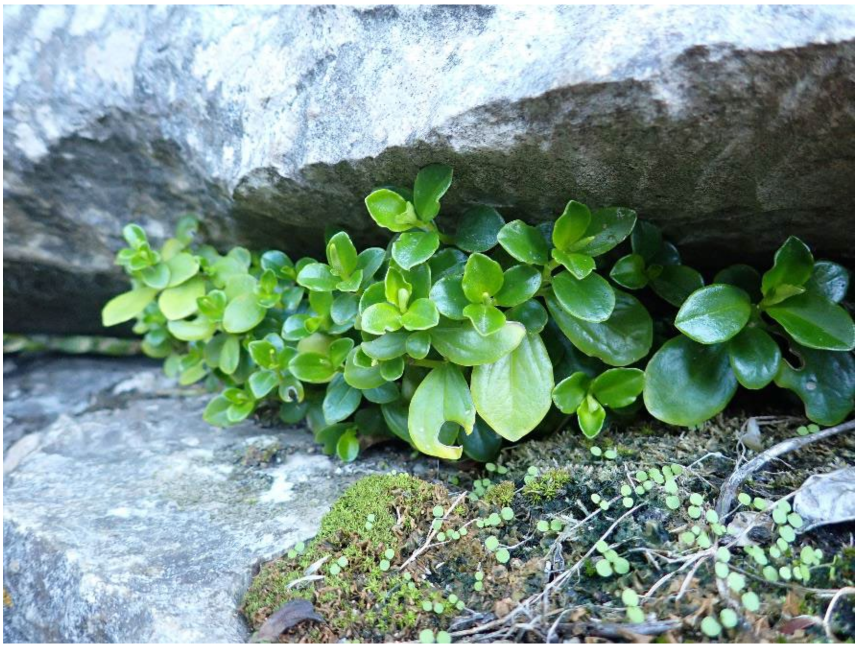

Figure 21. *Peperomia urvilleana* growing in a limestone rock crevice on the Whaingaroa harbour coastline, near Raglan. Photo: M. Nelson-Tunley

6.5 Cave and subterranean stream fauna

The physical and biological features of the subterranean landscape, including the epikarst, are interconnected with and dependent on the surface landscape, its vegetation cover and land use. There is a flow of sustaining energy from the surface to the underground world. Cave streams respond to the quantity and speed of drainage from the surface, and their water quality reflects the land it crossed before sinking. The food web sustaining subterranean biota relies on organic matter washed in by rain and transported by percolating water, streams and air currents. Thus, the reproductive cycles of resident and transiting species, indeed the viability of these subterranean ecosystems, depends on the quality of the surface environment. This affects both troglobites, that live exclusively in air-filled parts of caves, stygobites their aquatic counterparts, and troglophiles and stygophiles that, like glow worms, can live in caves but also outside. A wide range of fauna can be found here, some very ancient in their lineage and rarely seen.

As with the aboveground terrestrial biota, karst aquatic ecosystems in the Waikato present some distinct habitats and species communities (Scarsbrook et al. 2008). Less is known about the extent of subterranean terrestrial habitats, but it has been found overseas that for some species these habitats extend into the epikarst and other normally inaccessible sites in and adjacent to the karst (Culver and Pipan 2009). In general, the karst-associated animal species in the Waikato do not display high diversity. This may be for a number of reasons, including the past effects of volcanism on the karst (e.g., May and Kermode 1972). Even so, within the few groups that have been investigated in detail, there are species which are endemic to the Waikato karst. These include tiny snails found in surface seepages and in cave streams; aquatic Crustacea and mites found in cave streams; and blind cave beetles and pseudoscorpions (Figures 22, 23). One genus of snails, *Leptopyrgus*, with three seepage-dwelling species, is endemic to Waikato region. Two of these snail species are only known from karst sites. The cave beetle *Neanops* has two species found only in southwest Waikato caves. Many of the outlying, smaller karst areas away from the main west Waikato karst have not been as actively searched for fauna and it is likely that some will have their own species.

Figure 22. An undescribed cave-dwelling amphipod crustacean from family Paraleptamphopidae. Photo: N. Boustead, NIWA

Figure 23. The rare aquatic snail *Leptopyrgus manneringi*. Photo: D. Roscoe

Due to their limited distributions, many cave- and karst-limited species are ranked as being "at risk" of extinction (Townsend et al. 2007). However, some Waikato species are known from so few sites or so few individuals that they are ranked as critical and "threatened with" extinction. This group comprises three species of snails: *Potamopyrgus acus*, possibly a terrestrial or amphibious species, known from a single site in the Waikawau Valley karst; *Leptopyrgus manneringi*, a more aquatic species known from three mossy seepages in the Waikaretu Valley; and *Potamopyrgus doci*, an aquatic snail known only from Ruakuri Cave, Waitomo; and the troglobitic beetle species *Neanops pritchardi*, known from a single small cave near Aria.

The Nationally threatened long-tailed bat (*Chalinolobus tuberculatus*) uses at least two cave sites in Waikato karst. Further native animals associated with, but not limited to, karst landscapes in the Waikato include several threatened fish species, including long-fin eel/ tuna (*Anguilla dieffenbachii*), the endemic glow worm/ titiwai (*Arachnocampa luminosa*) (Figure 24), several cave wētā species (Figure 25) and many more undescribed invertebrate species (Figure 26). Glow worms reside in caves and damp forests and are a key tourist attraction for the Waitomo area. Glow worm larvae lure their insect prey into drops of sticky mucus on silk threads using bioluminescence. The Māori name for glow worm, titiwai, translates as "projected over water" describing their light reflecting on water.

Figure 24a and 24b. Glow worm (*Arachnocampa luminosa*) larvae in the "nest" with hanging sticky silk threads to capture small insect prey, Nikau Cave. Photos: Y. Deng

Figure 25. A Cave wētā species in the Nikau cave. Photo: Y. Deng

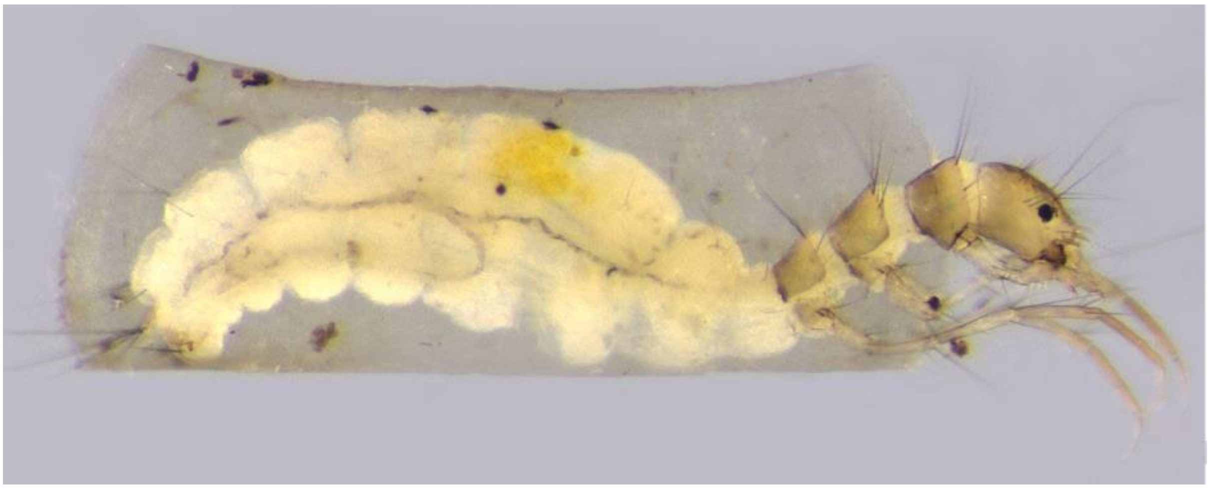

Figure 26. A surface-dwelling caddisfly larva from a Waikato karst lake. An undescribed micro-caddisfly from the genus *Paroxyethira* (family Hydroptilidae), Lake Koraha. Photo: B. Smith, NIWA

6.6 Links to the past

Caves have immense value in recording evidence of past fauna and flora compositions, paleoclimates and geological histories (Kenny and Hayward 2009). The stable environmental conditions and high calcium levels aid the fossilisation of organisms and the preservation of archaeological material. Deposits of bird bones preserved in caves and sinkholes have contributed to knowledge of New Zealand's rich avifauna history. Plant pollen and spores washed underground and protected within layered cave sediments provide detailed information on vegetation change in both relatively recent times, just prior to forest clearance, and through the ice age cycle of the last 20-50,000 years. Stalactites and stalagmites (speleothems) in caves provide detailed information on old climates (temperature and rainfall changes) through studying the thickness of ring deposits and analysing oxygen isotopes.

7 Threats to karst landforms and ecosystems

Karst in New Zealand continues to be under pressure from population growth and development which threaten to irreversibly damage this special and fragile landscape (Kenny and Hayward 2009). Much of New Zealand’s karst is located within protected public conservation land or reserves), while some occurs on private land with varying degrees of formal, e.g., Queen Elizabeth II Trust covenant or Ngā Whenua Rāhui kawenata, and informal protection by landowners (Department of Conservation 1999, Hayward 2019). While all karst is naturally uncommon, some karst ecosystems are considered to be under greater threat of loss and degradation than others. Holdaway et al. (2012) identify cave entrances as being critically endangered ecosystems; sinkholes and coastal cliffs as endangered; while inland cliffs, scarps and tors are considered vulnerable ecosystems. Caves and cracks in karst, as an ecosystem, are identified as not threatened largely due to restricted access and current lack of knowledge on the fauna present.

Historical forest clearance and poor land management practices are the main threats to karst landscapes. Indigenous lowland forest or shrubland was once widespread over karst landscapes, now it is much reduced in extent and often consists of secondary forest recovering from previous clearance by burning or logging. Vegetation clearance and agricultural land use damages natural habitats and stream water quality through accelerated soil erosion, increased nutrient and sediment loads and raised temperature in subterranean aquatic ecosystems. Human settlements and infrastructure can cause further soil erosion and introduce pests and pollutants.

7.1 Abiotic impacts – altered drainage, erosion and sedimentation

In most environments it is well documented that forest clearance increases runoff because natural evapotranspiration losses from plants are considerably reduced. But because timber debris and loosened soil moves downslope to the base of sinkholes, in karst landscapes natural drainage pathways become clogged following forest clearance. As a result, although more water runs through cave streams beneath land cleared of forest, flood peaks are delayed and lessened compared to underground streams in areas beneath natural bush that operate more efficiently. Under natural bush cover, rainfall is intercepted, and trees and their roots restrain soil movement allowing natural rock fissures on the sinkhole floor to remain more open, whereas in cleared areas drainage can become clogged with vegetation debris and eroded soil. On a catchment scale large-scale forest vegetation loss effects hydrology increasing risk of the frequency and magnitude of flood events due to altered drainage.

On the Waikato karst, forest clearance could result in an extra 700 mm of water running off down streams and through karst groundwater systems each year, giving much more energy for erosion and sedimentation.

Forest clearance breaks and disturbs the soil, so erosion accelerates until slowed by the re-establishment of vegetation cover. Logging roading works increase the soil erosion problem. These issues have been thoroughly documented in New Zealand since at least the 1940s and although not specifically assessed in karstlands, because of the relatively small area of the country involved, the effects are similar. Following forest clearance in the Waitomo catchment in the early 20th Century increased sedimentation caused the Glow worm Cave stream bed to rise 2-3 m and the adjacent floodplain to build up by 4 m or more. This is well known because the Glow worm Cave survey in 1889 by the Chief Surveyor, Auckland, provided detail and photos against which later situations can be compared. Fresh mud banks can be seen in many caves, although the frequency of overbank deposition of mud across pastureland appears to have reduced, probably mainly because of reduced road works.

In some situations where natural soil cover is relatively thin, problems from erosion on karst can be more severe, because soil is lost underground and a form of 'rocky desertification' emerges across the surface. This is a very serious problem in some overseas countries; however, it has not become a critical issue in the Waikato only because of the very thick cover of volcanic ash soils.

7.2 Biotic impacts - biodiversity and habitat loss

Patches of remnant native vegetation are now confined to cliffs or gullies which offer protection from disturbance. These inaccessible landforms become refugia for native plants and animals lost from neighbouring habitats (Figures 27 and 28). Remnant vegetation provides a seed source for future regeneration and offers valuable habitat where native animals can feed and reproduce. In many areas forest cover continues to be lost and is degraded from ongoing disturbances associated with forest fragmentation such as reduced buffering due to the small size and increased distance between remnant patches. Additionally, ongoing stock grazing and feral animal browsing can prevent native regeneration allowing exotic weed invasion. Goats are a major threat due to their ability to access cliff vegetation. They have been responsible for serious and ongoing decline of native vegetation and the uncommon native plants characteristic of rock outcrops and cliff faces. Reduced habitat for native fauna is further exacerbated by predation from introduced mammals such as possums, rodents and mustelids, which contribute to the decline of many native species populations.

Native vegetation on and around limestone features is valuable in influencing microclimate, nutrient cycling and animal food webs. Forest vegetation buffers drying winds and prevents extreme fluctuations in temperature leading to increased air humidity and soil moisture. This affects the microclimate and biota around cave entrances and throughout entire cave systems. Dense canopy cover also lowers light levels discouraging weed establishment and provides an accumulation of leaf litter and humus into the nutrient cycle.

Figure 27. Coastal karst exposed by vegetation clearance and with ongoing stock grazing limiting native plants to inaccessible outcrops. Photo: B Hayward

Figure 28. Native vegetation restricted to isolated and inaccessible rock outcrops in a karst landscape historically cleared for agricultural landuse, western Waikato. Photo: B. Hayward

7.3 Further human impacts

Karst ecosystems are also impacted by the destructive activities of quarrying and the more subtle effects of construction, tourism, forestry harvesting and waste dumping. Damaging activities include:

- Pollution of groundwater through wastewater discharge.
- Housing development damaging surface karst features and altering surface drainage.
- People in cave systems may damage fragile rock formations, deposits and artefacts and alter air temperature and humidity affecting cave flora, fauna and the growth of rock formations.
- Increased tourism may also introduce unwanted impacts, depending on the season and the intensity and style of activities from tramping to trail bikes and cross-country fun-runs. Any form of racing through caves is totally unacceptable and against the ethics if the International Union of Speleology, because of the damage that can be done to formations and deposits that may have taken thousands of years to form, as well as to the normally quiet habitats of subterranean species. Even well-managed adventure tourism underground requires some sensitive areas in the cave to be excluded from visitation and to be marked off as no-go.
- Dumping of chemical pollutants in and around sinkholes can get into groundwater and pollute water sources quickly and unpredictably, potentially emerging again through springs some distance away.
- Forestry increases erosion following harvest, and pine trees produce particularly acidic leaf litter altering the alkaline environment and are not appropriate for reforestation.
- Climate change may impact both native and exotic species geographical distributions in relation to karst habitat and could also result in increased erosion and inundation of karst landforms, particularly coastal karst.

In summary, forest clearance and poor land management practices (‘maladjusted land use’ in Figure 29) can set off a chain reaction that seriously diminishes natural karst ecosystem services. This usually starts from vegetation clearance that accelerates soil erosion, although the establishment and maintenance of close grass cover can arrest deterioration. Figure 29 shows the cascading effects, and matters can be made worse if human settlements and infrastructure cause more soil erosion (e.g. through roading and track creation), kill wildlife and introduce foreign pollutants (e.g. from urban discharges and agricultural chemicals).

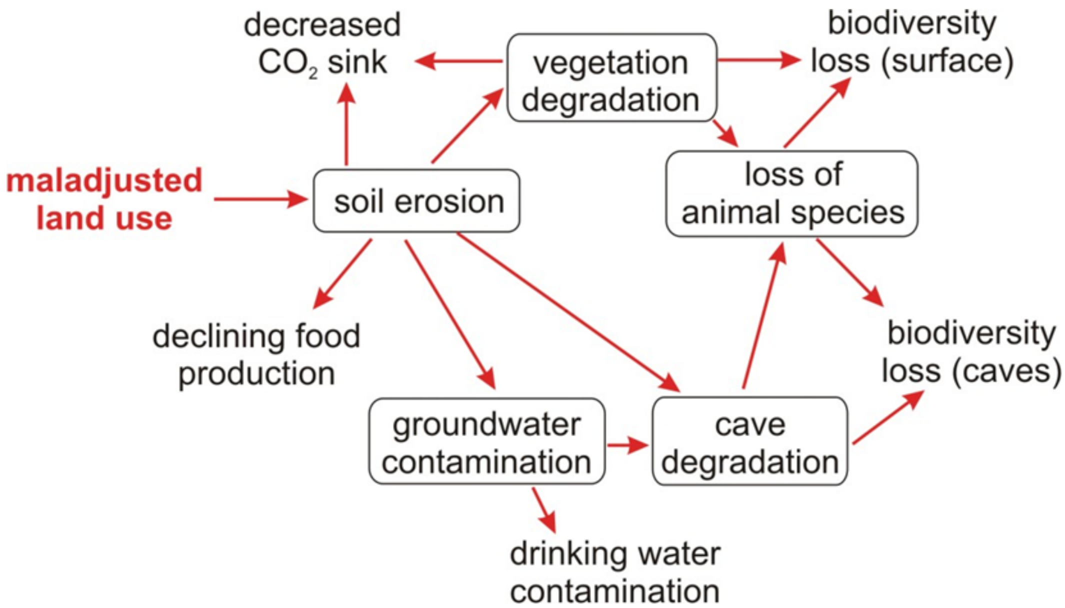

Figure 29. Pathways of deleterious impact through a karst ecosystem that stem from vegetation clearance and inappropriate land use practices at the surface (from Goldscheider 2019).

8 Recommendations for Restoration

As in other natural landscapes, there are many restoration opportunities for karst landscapes. Good stewardship practices in agriculture, forestry and feral animal and weed control that apply to other landscapes are also required in karst landscapes, as they are no less vulnerable. Limestone rocks are relatively resistant to erosion, but their associated soil cover, once exposed, is readily stripped, and lost underground. The most important step that can be taken to conserve karst, its ecosystem and water quality is to encourage native vegetation conservation and restoration, to redress forest loss, especially around places where water goes underground. This will lead to habitat recovery, reduced flooding and sedimentation, and water quality improvement.

8.1 Groundwater and riparian margin protection

Sinkholes are natural centripetally draining basins, usually with a soak hole or seepage focus somewhere near bottom-centre, and sometimes in more than one place. They are the headwaters of underground trickles and streams. Consequently, water quality underground depends on what infiltrates down from the surface, just as the quality of a headwater surface stream depends on runoff from the nearby paddock. Headwater protection is clearly very important.

Karst underground drainage can go in unexpected directions, and travel quickly too, so leachate from informal farm dumps and soak-pits will go to groundwater and on to a spring-fed stream – maybe your own. All around the world karst sinkholes have been used as convenient rubbish dumps- out of sight out of mind- but these practices can have serious consequences, especially with respect to farm chemicals. Contaminants will get to groundwater, so dumping practices must be minimised.

Fencing is one of the traditional tools for managing farm animal movement, protecting vegetation, natural habitats and special features, isolating hazardous areas, and for enhancing water quality by protecting riparian zones. Around the periphery of karst areas, conventional riparian fencing is important to protect the quality of inflowing streams that disappear into caves and potholes or drain into stream-sinks. Both permanent and intermittent water courses are important, although the imperative for fencing depends also on the type of stock involved and the intensity and season of grazing. Catchment protection may be a challenge where sinkholes are numerous e.g. to the west of Te Kuiti. Each one is a kind of riparian zone for karst, as well as being a valued piece of grazing land, but they deliver water underground during and after heavy rain. Seepage zones at the base of sinkholes can be simply too numerous for practicable fencing and may not require fencing if there is no obvious open drainage-way and impact can be managed by limiting stock movement in those places during the wetter times of year.

Fencing can reduce damage to the karst ecosystem, risk to people and stock loss. Potholes, shafts or tomo developed from collapse of cave roofs and soil cover can provide serious hazards to animals and visitors. Potholes are nature's pitfall traps and are well known for that reason by palaeontologists and archaeologists. Under native bush they should be left alone as part of the natural landscape, but visitors should be advised (verbally or on signs) to take care according to their experience. Tomo are generally smaller, but some are sufficiently hazardous to stock to justify fencing off, although allowance may be required for expansion by natural on-going slumping activity.

8.2 Restoring biodiversity

The reestablishment of appropriate vegetation through planting adjacent to limestone features (e.g., Figure 30) and along corridors connecting remnant forest patches will provide suitable soil, humidity and light conditions to supress weeds and encourage further establishment of native shrub and groundcover species. Creating and enhancing corridors will encourage the movement of native animals including bats, birds and insects, restoring ecosystem processes such as pollination and dispersal of native seed. Restoration of native vegetation will improve microclimate and the accumulation of organic litter to repair surface to subsurface food webs and energy flows. The exclusion of grazing stock and feral animals will protect native habitat from browsing and trampling, while predator control can restore native fauna populations.

Figure 30. Lost World shaft, Mangapu river, in 2019 after restoration planting. Photo: A. John (inset Lost World shaft c1980. Photo: P. Williams)

8.3 Protecting karst on your property

The rarity and fragility of karst landscapes make them a priority for protection and restoration in the Waikato. Many high value karst ecosystems occur on private land and assistance from council and other agencies may be available to support landowners.

Restoration of karst landscapes should involve careful planning and consider the appropriate measures to take and in what order (see Appendix I). This will vary with differing karst landforms and levels of degradation. Riparian margin protection for springs and streams that flow into cave systems and protecting catchments of sinkholes or tomo is valuable in reducing sediment and nutrient runoff into cave systems. Fencing and planting around limestone rock outcrops or cliffs will buffer these special habitats. Broad habitat protection can involve stock exclusion and the control or exclusion of large pest animals (goats, deer, pigs) while more site-specific activities may include control of small pest animals (possums, rodents, mustelids, hares and rabbits), exotic weed control and planting of suitable native species.

- Use the action plan in Appendix I to help you identify priorities for the management of karst ecosystems on your land
- Websites with further information e.g. restoration planting, predator control and funding are listed below
- Seek advice if you need help identifying the management issues for your site

Please contact Waikato Regional Council to find out about 1) rules around water abstraction or discharge, undertaking earthworks, vegetation removal or overburden and small-scale cleanfill disposal and 2) assistance with restoration of on karst land including fencing and pest control funding. Freephone 0800 800 401.

Please contact your local District Council to find out about rules relating to land development on karst areas in your District including forestry, extractive industries, vegetation clearance, earthworks and fill placement and establishing structures.

9 Further Information

- Waikato Regional Council Click here https://www.waikatoregion.govt.nz/
- Waitomo District Council Click here https://www.waitomo.govt.nz/
- Waitomo Museum Click here https://www.waitomocavesmuseum.nz/
- QEII National Trust Click here https://qeiinationaltrust.org.nz/
- Waikato Biodiversity Forum: Biodiversity resources (Restoring Waikato's Indigenous Biodiversity: Ecological priorities and actions) Click here https://www.waikatobiodiversity.org.nz/resources/
- Waikato Regional Council Funding: Natural Heritage Fund Click here https://www.waikatoregion.govt.nz/community/funding-and-scholarships/natural-heritage-fund/
- Waikato Regional Council Funding: Small Scale Community Initiatives Fund Click here https://www.waikatoregion.govt.nz/community/funding-and-scholarships/small-scale-community-initiatives-fund/
- Waikato Regional Council: Native plant nurseries supplying the Waikato Click here https://www.waikatoregion.govt.nz/environment/biodiversity/planting-guides/native-plant-nurseries/
- Department of Conservation: Planting guide for Western Waikato (includes karst landscapes) Click here https://www.doc.govt.nz/globalassets/documents/conservation/native-plants/waikato-ecological-restoration/planting-guide-western-waikato.pdf
- Department of Conservation: Predator free 2050 How to trap in your community Click here https://www.doc.govt.nz/nature/pests-and-threats/predator-free-2050/community-trapping/
- Manaaki Whenua Landcare Research: Naturally uncommon ecosystems, including karst Click here https://www.landcareresearch.co.nz/publications/naturally-uncommon-ecosystems/
- Waikato Regional Policy statement: Criteria for determining significance of indigenous biodiversity 11A Click here https://www.waikatoregion.govt.nz/council/policy-and-plans/regional-policy-statement/regional-policy-statement-review/section32/

10 References

Clark R, Floyd C, Clarkson BD 2017. Significant natural areas of the Waikato Region: karst ecosystems. Waikato Regional Council Technical report 2017/35. Hamilton, Waikato Regional Council.

Clarkson BD 2002. Karst landscapes. In: Clarkson BD, Merrett M, Downs TM. Botany of the Waikato. Hamilton, Waikato Botanical Society. 91-98.

Crossley PC ed. 2014. New Zealand cave atlas: North Island. NZ Speleological Society Occasional Publication 21. Waitomo Caves, New Zealand Speleological Society Inc.

Culver DC, Pipan T 2009. The biology of caves and other subterranean habitats. Oxford University Press, Oxford.

Department of Conservation 1999. Karst management guidelines: policies and actions. Wellington, Department of Conservation.

Floyd C, Clarkson BD 2009. Identification of potential karst ecosystems in the Waikato Region. Centre for Biodiversity and Ecology Research Contract Report 102. Hamilton, University of Waikato.

Goldscheider N 2019. A holistic approach to groundwater protection and ecosystem services in karst terrains. Carbonates and Evaporites 34: 1241–1249. https://doi.org/10.1007/s13146-019-00492-5

Goldscheider N, Chen Z, Auler AS, Bakalowicz M, Broda S, Drew D, Hartmann J, Jiang G, Moosdorf N, Stevanović Z, Veni G 2020. Global distribution of carbonate rocks and karst water resources. Hydrogeology Journal 28: 1661-1677.

Gunn J 1978. Karst hydrology and solution in the Waitomo district, New Zealand. PhD thesis. Auckland, University of Auckland.

Hayward BW 2019. Mapping significant natural areas of the Waikato region : the physical basis for the identification of karst ecosystems. Updated methodology report. Waikato Regional Council Technical Report 2022/03. Hamilton, Waikato Regional Council.

Holdaway RJ, Wiser SK, Williams PA 2012. Status assessment of New Zealand's naturally uncommon ecosystems. Conservation Biology 26: 619-629. https://doi.org/10.1111/j.1523-1739.2012.01868.x

Kenny JA, Hayward BW 2009. Karst in stone: karst landscapes in New Zealand: a case for protection. Geological Society of New Zealand Guidebook No. 15. Lower Hutt, Geological Society of New Zealand Inc.

Lewis S 2018. Significant karst areas, Waikato. A report prepared for the Waikato Regional Council. Hamilton, University of Waikato.

May BM, Kermode LO 1972. Distribution and raciation in the troglobitic carabid beetle Duvaliomimus mayae (Trechinae). Journal of the Royal Society of New Zealand 2: 83-90.

Ministry for the Environment, Department of Conservation 2007. Protecting our places: information about the statement of national priorities for protecting rare and threatened biodiversity on private land. Wellington, Ministry for the Environment/Department of Conservation.

Rogers GM, Courtney SP, Heenan PB 2018. The calcicolous vascular flora of New Zealand: life forms, taxonomy, biogeography and conservation status. Science for Conservation 331. Wellington, Department of Conservation.

Scarsbrook M, Wright-Stow A, van Houte-Howes K, Joy K 2008. Aquatic ecosystems of the Maniapoto karst. Environment Waikato Technical Report 2008/31. Hamilton, Waikato Regional Council (Environment Waikato)

Stevanović Z 2019. Karst waters in potable water supply: a global scale overview. Environmental Earth Sciences 78(23): 662-673.

Taylor-Smith B, Kessels G, van der Zwan W 2020. Methodology for assessing and ranking the biotic values of karst sites in the Waikato Region. A report prepared for Waikato Regional Council by Tonkin & Taylor Ltd.

Thomas M, Silverwood N 2017. Caves: exploring New Zealand's subterranean wilderness. Wellington, Whio Publishing.

Townsend AJ, de Lange PJ, Duffy CAJ, Miskelly CM, Molloy J, Norton DA 2007. New Zealand Threat Classification System manual. Wellington, Department of Conservation.

Urich PB 2002. Land use in karst terrain: review of impacts of primary activities on temperate karst ecosystems. Science for Conservation 198. Wellington, Department of Conservation.

Waikato Regional Council 2016. Waikato Regional Policy Statement. Waikato Regional Council Policy Series 2016/01. Hamilton, Waikato Regional Council.

Williams PA, Wiser SK, Clarkson B, Stanley M 2007. New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. New Zealand Journal of Ecology 31: 119-128.

Williams PW 2017. New Zealand landscape: behind the scene. Amsterdam, Elsevier.

Wiser SK, Buxton RP, Clarkson BR, Hoare RJB, Holdaway RJ, Richardson SJ, Smale MC, West C, Williams PA 2013. New Zealand's naturally uncommon ecosystems. In Dymond JR ed. Ecosystem services in New Zealand : conditions and trends. Lincoln, Manaaki Whenua Press. 49–61.
New Zealand's Naturally Uncommon Ecosystems - book section (landcareresearch.co.nz)

Appendix I: Choosing actions to protect your karst ecosystem.

Reproduced from Clarkson BD, Cursey M and Denyer K 2006 (updated 2018) Restoring Waikato's Indigenous Biodiversity: Ecological Priorities and Actions. The Waikato Biodiversity Forum, pp 68-69. See link above, in further information section.

ACTION AND PRIORITY	COMMENTS
Protect water table -Avoid damming or diverting water	Karst ecosystems are created by the erosive effects of water. Changes in water supply can damage cave systems. Major dams, in-cave dams and major water takes could create an issue. Talk to Waikato Regional Council if you are concerned about possible damming or diverting.
Reduce pollution -Sediment -Nutrient run-off	If your cave system has a stream flowing into it, consider retiring the riparian margin and providing a planted swale to absorb excess nutrients out of the water. See planting below to deal with run-off.
Reduce human damage -Don't take 'trophies' -Limit trampling -Take all rubbish from cave	• Cave formations can be damaged by touching. Leave some caves 'untouched' and use well visited caves to reduce the number damaged by humans. • Never touch, break off or damage cave formations. Leave them for others to enjoy. Take only photos. Even broken bits of stalactite should always be left in the cave. • Use designated tracks where marked to reduce trampling damage in caves. Avoid bone deposits and untrampled cave floor surfaces. • Take out all rubbish and human waste and dispose appropriately. • Go caving with a leader who understands cave conservation and cave safety.
Control stock	If grazing animals can enter your site they will trample the soil and eat the plants, and their dung and urine will pollute the site. Heavier animals, such as cattle are generally more damaging. Even a hot wire will be a good start to keep cattle out. A more robust type of fence will be required to keep out deer, pigs and goats. Priorities for fencing include bush margins, stream margins, spring heads and cave entrances. Be ready to tackle weeds as soon as the last stock are out, you may find the weeds 'take off' when grazing stops.
Control weeds -Regional plant pests -Limestone specialists -Other weeds	• While weeds won't grow in the dark of underground karst ecosystems, they can reduce the natural value of the landscape on the surface and around cave entrances. • Deal with weeds you are legally obliged to. See the plant and animal pests section in • Waikato Regional Council's website. Be vigilant for weeds in nearby sites that are not in your site - yet! • Weed control may need to be targeted in relation to karst-reliant native plants. A particular weed of karst landscapes is Geranium robertianum - the common herb robert - which grows in limestone rock cracks that could be habitat to rare ferns. • Note also that getting rid of some weeds can just encourage others! Get good advice on weed management.
Control pests -Hoofed animals -Possums, rodents, mustelids, cats -Rabbits/hares (if planting)	• • Pests cause damage to the special forest systems that grow on the surface in karst landscapes. Pests include deer, pigs, goats, rodents, possums, mustelids, rabbits, hares and feral cats. It is also likely that rats impact on cave ecosystems. • Target the large animals first - they will be easier to find and if the site is well fenced may be able to be eliminated. Use a trained hunter to shoot deer, goats and pigs. Other pests will need ongoing control using traps or poisons. Seek advice from the Department of Conservation regarding control methods and best practice.

ACTION AND PRIORITY	COMMENTS
Planting **-**Buffer -Enhance -Connections -Maintain	• Firstly, you should consider planting the edges of streams, springs, tomos and cave entrances to trap sediment and run-off. Also consider planting to buffer existing native bush remnants. • If the site is of unnaturally low diversity and isolated from natural seed sources, consider enhancement plantings. Make sure they are appropriate to the site - get advice. If you have to remove a lot of weeds, consider enhancement planting of natives as soon as possible to reduce the chance of another weed filling the space. • If your site is isolated from other natural areas, consider planting corridors of vegetation to encourage birds to move between them. Retirement and planting of streams will provide for this. • Keep your plantings weed free until the plants are well established. Small plants can be smothered by rank grass. Protect from rabbits, hares, and stock. • Retiring areas around cave entrances, including shaft entrances, will help the caves.
Enhance native fauna -Cave species -Surface fauna	• Cave fauna are often present in low numbers and are vulnerable to impacts. Help protect them by reducing pollution and human damage (see previous page). • Surface fauna such as forest birds and/or bats will benefit from the actions noted above (particularly pest control and fencing).
Monitoring -Measure change	It is important to be able to measure the effect of any management activities on karst features. Having baseline data is important. Take photos of your site prior to any action. Undertake photo monitoring at set intervals. Visual inspections and biological surveys may also be useful. In terms of any restoration planting, keep records of which plants survived and those that didn’t so you can learn for next time. If the project is large and needs a lot of funding get a professional monitoring programme in place, to justify the next round of grants.
Legal protection	If a site is not legally protected as a reserve or private covenant, it’s generally best to seek legal protection when the site is in good condition. However, if you are planning to protect the site and you need to fence it, it pays to contact QEII National Trust first, as they usually share the fencing costs. Talk to the Department of Conservation about other options for protecting karst and cave features.