Ecological character description:
Blue Lake Ramsar site

Australian Government
Department of the Environment, Water, Heritage and the Arts

Department of Environment & Climate Change NSW

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Cover photograph of Blue Lake, 5 January 2006, courtesy of Steve Jacobs, DECC

Summary

Ecological character has been defined as ‘the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point’. Blue Lake and Hedley Tarn became a Ramsar site on 17 March 1996, and the Australian Government is required to establish the ecological character of sites at the time of listing. This document summarises the ecological information available for this Ramsar site. Key ecological benefits/services provided by the Blue Lake Ramsar site include that it is a rare and unique example of a near-natural wetland; flora, fauna, bioregion and biosphere support; hydrological stability; sediment retention; recreation and tourism; and cultural heritage. Processes and components that support these services may be summarised as climate, geomorphology, hydrology, physico-chemical environment, habitats, flora and fauna.

Blue Lake and Hedley Tarn are located in Kosciuszko National Park in the alpine region of NSW at a surface elevation of approximately 1890 m and 1850 m above sea level, respectively. Together with Lake Cootapatamba, Albina Lake and Club Lake, they make up the alpine lakes of south-eastern Australia. Blue Lake is one of only four cirque lakes on mainland Australia and is the only lake exhibiting a dimictic thermal regime.

The Blue Lake Ramsar site has been protected for its conservation values since 1944 when Kosciuszko State Park was gazetted. Ecological impacts to the Blue Lake and Hedley Tarn area prior to its protection have been minimal, and the lakes remain in a near-natural state. The Ramsar site also supports rare, endemic, endangered and vulnerable populations of animals and plants, including the mountain pygmy possum (*Burramys parvus*), the broad toothed rat (*Mastacomys fuscus*), the alpine tree frog (*Litoria verreauxii alpina*) and the anemone buttercup (*Ranunculus anemoneus*). Furthermore, the site is internationally recognised for maintaining biological diversity within its biogeographical region through the inclusion of Kosciuszko National Park as a biosphere reserve within the UNESCO Man and the Biosphere Programme.

Despite the near-natural state of the Blue Lake Ramsar site, threatening processes may significantly alter the components and processes and change the ecological character of the area. Key threats include climate change, cloud seeding, recreation and tourism, bushfires, and erosion and sedimentation. Detailing the ecological character was hindered by knowledge gaps about threatening processes and the ecological character of the Blue Lake Ramsar site. Therefore, knowledge gaps have been identified, and recommendations for addressing these gaps have been given.

Ecological character description details for the Blue Lake Ramsar site

Ramsar Site	Blue Lake
Geographical coordinates	36º24’S, 148º19’E
Location	28 km west of Jindbayne and 3.5 km north of Charlotte Pass
Altitude	Blue Lake is 1890 m asl
Boundaries	Bounded in the north by Mt Twynam (2196 m asl), in the east by Little Twynam (2120 m asl). Includes the catchment of Hedley Tarn to an elevation of 1850 m asl
Area	320 ha
Date of listing as a Ramsar site	17 March 1996
Date for which the description of ecological character applies	The description is for the Ramsar site at the time of listing on 17 March 1996
Management authority	Department of Environment and Climate Change NSW
Status of description	This is the first description of the ecological character of the Blue Lake Ramsar site.
Name of compiler	Rogers K., Ling J.E., Spencer J., and Jelbart, J. Water and Catchments Science Section Department of Environment and Climate Change NSW
Date of Compilation	July 2006
Reference for Ramsar Information Sheet	Blue Lake Ramsar Information Sheet, January 1998 (RIS 1998) http://www.environment.gov.au/cgi-bin/wetlands/search.pl?smode=RAMSAR

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1 Introduction

The Convention on Wetlands of International Importance, commonly known as the Ramsar Convention, was signed in Ramsar, Iran, in 1971. The Ramsar Convention is an intergovernmental treaty with a mission for ‘the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world’ (Ramsar 2002). By signing this treaty Australia has committed to designating at least one wetland that meets the criteria for inclusion in the list of wetlands of international importance. In 2006 Australia had 64 wetlands listed as Ramsar sites (Wetlands International 2006).

Blue Lake was listed as a Ramsar site on 17 March 1996. In doing so, the Australian Government has a number of obligations including formulating and implementing planning to promote conservation and maintaining the ‘ecological character’ of this site.

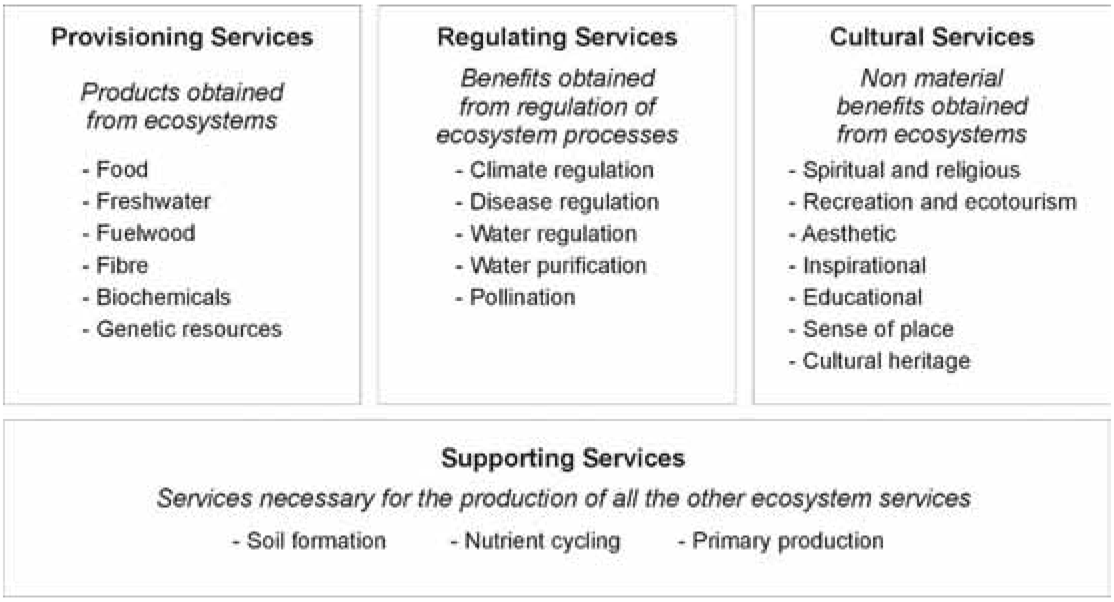
1.1 Ecological character

The Ramsar Convention defines ecological character as ‘the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point’ (Ramsar 2005; see Glossary for definitions of other terms).

In simple terms, an ecological character description for a given wetland is a description of the living and non-living components and how they interact. An ecological character description should also provide information on the natural variability of the wetland and enable limits of acceptable change to be identified (Lambert and Elix 2006).

Within this context, ecosystem benefits/services are defined in accordance with the Millennium Ecosystem Assessment (2003) definition as ‘the benefits that people receive from ecosystems’. The Millennium Ecosystem Assessment (2003) separates ecosystem services further into provisioning, regulating and cultural services, which directly affect people, and supporting services needed to maintain these services (Figure 1).

As a part of the ecological character of a wetland, ecological processes are defined as the dynamic biotic and abiotic interactions within an ecosystem such as primary production, decomposition, carbon and nutrient cycling, sedimentation and provision of habitats for other biota (Figure 2). These may or may not provide benefits or services to humans. Components are the physical, chemical and biological elements of the system, with the latter being defined as habitat, species and genes. Due to the dynamic nature of wetland ecosystems, there is considerable overlap between the components and processes that make up a wetland’s ecological character.



Source: Millennium Ecosystem Assessment (2003)

Figure 1: Summary of ecosystem services

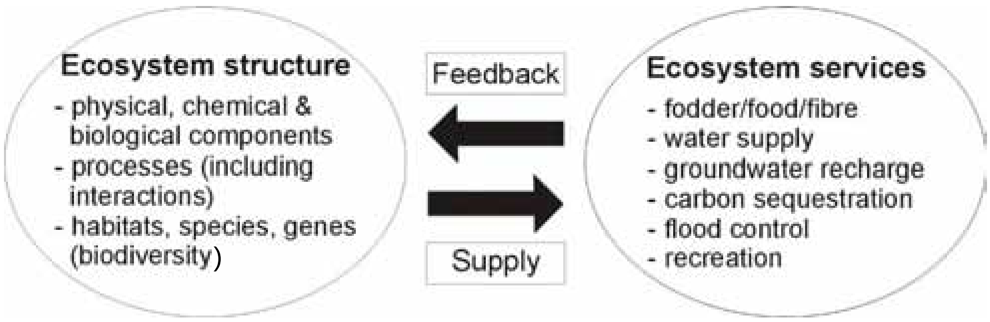


Figure 2: The Millennium Ecosystem Assessment's (2003) description of ecosystems

1.2 Reasons for describing ecological character

Ecological character descriptions have been developed for numerous Ramsar sites throughout NSW (Taylor-Wood and Jaensch 2005a, 2005b) and Australia (DSE 2005; Phillips et al. 2005) to assist in meeting Australia's obligations under the Ramsar Convention, as defined in the *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBCA). In a legal review of the Victorian Department of Sustainability and Environment framework (DSE 2005), which has been used to compile a number of ecological character descriptions, McGrath (2006) summarised these obligations as follows:

1 to assist in implementing Australia's obligations under the Ramsar Convention, as stated in Schedule 6 (Managing wetlands of International importance) of the Environment Protection and Biodiversity Conservation Regulations 2000 (Commonwealth): (a) to describe and maintain the ecological character of declared Ramsar wetlands in Australia; and (b) to formulate and implement planning that promotes: (i) conservation of the wetland; and (ii) wise and sustainable use of the wetland for the benefit of humanity in a way that is compatible with maintenance of the natural properties of the ecosystem

2 to assist in fulfilling Australia's obligation under the Ramsar Convention to arrange to be informed at the earliest possible time if the ecological character of any wetland in its territory and included in the Ramsar List has changed, is changing or is likely to change as a result of technological developments, pollution or other human interference

3 to supplement the description of the ecological character contained in the Ramsar Information Sheet submitted to the Ramsar Convention for each listed wetland, and collectively form an official record of the ecological character of the site

4 to assist the administration of the EPBCA, particularly: (a) to determine whether an action has, will have or is likely to have a significant impact on a declared Ramsar wetland in contravention of sections 16 and 17B of the EPBCA; or (b) to assess the impacts that actions referred to the Minister under Part 7 of the EPBCA have had, will have or are likely to have on a declared Ramsar wetland

5 to assist any person considering taking an action that may impact on a declared Ramsar wetland whether to refer the action to the Minister under Part 7 of the EPBCA for assessment and approval

6 to inform members of the public who are interested generally in declared Ramsar wetlands to understand and value the wetlands.

In addition to meeting Australia's obligations as a signatory to the Ramsar treaty, the ecological character description also provides domestic benefits by guiding planners and managers, and as a resource for natural resource planning and site management plans (Lambert and Elix 2006). The ecological character description also feeds into the Ramsar Information Sheet to enable updating of information on this document.

The ecological character description workshop held in Canberra on 3–4 May 2006 also identified a number of 'primary, secondary and tertiary' users of an ecological character description. It was identified that these users have different expectations and applications for the document, such as informing plans of management, monitoring programs and impact assessment (Lambert and Elix 2006).

1.3 Legislative framework

In addition to being listed as a wetland of international importance, the Blue Lake Ramsar site and its ecological assets are also recognised under other international agreements including:

- UNESCO's Man and the Biosphere Programme: identifies biosphere reserves as areas of terrestrial and coastal ecosystems managed to promote solutions that reconcile the conservation of biodiversity with sustainable use
- Convention on Biological Diversity: aimed at promoting conservation of biological diversity, the sustainable use of its components and the fair and equitable use of genetic resources
- Japan–Australia Migratory Bird Agreement (JAMBA, in 1981), between the Government of Australia and the Government ofJapan: for the protection of migratory birds, birds in danger of extinction and their environment
- China–Australia Migratory Bird Agreement (CAMBA, in 1988), between the Government of Australia and the People's Republic of China: for the protection of migratory birds, birds in danger of extinction and their environment

- Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA, in 2006), between the Government of Australia and the Government of the Republic of Korea
- the Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention, in 1983).

Australia's obligations concerning the international agreements are translated into Commonwealth legislation through the provisions of the EPBCA and Environment Protection and Biodiversity Conservation Regulations 2000. The Act and its Regulations provide:

- guidelines for the protection and management of biosphere reserves
- guidelines for managing wetlands of international importance (Ramsar wetlands) and for the assessment and approval of actions that may impact these wetlands
- assessment and approval requirements that are likely to significantly impact migratory species.

The EPBCA also provides for the:

- identification and listing of threatened species and ecological communities
- preparation and implementation of recovery plans
- identification of key processes that threaten biodiversity
- preparation of threat abatement plans.

The following NSW legislative frameworks also afford protection to the Blue Lake Ramsar site:

- *National Parks and Wildlife Act 1974*: provides for the care, control and management of all national parks, historic sites, nature reserves, reserves, Aboriginal areas and state game reserves. State conservation areas, karst conservation reserves and regional parks are also administered under the Act.
- *Threatened Species Conservation Act 1995* (TSCA): provides the legislative framework for protecting threatened species, communities and critical habitat in NSW.
- *Environmental Planning and Assessment Act 1979*: provides the legislative framework for the assessment of environmental impacts of proposed activities.
- *Environmental Planning and Assessment Act Amendment (Ski Resort Areas) Act 2001*: provides a separate regime which allows ski resort areas to remain within Kosciuszko National Park, to provide planning for alpine resorts through a regional environmental plan, and identifies the appropriate planning authority.

Other important NSW legislation also directs aspects of management of the Kosciuszko National Park and may influence management of the Blue Lake Ramsar site. These include:

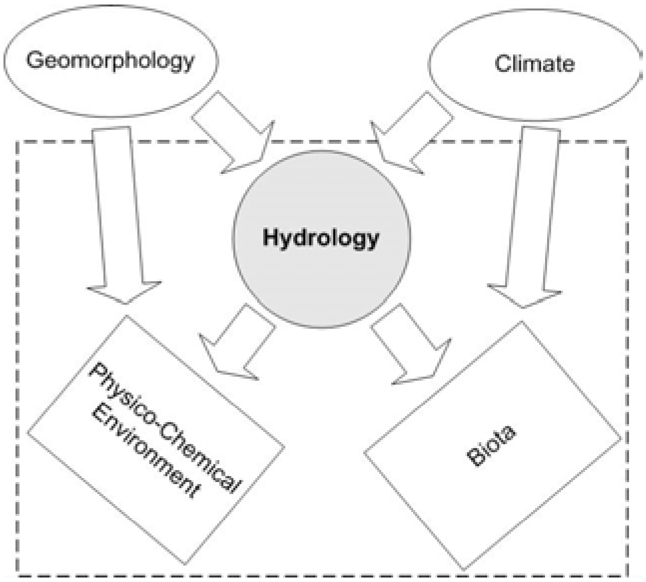
- *Snowy Hydro Corporatisation Act 1997*
- *Snowy Mountains Cloud Seeding Trial Act 2004*
- *Protection of the Environment Operations Act 1997*
- *Aboriginal Land Rights Act 1983*
- *Rural Fires Act 1997*
- *Noxious Weeds Act 1993*
- *Rural Lands Protection Act 1998*
- *Heritage Act 1977*
- *Public Health Act 1991*.

1.4 Approach taken

This description of ecological character was prepared using the *Framework for describing the ecological character of Ramsar wetlands* (DSE 2005) and was modified according to the approaches taken by Biosis Research (Taylor–Wood and Jaensch 2005a, 2005b) and Phillips et al. (2005). The advice provided by Sorrell (2006), Davis and Sim (2006), Phillips et al. (2002) and McGrath (2006), and the early recommendations from the ecological character description workshop, held in Canberra on 3–4 May 2006, were also incorporated into the approach.

Five essential elements were used to compile the ecological character description for the Blue Lake Ramsar site; hydrology, climate, geomorphology, biota and physico-chemical elements (Figure 3). Each of these elements is considered an essential component of a wetland ecosystem.

Once consideration was given to previous ecological character frameworks and reviews, and the Blue Lake Ramsar site was conceptualised, the approach outlined in Table 1 was adopted to prepare this ecological character description.



Source: Mitsch and Gosselink (2000)

Figure 3: Generic conceptual model

Table 1: Steps taken in describing the ecological character of the Ramsar site

Step	Section
1. Ecological character and its purpose defined	1
2. Site location, site description and Ramsar criteria used for listing the site described	2
3. Summary of the ecological character of the Ramsar site, including services and the components and processes that contribute to each service, prepared	3
4. Conceptual model of the linkages between components and processes developed	3
5. Ecosystem services described	4
6. Key components/processes that support ecosystem services described	5
7. Limits of acceptable change in key components developed	6
8. Key threats identified	7
9. Knowledge gaps identified and recommendations provided	8
10. Recommendations for updating the Ramsar Information Sheet	8.2
11. Update Ramsar Information Sheet	RIS

2 Blue Lake and Hedley Tarn site description

2.1 Site location

The Blue Lake Ramsar site (36°24'S, 148°19'E) lies within the alpine region of NSW, approximately 3 km north-west of Charlotte Pass (Figure 4). Charlotte Pass is the highest township in Australia and is located within the Australian Alps, approximately 215 km south-west of Canberra, 500 km south-west of Sydney and 610 km north of Melbourne. Blue Lake and Hedley Tarn are in Kosciuszko National Park at an elevation of approximately 1890 m and 1850 m above sea level (asl), respectively. Together with Lake Cootapatamba, Albina Lake and Club Lake, they make up the alpine lakes of south-eastern Australia. The Ramsar site includes the catchment area of Blue Lake and Hedley Tarn. Blue Lake Ramsar site is bounded in the north-west by a ridge between Mt Twynam and Carruthers Peak and in the north-east by Little Twynam. The southern boundary is the southern side of Hedley Tarn. The northern side of Blue Lake has a sheer drop and the southern side of the Ramsar site gently slopes toward Hedley Tarn, continuing downstream following Blue Lake Creek, which is a tributary to the Snowy River that enters the ocean at Marlo, Victoria.

2.2 Wetland description

The Blue Lake Ramsar site is classified as type Va, which relates to high altitude alpine wetlands (Table 2). It includes deep water areas (up to 28 m deep) with muddy sediments (up to seven metres deep), a narrow littoral zone dominated by steep bedrock and boulders, and catchment vegetation dominated by alpine herbfields, heaths, fens and bogs (Costin and Wimbush 1972; Raine 1982; Hancock et al. 2000) (Figure 5).

Two regional classification schemes for Australia have been used in this document: the Interim Biogeographical Regionalisation of Australia (IBRA) and the Australian Drainage Divisions and River Basins (ADDRB) (Appendix 1). Since the Blue Lake Ramsar site is the only type Va wetland in Australia, it is classified as representative of type Va wetlands within its biogeographic region, according to either the IBRA or ADDRB classification schemes.

2.3 Ramsar criteria

At the time of listing of Blue Lake and Hedley Tarn on the Ramsar register, the pre-1999 Ramsar criteria 1a, 1d, 2b and 2d were met (RIS 1998); these equate to current Ramsar criteria 1 and 3.

Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.

Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.

Since the listing of Blue Lake and Hedley Tarn as a Ramsar site in 1996, further information has become available that indicates additional services that relate to Ramsar criterion 2.

Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.

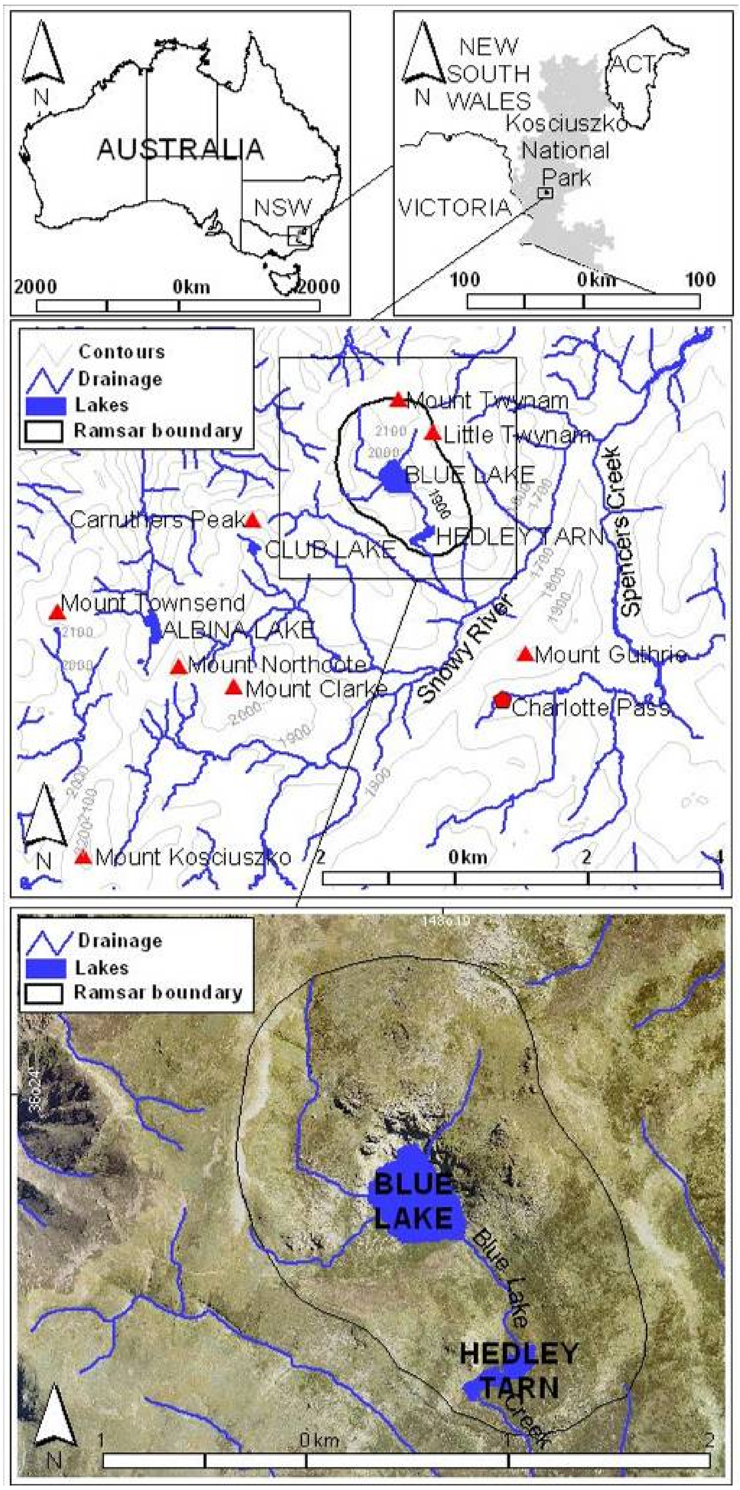


Figure 4: Location of the Blue Lake Ramsar site

Source: Steve Jacobs, DECC

Figure 5: Blue Lake, Blue Lake and Blue Lake Creek outflow, Hedley Tarn

Table 2: Ramsar wetland type classification scheme for inland waters

Fresh water	Flowing water	Permanent	Rivers, streams, creeks	M	Permanent rivers/streams/creeks; includes waterfalls
			Deltas	L	Permanent inland deltas
			Springs, oases	Y	Freshwater springs; oases
		Seasonal/ intermittent	Rivers, streams, creeks	N	Seasonal/intermittent/irregular rivers/streams/creeks
	Lakes and pools	Permanent	>8 ha	O	Permanent freshwater lakes (over 8 ha); includes large oxbow lakes
			<8 ha	Tp	Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season
		Seasonal/ intermittent	>8 ha	P	Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes
			<8 ha	Ts	Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes
	Marshes on inorganic soils	Permanent	Herb-dominated	Tp	Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season
		Permanent/ seasonal/ intermittent	Shrub dominated	W	Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils
			Tree-dominated	Xf	Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils
		Seasonal/ intermittent	Herb-dominated	Ts	Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes
	Marshes on peat soils	Permanent	Non-forested	U	Non-forested peatlands; includes shrub or open bogs, swamps, fens
			Forested	Xp	Forested peatlands; peatswamp forests
	Marshes on inorganic or peat soils	High altitude (alpine)		Va	Alpine wetlands; includes alpine meadows, temporary waters from snowmelt
		Tundra		Vt	Tundra wetlands; includes tundra pools, temporary waters from snowmelt
Saline, brackish or alkaline water	Lakes	Permanent		Q	Permanent saline/brackish/alkaline lakes
		Seasonal/intermittent		R	Seasonal/intermittent saline/brackish/alkaline lakes and flats
	Marshes and pools	Permanent		Sp	Permanent saline/brackish/alkaline marshes/pools
		Seasonal/intermittent		Ss	Seasonal/intermittent saline/brackish/alkaline marshes/pools
Fresh, saline, brackish or alkaline water	Geothermal			Zg	Geothermal wetlands
	Subterranean			Zk(b)	Karst and other subterranean hydrological systems, inland

Source: Ramsar Convention Secretariat (2004)

3 Ecological character

3.1 Introduction

The ecosystem services used for the basis of the Blue Lake ecological character description are derived from those described by the Millennium Ecosystem Assessment (2003). These include:

- provisioning services: products obtained from the ecosystem, such as food and water
- regulating services: benefits obtained from the regulation of ecosystem processes, such as regulation of floods, drought, land degradation and disease
- cultural services: non-material benefits through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences, such as recreational spiritual, religious and other non-material benefits
- supporting services: those necessary for the production of all other services, such as soil formation, nutrient cycling, primary production, reservoir of biodiversity.

It is the supporting and regulating services that are fundamental to the functioning of Blue Lake and Hedley Tarn and the development of its unique ecological character. The cultural services attest to the affinity people have with the Blue Lake and Hedley Tarn ecosystem. Since Blue Lake, Hedley Tarn and their catchment lie entirely within Kosciuszko National Park, the site does not directly provide provisioning services, but does contribute to water supplies downstream. Blue Lake and Hedley Tarn have provided provisioning services for Aborigines, graziers and livestock in the past.

The ecosystem services provided by Blue Lake and Hedley Tarn are unique and developed on the basis of interactions between unique processes and components. While these processes and components broadly fit the generalised conceptual model (Figure 3), this model has been revised according to the key processes and components of Blue Lake and Hedley Tarn (Figure 6). The key component of this model is the hydrology at the centre of the ecosystem. The hydrology is largely controlled by the unique geomorphology of the region and the alpine climate. These three key components – hydrology, geomorphology and climate – interact with the physico-chemical environment, habitats, flora and fauna.

3.2 Summary of ecosystem services, components and processes

The ecosystem services and associated components and processes are summarised in Table 3.

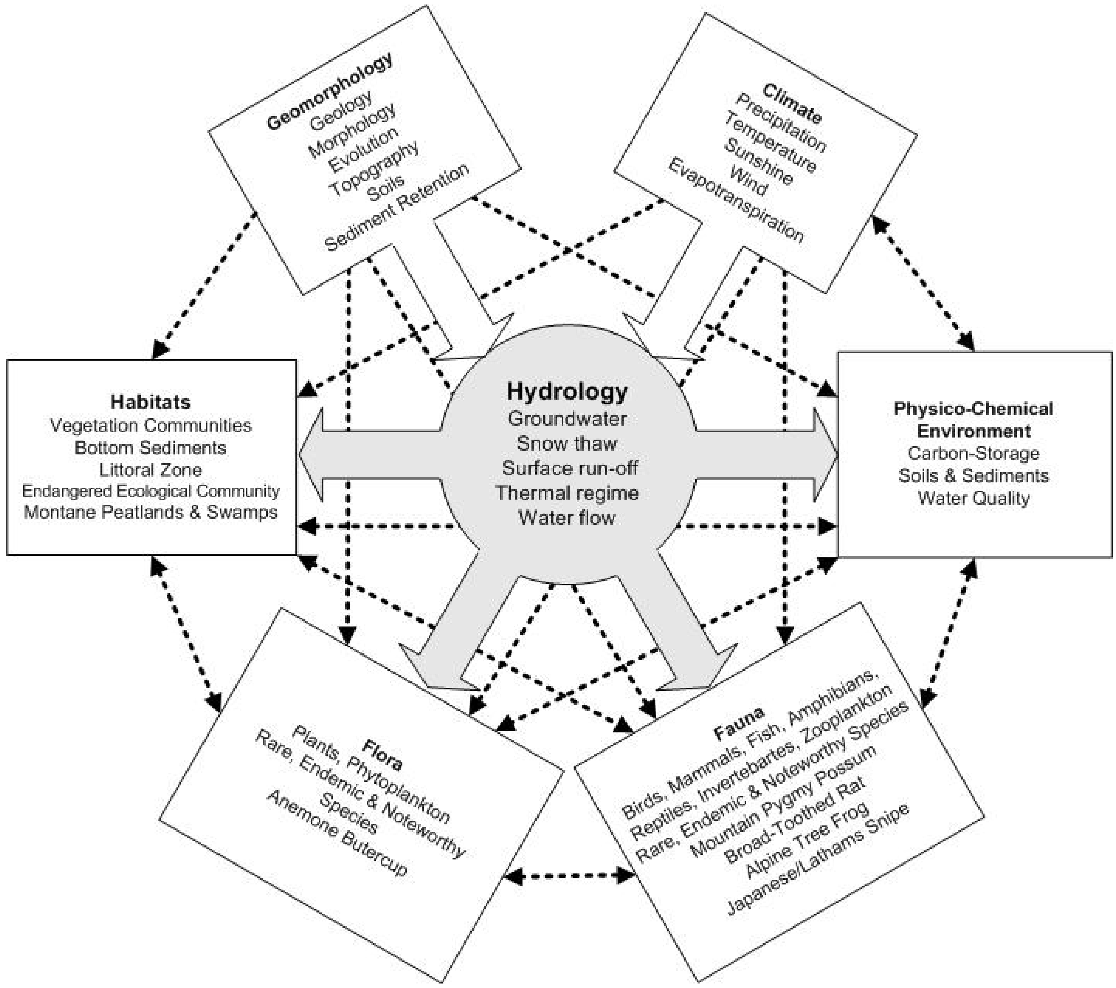


Figure 6: Conceptual model of key processes and components of the Ramsar site

Table 3: Ecosystem services for the Blue Lake Ramsar site

Ecosystem service		Service relating to Blue Lake and Hedley Tarn	Ramsar criteria	Components/Processes
Supporting				
Rare and unique example of near-natural wetland type	Rare and unique example of near-natural wetland type	Blue Lake is a rare and unique example of a near-natural wetland type found within the Australian Alps biogeographic region, and the south-east coast division biogeographic region, and Australia.	1	Climate, geomorphology, hydrology, physico-chemical environment
Wildlife support	Fauna	Supports native fauna	2, 3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Supports endangered species: *Burramys parvus* (mountain pygmy possum)	2, 3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Supports vulnerable species: *Litoria verreauxii alpina* (alpine tree frog)	2, 3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Supports vulnerable species *Mastacomys fuscus* (Broad toothed rat)	2, 3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Supports the JAMBA, CAMBA, and ROKAMBA listed *Gallinago hardwickii* (Japanese/Latham's snipe)	3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
	Flora	Supports native and introduced flora	3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Supports vulnerable species *Ranunculus anemoneus*	2, 3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Supports species endemic to Kosciuszko National Park	3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
	Bioregion and Biome	Supports populations of plant and animal species representative of the biogeographic region	3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
		Biosphere Reserve	3	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
Food web support	Organic carbon storage	Organic carbon storage	na	Habitats, fauna, flora
	Primary production	Primary production	na	Habitats, fauna, flora
	Nutrient cycling	Nutrient cycling	na	Physico-chemical environment, habitats, fauna, flora

Ecosystem service		Service relating to Blue Lake and Hedley Tarn	Ramsar criteria	Components/Processes
Regulating				
Hydrological stability	Regulation of water flow	Freezing and thawing of snow regulates downstream water flow	1	Climate, geomorphology, hydrology
	Regulation of water temperature	Blue Lake is the only mainland dimictic lake. Dimictic regime of Blue Lake regulates water temperatures flowing from Blue Lake.	1	Climate, geomorphology, hydrology, physico-chemical environment
Sediment retention	Sediment retention	Reduces downstream sediment loads by retaining sediments	1	Geomorphology, hydrology
Climate change mitigation	Inorganic carbon storage	Inorganic carbon storage	na	Habitats, flora
Cultural				
Recreation and tourism	Nature observation	Observation of wildlife, geology and geomorphology	na	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
	Alpine sports	Rock/ice climbing, cross-country skiing	na	Climate, geomorphology, hydrology
Cultural heritage	Research and education	Research and educational value as Blue Lake is only mainland dimictic lake and largest of mainland cirque lakes	na	Climate, geomorphology, hydrology, physico-chemical environment, habitats, fauna, flora
	Aboriginal heritage	Aboriginal cultural value	na	Climate, hydrology, fauna
	European heritage	Past European use of Blue Lake for provisioning for livestock	na	Climate, hydrology, physico-chemical environment, habitats, flora
Provisioning				
Water supply	Indirect water supply	Water from Blue Lake and Hedley Tarn contribute to water supplies for the Snowy Mountains region.	na	Climate, geomorphology, hydrology, physico-chemical environment
	Direct water supply	Blue Lake and Hedley Tarn have been a water supply for Aborigines, graziers and livestock in the past.	na	Climate, geomorphology, hydrology, physico-chemical environment
Food supply	Food supply	Blue Lake and Hedley Tarn have been a source of food for Aborigines and livestock in the past.	na	Climate, geomorphology, hydrology, physico-chemical environment, habitats, flora

4 Description of key ecosystem services

4.1 Introduction

This section describes each ecosystem service that is relevant to the listing of the Blue Lake Ramsar site and relates to Ramsar criteria that the Blue Lake Ramsar site meets, as detailed in Table 3. Components and processes that support each ecosystem service are described further in section 5. Where specific data on ecosystems services for Blue Lake and Hedley Tarn was unavailable, data for Kosciuszko National Park or the Australian Alps was used and applied to the Blue Lake Ramsar site. In some cases data about ecosystem services may be unavailable for both the Blue Lake Ramsar site, Kosciuszko National Park or the Australian Alps; hence further description of services is limited. This ecological character description has been prepared restrospectively for the Ramsar site at the time of Ramsar listing. Where more recent information is representative of the character of the site at the time of listing, it has been used.

4.2 Rare and unique example of near-natural wetland type

Blue Lake is one of only four cirque lakes found on mainland Australia. These four lakes, together with Hedley Tarn, make up the alpine lakes and are the highest lakes in Australia. Blue Lake is the largest (14.4 ha) and deepest (28 m) lake. The geomorphology of the lake lends itself as a sedimentation sink and in doing so holds important information about past climates and vegetation communities. Blue Lake exhibits well-developed thermal stratification and is the only mainland lake deep enough to develop a dimictic thermal regime (Raine 1982; Hancock et al. 2000).

The Blue Lake Ramsar site is in a near-natural state. Since the Australian alpine regions are relatively poor in game, it is likely that Aboriginal people did not live in the vicinity of Blue Lake and Hedley Tarn or burn vegetation (Costin et al. 2000). Records from explorers and early settlers indicate that Aboriginal people did not permanently occupy the Australian Alps. While summer grazing of sheep and cattle and burning of the vegetation to promote fresh regrowth was well established within the region prior to 1944, impacts on Blue Lake and Hedley Tarn were most significant during the drought period of 1890–1901. Concern about widespread damage to vegetation and soils led to the establishment of Kosciusko State Park in 1944. Grazing was prohibited in the alpine area and some of the alpine flora were able to recover (Costin et al. 2000). By 1972, 135 years of recorded grazing history ended with the termination of grazing within the entire park area. With the establishment of the *National Parks and Wildlife Act 1967*, the park was renamed Kosciuszko National Park (DEC 2006). The Blue Lake Ramsar site lies entirely within Kosciuszko National Park and is managed by the Department of Environment and Climate Change NSW (DECC) to maintain its near-natural state.

The near-natural state of Blue Lake and Hedley Tarn is evident since the water is of high quality. The Ramsar site receives water from Blue Lake Creek and is the drainage basin for a relatively small catchment area of 320 ha. The waters exhibit low turbidity, conductivity and salinity and near neutral pH values (Cullen and Norris 1989; Balmaks 1984).

4.3 Fauna support

4.3.1 Native fauna

The combination of the unique physico-chemical environment, flora and hydrology enables the Blue Lake Ramsar site to support numerous fauna species, which include birds (16), mammals (7), reptiles (5), amphibians (2), fish (1), benthic macroinvertebrates (12), and zooplankton (Bayly 1970; Timms 1980; RIS 1998). Other fauna likely to exist at Blue Lake and Hedley Tarn include microinvertebrates and non-benthic macroinvertebrates.

4.3.2 Endangered species: *Burramys parvus*

The endangered mountain pygmy possum (*Burramys parvus)* is the largest of Australia's five species of pygmy possum, and was thought to be extinct until it was observed in 1966. It is found only in snow-covered alpine and subalpine regions above 1400 m in Victoria and NSW and its distribution coincides with Australia's ski resorts covering an area of approximately 10 km^2 (DEC 2005a; DEH 2006a). For this reason the mountain pygmy possum has been listed as an endangered species in the IUCN Red List in 1996 and the EPBCA, and as a vulnerable species under the TSCA.

4.3.3 Vulnerable species: *Mastacomys fuscus*

The vulnerable broad toothed rat (*Mastacomys fuscus*) lives in a series of runways in wet alpine and subalpine heath and woodlands in Kosciuszko National Park (DEC 2005b). While it is not nationally endangered or vulnerable, its distribution in NSW is limited. Due to its limited distribution and known threats, including climate change and predation by foxes, the broad toothed rat has been listed as vulnerable under the TSCA.

4.3.4 Vulnerable species: *Litoria verreauxii alpina*

The alpine tree frog (*Litoria verreauxii alpina*) is found over about 3500 km^2 throughout the high country of Australia (Osborne et al. 1999); however recent searches indicate that its distribution throughout this region is small. It is found mainly in woodlands, heaths, grasslands and herbfields at montane, subalpine and alpine altitudes. The Blue Lake Ramsar site is particularly important for the alpine tree frog as breeding populations occur on plains or open valleys where there are streams, side pools, fens and bogs (Gillespie et al. 1995). Due to its limited distribution, the alpine tree frog has been listed as critically endangered in the IUCN Red List in 2002, vulnerable under the EPBCA and endangered under the TSCA.

4.3.5 JAMBA, CAMBA and ROKAMBA listed species: *Gallinago hardwickii*

The Japanese/Latham's snipe (*Gallinago hardwickii*, also known as *Capella hardwickii*) has been observed within the Blue Lake Ramsar site (K. Green 2006, pers. comm.). This migratory bird species breeds in Japan and spends the summer in southern Australia. It is not observed annually within the Blue Lake Ramsar site and is a highly mobile visitor. It appears to move in response to rainfall and may be observed at the Blue Lake Ramsar site in response to dry wetland conditions elsewhere. Numbers of Japanese/Latham's snipe have declined this century, presumably due to excessive hunting and the decline of suitable habitats (Blakers et al. 1984). For this reason, the Japanese/Latham's snipe has been listed on CAMBA, JAMBA, ROKAMBA and the Bonn agreement (1983).

4.4 Flora support

4.4.1 Native flora and communities

The catchment of Blue Lake Ramsar site supports numerous native and introduced flora. The Kosciuszko alpine area supports 212 species (Costin et al. 2000), of which 48 are introduced species (Mallen 1986). Since Kosciuszko is a diverse area in terms of climate, soils, aspect and competition, it supports a mosaic of plant communities. Of particular importance for the Blue Lake Ramsar site is alpine communities of tall alpine herbfields, wet and dry heaths, fen and bogs.

4.4.2 Species endemic to Kosciuszko National Park

Kosciuszko National Park and the Blue Lake Ramsar site support numerous plant species that are rare and endemic to the Kosciuszko area. Of the 212 plant species found in the Kosciuszko area, about 30 are exclusively alpine and at least 21 are endemic (Costin et al. 2000). Noteworthy flora observed within the Blue Lake and Hedley Tarn catchment includes *Oremyrrhis brevipes, Oschatzia cunefolia, Abrotanella nivihena, Brachycome stolonifera, Craspedia leucantha, Erigeron setosus, Parantennaria uniceps, Colobanthus nivicola, Colobanthis pulvinatus, Carex cephalotes, Astelia psychoracharis, Agrostis meionectes, Deyeuxia affinis, Ranunculus anemoneus* and *Ranunculus niphophilus* (RIS 1998).

4.4.3 Vulnerable species: *Ranunculus anemoneus*

The anemone buttercup, *Ranunculus anemoneus*, is found in a narrow band about 8 km wide and 32 km long which includes the Blue Lake Ramsar site. Its distribution is entirely within Kosciuszko National Park and for this reason it has been listed as vulnerable under the EPBCA and the TSCA.

4.4.4 Endangered ecological community: montane peatlands and swamps

Montane peatlands and swamps comprise dense, sparse or open layers of shrubs, sedges, grasses and forbs, and contain sphagnum moss. These communities are associated with an accumulation of peaty or organic mineral sediments on poorly drained flats. Due to the limited distribution of this community and threats from clearing, grazing, trampling, disturbance, peat mining, fires, weed invasion, erosion, sedimentation and climate change, this ecological community has been identified under the TSCA as an endangered ecological community (DEC 2005c).

4.5 Bioregion and biosphere support

4.5.1 Populations representative of the biogeographic region

The Blue Lake Ramsar site lies within the Australian Alps biogeographic region according to IBRA, and within the Snowy River – Southeast Coast Division according to ADDRB (Appendix 1). The Blue Lake Ramsar site is the only type Va Ramsar wetland in Australia and is the only wetland with alpine vegetation communities. Furthermore it supports numerous flora species endemic to either Kosciuszko National Park or the Australian Alps and supports fauna limited to alpine or subalpine regions of south-eastern Australia. Therefore, the Blue Lake Ramsar site supports plant and animal species representative of its biogeographic region.

4.5.2 Biosphere reserve

Kosciuszko National Park is one of 440 biosphere reserves distributed throughout the world. Biosphere reserves are areas of terrestrial and coastal ecosystems managed to reconcile biodiversity conservation and sustainable use (DEC 2006). Biosphere reserves are designated by the International Co-ordinating Committee of UNESCO's Man and the Biosphere Programme. Kosciuszko National Park satisfies the criteria for designation as a biosphere reserve as it provides 'representation of a biome, unique communities or areas with unusual natural features of scientific or aesthetic interest' (Kirkpatrick 1994). The Blue Lake Ramsar site contributes significantly to the designation of Kosciuszko National Park due to its status as a rare or unique near-natural wetland type and the flora and fauna communities that it supports.

4.6 Hydrological stability

4.6.1 Regulation of water flow

Due to colder air temperatures in the Australian Alps during winter, permanent ice covers the surface of Blue Lake during winter. Stream flow from Blue Lake and Hedley Tarn is extremely low during winter (Raine 1982) and typically increases in November. The volume of stream flow is dependent on snowfall within the catchment.

4.6.2 Regulation of water temperature

Blue Lake exhibits a dimictic thermal regime (Raine 1982). This regime partly regulates water temperatures within Blue Lake, Hedley Tarn and downstream of the Ramsar site.

4.7 Sediment retention

Blue Lake was excavated by glacial action and upon deglaciation Blue Lake emerged as a deep lake consisting of two main basins. These basins have depths of 26 m and 28 m. Due to the depth of Blue Lake, sediments have been retained within these basins for 15.4 ka; Holocene aged sediments typically originate from aeolian formations from the mallee region west of the Snowy Mountains (Stanley and De Deckker 2002), while contemporary sediments are largely derived from the catchment as a result of erosion.

4.8 Recreation and tourism

Mountain summits are major tourist and recreation destinations worldwide. Since Mt Kosciuszko is the highest and most accessible continental summit in mainland Australia, the region is increasingly used for recreation. Due to the short distance from Charlotte Pass, Blue Lake is a popular day walk destination and is readily accessed by a well-established trail (Pickering and Buckley 2003). Tourism and recreational activities at Blue Lake include hiking, picnicking, rock climbing, cross-country skiing, scuba diving and wind surfing.

4.9 Cultural heritage

4.9.1 Research, education and communication

Kosciuszko National Park has been an area of interest for scientists and researchers for some time and is one of the most intensively studied national parks in NSW (DEC

2006). Research in the Australian Alps has a long history, commencing shortly after European exploration in the mid to late 1800s, and has continued in the national park since this time with interest now largely focused on threatened species. Research at Blue Lake and Hedley Tarn commenced with the work of Dulhunty (1945) and has continued sporadically since this time.

Communication to promote public appreciation of the area's natural history and values has been central to the management of Kosciuszko National Park (DEC 2006). Blue Lake is of particular interest for education and communication since it is a unique and rare example of an alpine lake and is the only cirque lake exhibiting a dimictic thermal regime. It is frequently visited by school and university groups for educational purposes, and information is provided to visitors about Blue Lake and Hedley Tarn.

4.9.2 Aboriginal heritage

Evidence indicates that Aborigines exploited food resources in the alpine zone of the Australian Alps for at least the past 100 years, and likely for much longer than this (Kamminga 1992). Few artefacts of Aboriginal settlement in the Australian Alps remain, as the granitic bedrock is acidic and not conducive for the preservation of archaeological sites (Kamminga 1992). However, it is known that Aboriginal men would gather and cook the Bogong moth (*Agrotis infusa*), which migrates from its breeding ground in western NSW and southern Queensland to aestivate in the summer months in the Australian Alps. Sustaining themselves in this way was relatively easy and did not take much time away from the ritual activities they undertook while in the Australian Alps (Flood 1992). Despite the alpine zone being relatively poor in fauna species, it is also likely that hunting within the Blue Lake and Hedley Tarn catchment occurred during summer. In contrast, it is likely that the alpine zone of the Australian Alps contains a larger and more concentrated quantity of plant food resources and the Blue Lake and Hedley Tarn catchment supports the edible tuber *Microseris* (Kamminga 1992).

4.9.3 European heritage

Europeans have had a strong affiliation with the Australian Alps since Captain Mark John Currie travelled through the region in 1823. Exactly when Europeans first visited Mt Kosciuszko and the Blue Lake and Hedley Tarn catchment is unknown. The explorer Paul Strzelecki is credited with the first ascent of Mt Kosciuszko in 1840. However, since his approach was from the River Murray side, it is unlikely that he visited Blue Lake and Hedley Tarn. It is plausible that stockmen, who had occupied either side of the Australian Alps, had reached the Kosciuszko summit prior to Strzelecki and utilised Blue Lake as a water source (Lennon 1992). However the most significant use of the Blue Lake and Hedley Tarn catchment was as a water source for grazing stock during the drought period of 1890–1901. Since this time grazing has ceased and the Blue Lake and Hedley Tarn catchment is now primarily used for tourism, recreation, wilderness appreciation and scientific research (Costin et al. 2000).

5 Processes and components that support selected ecosystem services

5.1 Introduction

This section details the components and processes that support the selected ecosystem services detailed in section 4 and summarised in Table 3. The relationship between processes and components and the influence they have on each other are detailed in Figure 6. Where specific data on the components and processes of Blue Lake and Hedley Tarn was unavailable, data for Kosciuszko National Park or the Australian Alps was used and applied to the Blue Lake Ramsar site. In some cases data about components and processes is unavailable for the Blue Lake Ramsar site, Kosciuszko National Park and the Australian Alps; hence description of components and processes is limited. For example, species numbers for noteworthy species may be unavailable and are therefore not provided.

5.2 Climate

The processes of the Blue Lake Ramsar site are largely driven by the alpine climate. Located within the Snowy Mountains region of the Australian Alps, the snow country covers an area of approximately 2500 km^2. Blue Lake and Hedley Tarn lie within the alpine zone (>1850 m asl), above the climatic limit of tree vegetation (Costin et al. 2000). The arrival and subsequent melting of snow governs the hydrology and influences the flora, fauna, habitats and physico-chemical environment of Blue Lake and Hedley Tarn.

The climate of the Australian Alps is primarily controlled by circulation systems moving from west to east across south-eastern Australia (DEC 2006). More specifically, the climate is controlled by three factors (Brown and Millner 1989):

- the latitudinal position of the westerly airstream that encircles the southern hemisphere
- the influence of depressions lying off the east coast of NSW
- the occasional intrusion of moist tropical air masses from northern Australia.

Westerly weather dominates in winter and spring causing the western slopes to receive heavy rain and snow, which increases with orographic lifting. A spillover effect, which declines with distance from the mountain peaks, is produced on the eastern side of the ranges (Brown and Millner 1989).

5.2.1 Precipitation

Snow dominates precipitation at Blue Lake and Hedley Tarn from late autumn to early spring. At an elevation of 1890 m Blue Lake is in a 34–194 km^2 area which experiences snow cover for 107 to 142 days (Table 4). Maximum observed snow depth at nearby Spencers Creek (elevation of 1830 m) is approximately 0.5–3.5 m (Brown and Millner 1989). At Charlotte Pass average annual precipitation, which includes rainfall, is 2243 mm and mean monthly precipitation is 133–252 mm (BOM 2006a).

Table 4: Estimated duration of snow cover and mean extent in the Snowy Mountains

Duration of cover (days)	Elevation (m)	Area (km^2)
38	1400	2282
73	1600	788
107	1800	194
142	2000	34

Source: Slatyer et al. (1985)

5.2.2 Temperature

Blue Lake and Hedley Tarn experience cold winters, and frosts may occur at any time of year (Brown and Millner 1989). Temperatures rarely exceed 25ºC and mean daily maximum temperature at Charlotte Pass averages 9.5ºC. Mean daily temperature ranges between –6.8ºC in July and 17.2ºC in February, however temperatures of –23ºC have been recorded (BOM 2006a).

5.2.3 Wind and sunshine

Sunshine and prevailing winds have a significant influence on snow depth at Blue Lake and Hedley Tarn. The prevailing winds are from the north-west in winter and may reach up to 180 km hr^{-1} (Brown and Millner 1989). Since Blue Lake and Hedley Tarn are on the eastern side of Mt Twynam (2196 m) and Carruthers Peak (2140 m), there is little sunshine in winter and the site is largely protected from the prevailing winds (Figure 7). This leads to reduced evaporation and wind transport of snow, and enables significant snow depths to accumulate and the lake surface to freeze for up to six months of the year (Raine 1982).

5.3 Geomorphology

5.3.1 Geology of the Kosciuszko region

The development of the geological features of Kosciuszko National Park may be divided into four periods (Galloway 2004):

- Ordovician to Lower Devonian (approximately 430–470 million years ago): a period of bedrock formation, followed by prolonged erosion
- Tertiary (approximately 50–2 million years ago): a period of uplift and continued erosion
- Pleistocene (approximately the last 2 million years): a period of climatic change that produced glacial and periglacial features, including Blue Lake and Hedley Tarn
- Holocene (approximately the last 10 000 years): a period of relatively stable climate and geological processes.

The Ordovician to Lower Devonian was a period when sedimentary rocks, mainly sandstone, siltstone and shale, were deposited in deep marine environments, which formed part of a large sea over eastern Australia (Costin et al. 2000) (Figure 8). Remnants of these sedimentary rocks still remain within the Kosciuszko region, although metamorphosed to slates, phyllites, quartzites and schists. Folding, uplift and sedimentation continued for some time. Volcanic activity enabled granitic rocks and some basalt to intrude.

After the mid-Devonian, the Earth's crust remained relatively stable and the area was subject to extensive erosion for 250–300 million years. This exposed the granitic intrusions and the region consisted of a lowland with ridges of more resistant rocks (Galloway 2004).

At this point, Australia was attached to Antarctica and New Zealand, forming the super continent Gondwana. The split between Antarctica and Australia started approximately 100 million years ago with real separation beginning 55 million years ago, marking a period of extensive uplift during the Tertiary. While the period at which uplift occurred and the possible causes of uplift vary, there is agreement that the highlands of south-eastern Australia uplifted after a long period of planation and that the region is close to being in isostatic equilibrium (Ollier and Wyborn 1989). Uplifting also caused extensive fracturing and faulting of rocks. Rivers and streams were able to erode uplifted features along zones of weakness.

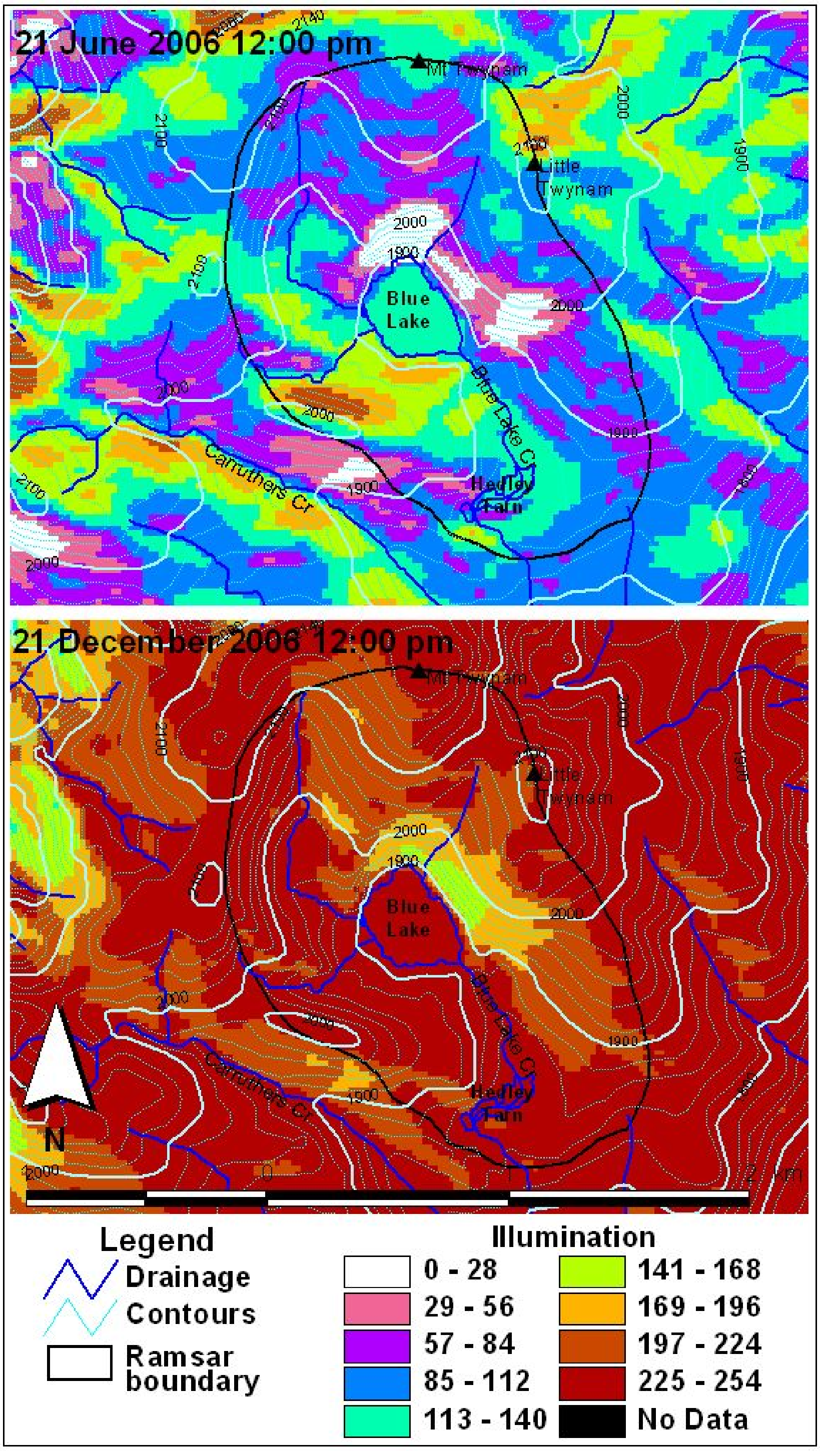
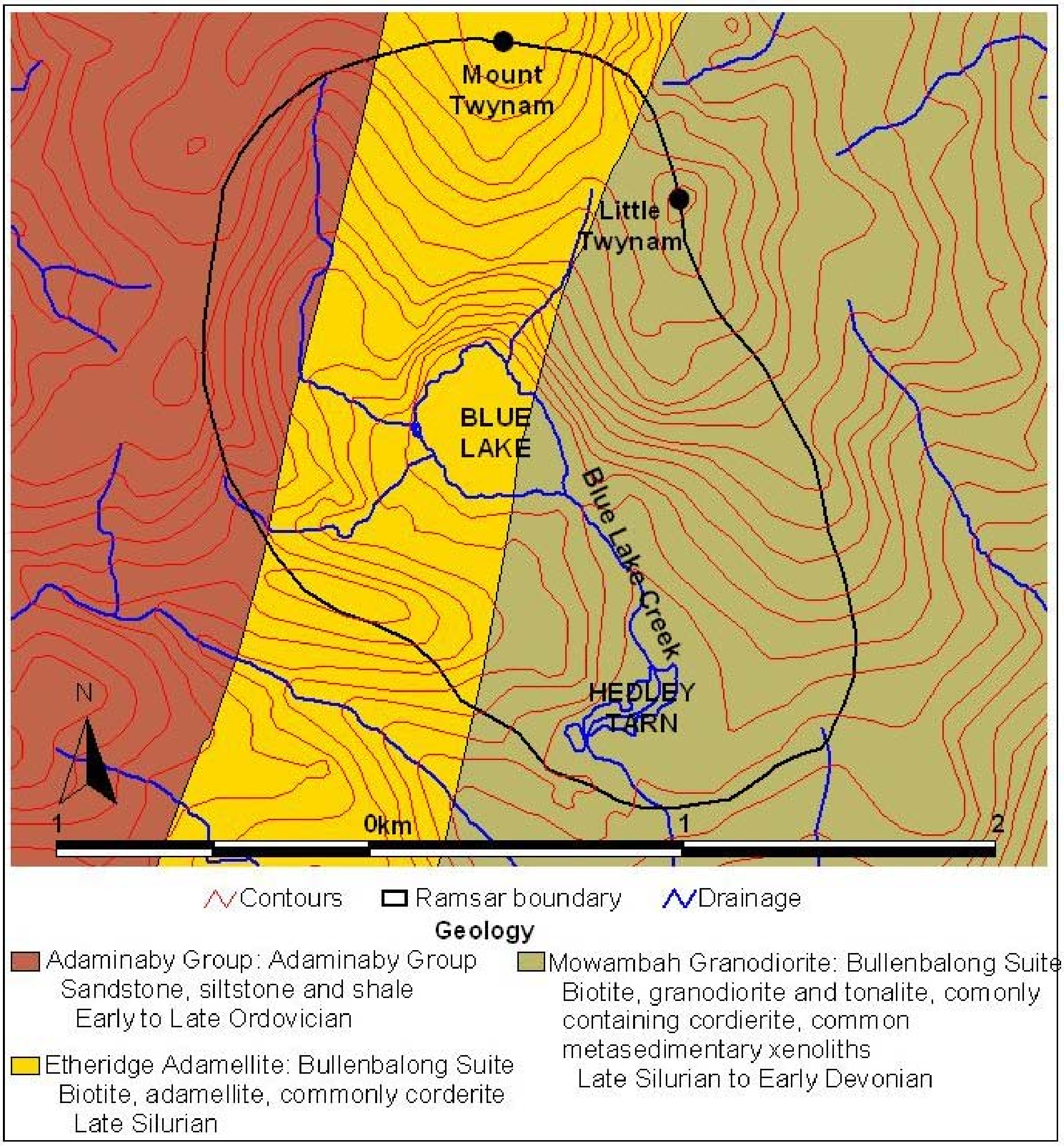


Figure 7: Hypothetical illumination at the Blue Lake Ramsar site

The Pleistocene marked a period of generally colder temperatures throughout the world and glacial conditions developed at higher latitudes and altitudes. This was the period at which the Kosciuszko region was weakly glaciated (Costin et al. 2000). Glacial features that developed during this period include cirques, moraines, lakes, erratics and ice-scratched surfaces. Five glacial lakes were formed during this period; however Blue Lake is the only lake formed by glacial erosion of the bedrock (Galloway 2004).

Glaciers persisted for some time; however, by 15 000 years ago the climate had warmed and glaciers had melted. The Holocene marks a period of climatic stability dominated by solifluction, erosion, nivation, frost heaving of soil, stone movement by snow pressure and the formation of string bogs (narrow turf contour ridges separating elongated ponds) in the Kosciuszko region (Galloway 2004).



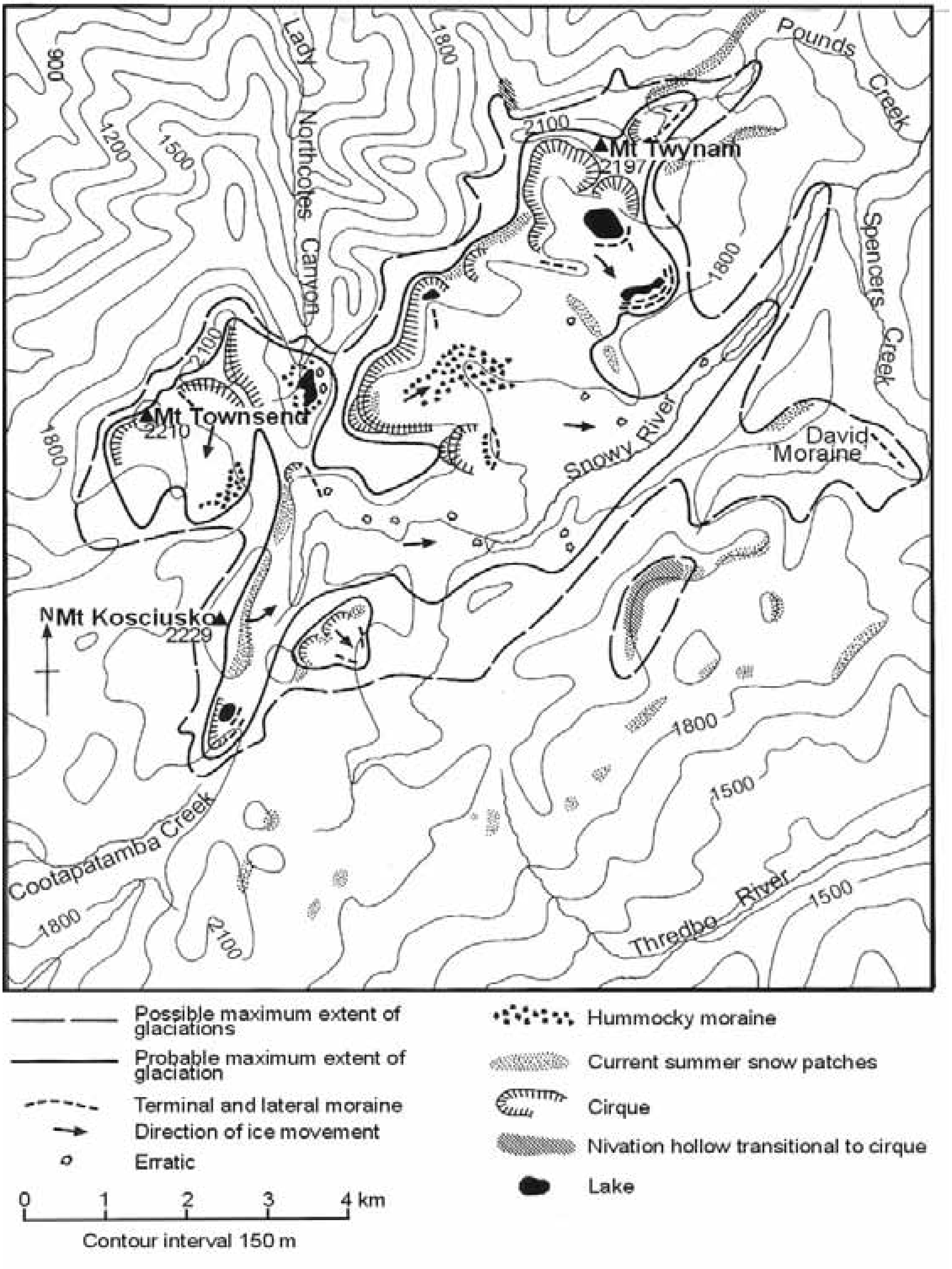
Source: 1: 100 000 Geology Sheet of Kosciuszko

Figure 8: Geology of the Blue Lake Ramsar site

5.3.2 Evolution

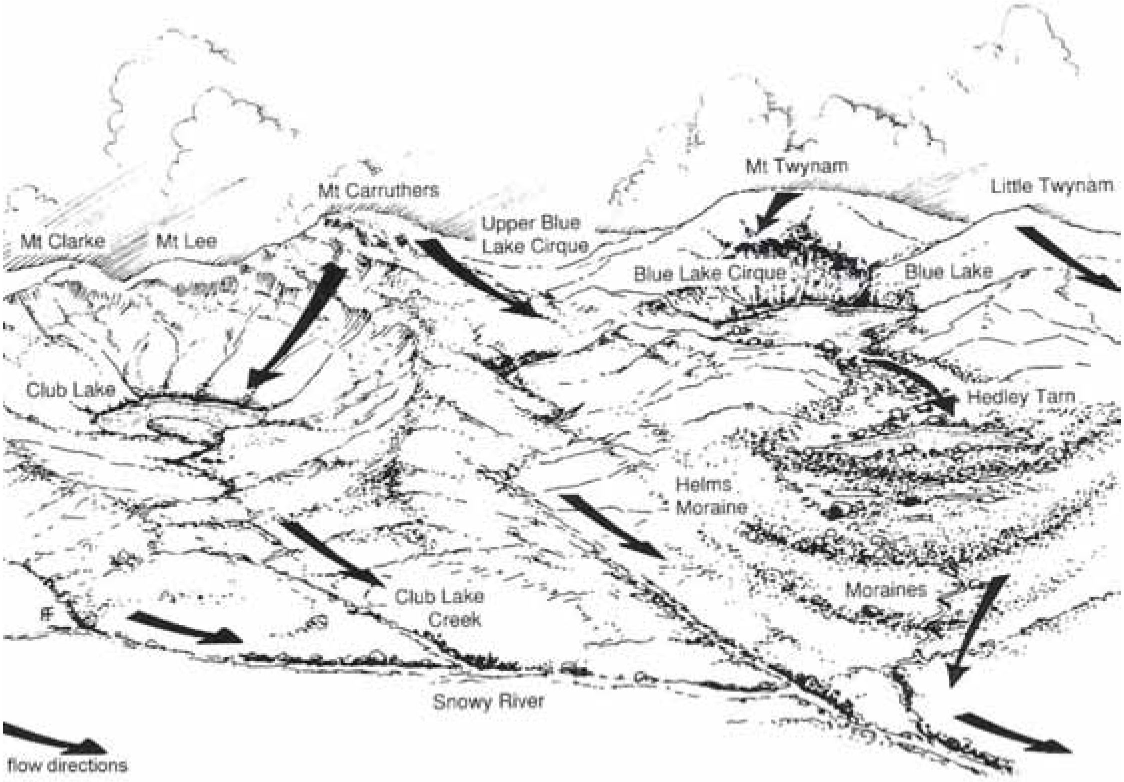
Blue Lake occupies the lower basin of a two-storeyed cirque that formed during the Pleistocene glaciations. It marks the junction of three valley glaciers, which deepened and gouged the deepest of the glacial lakes in the Kosciuszko area (Dulhunty 1945) (Figure 9; Figure 10).

The largest glacier gathered in the amphitheatre lying to the south-west of Mt Twynam and along the eastern side of the range and forms the head of the valley in which Blue Lake and Hedley Tarn lie. The second glacier appears to have gathered to the east and north-east of Carruthers Peak and moved east. The third glacier accumulated to the north-north-east of the lake between Mt Twynam and Little Mt Twynam, passing directly down the steep mountain side to join the other glaciers between the centre and south-eastern end of the lake. Convergence of the glaciers may have produced the greatest depth in the lake. Granite observed downstream from Blue Lake indicates that the old-valley floor, where Blue Lake now is, was over-deepened by glacial action to the extent of approximately 25 m (Dulhunty 1945). The terminal moraine deposited at the lower end played only a minor part in damming the waters of Blue Lake.



Source: Galloway (1989)

Figure 9: Location of glacial and periglacial features of the Kosciuszko alpine zone



Source: Good (1992)

Figure 10: Location of Blue Lake cirque and associated moraines

5.3.3 Morphology

Bathymetry of Blue Lake shows the two-basin form and extension of ground morraine ridges below the lake level (Figure 11). These longitudinal ridges were deposited with the flow of ice down-valley. A small basin, barred by a submerged ridge, was observed in the northern corner of the lake. The origin of the ridge is unknown, but may be related to a period of more intense periglacial activity 3000–1500 years ago. Shoreline development is minimal except where three non-lobate deltas have developed from influent streams at the north, west and south-west corners of the lake. These deltas have only slightly modified the lake morphology (Dulhunty 1945). A narrow cobble-paved beach has developed where the water abuts talus and moraines, and granite bluffs drop vertically into the water. The water level in the lake varies by less than one metre, and the lake has a surface area of 1.4×10^5 m^2 (14 ha) and a volume of 1.9×10^6 m^3 (1.9 GL) (Raine 1982).

5.3.4 Topography

The Blue Lake Ramsar site includes the catchment area for Blue Lake and Hedley Tarn. The catchment area is bounded in the north-west by the ridge between Mt Twynam and Carruthers Peak and in the north-east by Little Twynam (Figure 4). The southern boundary is the southern side of Hedley Tarn at an elevation of 1850 m. The northern side of Blue Lake has a sheer drop with a gradient of 7.4, while the southern side of the catchment gently slopes toward Hedley Tarn, continuing downstream following Blue Lake Creek.

Source: Raine (1982)

Figure 11: Bathymetry and surface geology of Blue Lake

5.3.5 Soils

Soils of the alpine zone at Kosciuszko National Park are alpine humus soils and associated soils dominated by organic matter, such as bog peats, acid fen peats, silty bogs, grey podsols, humified peats, meadow soils and lithosols (Table 5). While alpine humus soils dominate the alpine zone, the associated peat soils of fen and bog communities are significant within the Blue Lake Ramsar site due to their contribution to catchment hydrology and landscape character. The soils of the fens and bogs have the capacity to retain large volumes of snow-melt water, thereby evening out the extremes of summer and winter stream flows. This is particularly important in determining the distribution, occurrence and survival of the vegetation communities (Good 1992).

5.3.6 Sediment retention

Since Blue Lake is relatively deep, it acts as a sink for sediment from the catchment. Post-glacial sediments seven metres deep were observed in cores from several locations (Raine 1982).

Table 5: Soil groups of the alpine zone of Kosciuszko National Park

Soils Group	Characteristics	Environment
Alpine Humus	Organo-mineral soils in which the profile shows no eluviation of sesquioxides and is acid to strongly acid	On all bedrock types and under most physiographic conditions. Supports tall alpine herbfield, sod tussock grassland and heath
Bog Peats	Organic soils with a high watertable at or near the soil surface. Organic matter often identifiable not being fully broken down	Widespread but of local occurrence in wet acid sites. Valley bogs in areas of seepages on side slopes and raised bogs in valley bottoms (valley and raised bog peats)
Fen Peats	Ground water formation with acid to strongly acid conditions prevailing	Permanently wet sites on level to gently sloping areas and sites with low base supply. Fen vegetation occasionally with snowpatch short alpine herbfield
Humified Peats	Organic soils in which the organic structure is readily identified	Associated with drained bog peas or where permanently wet conditions no longer prevail
Meadow Soils	Organo-mineral soils or mineral soils with a high watertable for part or all of the year	Widespread with the snowpatch meadow soils restricted to wet lower snowpatch sites. These sites are continually washed with suspended soil and rock material during snow melt periods
Alluvial Soils	Soils in which the watertable occurs in the solum for part of the year	Mainly on the plains of the tablelands
Grey Podsols	Organic soils which are mildly to strongly acid	Damp sites where acid watertables exist for much or all of the year
Silty Bogs	Accumulations of inorganic and organic material mostly transported from other sites by water and wind. Properties intermediate between peats and alpine humus soils	Wet valley bottoms where the accumulated organic and inorganic material develops into a fine silt soil
Lithosols	Skeletal soils with no profile development. Mineral in character	Sites unsuitable for soil development, exposed wind blown sites, areas of shallow scree and surface soil erosion

Source: Good (1992)

5.4 Hydrology

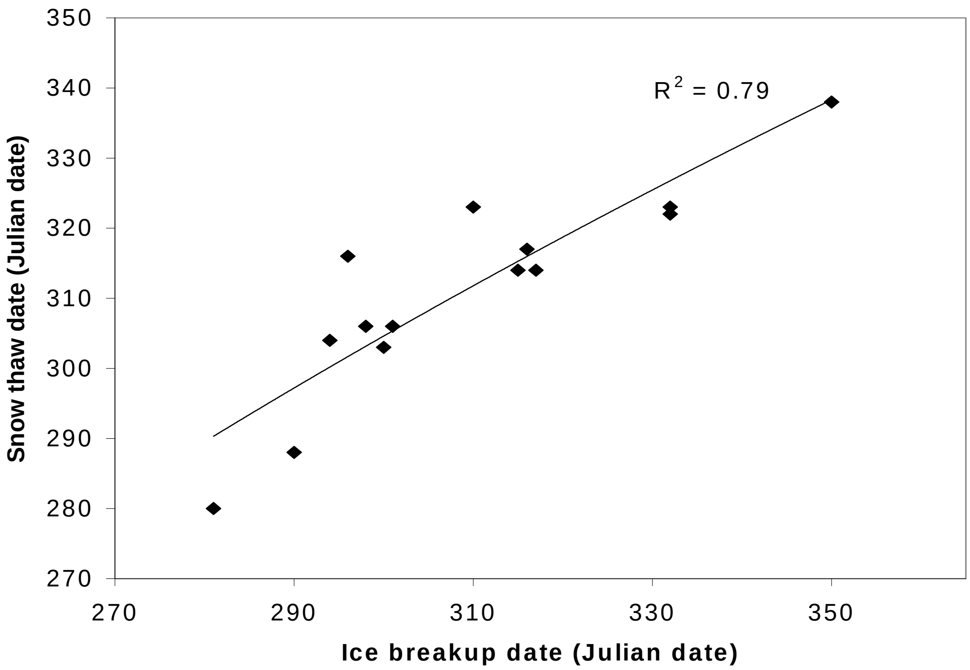
5.4.1 Ground water

A knowledge gap exists about the contribution of ground water to Blue Lake and Hedley Tarn and the contribution that these lakes make to ground water in the Snowy River region. Blue Lake and Hedley Tarn are likely to be 'perched' above the local watertable and infiltration of waters to the underlying watertable are likely to be minimal due to the virtually impermeable nature of the granite matrix. Furthermore, due to the location of Blue Lake and Hedley Tarn in the upper Snowy River catchment, the contribution of ground water to Blue Lake and Hedley Tarn is minimal (W. Timms 2006, pers comm.). However, ground water contribution has been suggested as a reason for increasing water temperatures in Blue Lake throughout winter (Raine 1982).

5.4.2 Snow thaw and surface run-off

Water in Blue Lake and Hedley Tarn is primarily derived from surface run-off (Cullen and Norris 1989). Three streams contribute water to Blue Lake and via Blue Lake Creek to Hedley Tarn, and then into the Snowy River.

The contribution of surface run-off to Blue Lake and Hedley Tarn is regulated by climatic conditions in the Australian Alps. In winter precipitation is predominantly snow (Brown and Millner 1989), and low air temperatures minimise snow thawing and reduce run-off into Blue Lake and Hedley Tarn. Permanent ice and an absence of open water outflow and major stream inflow into Blue Lake is evident from June to November (Raine 1982; K. Green 2006, pers. comm.). Furthermore, there is a strong correlation between snow thaw date in the Blue Lake catchment and the ice break-up within Blue Lake (Figure 12).



Julian date refers to the day number within a calendar year. That is, day 270 corresponds to 27 September and day 365 corresponds to 31 December.
Source: K. Green (2006, pers. comm.)

Figure 12: Correlation between catchment snow melt and ice breakup at Blue Lake

While run-off in the Australian Alps varies greatly over relatively small distances due to orographic effects and rain shadowing, run-off in the Blue Lake Ramsar site is likely to be high. Mean annual run-off at nearby Club Lake was 3660 mm and was 2850 mm in the Snowy River catchment at Guthrie Creek (Brown and Millner 1989).

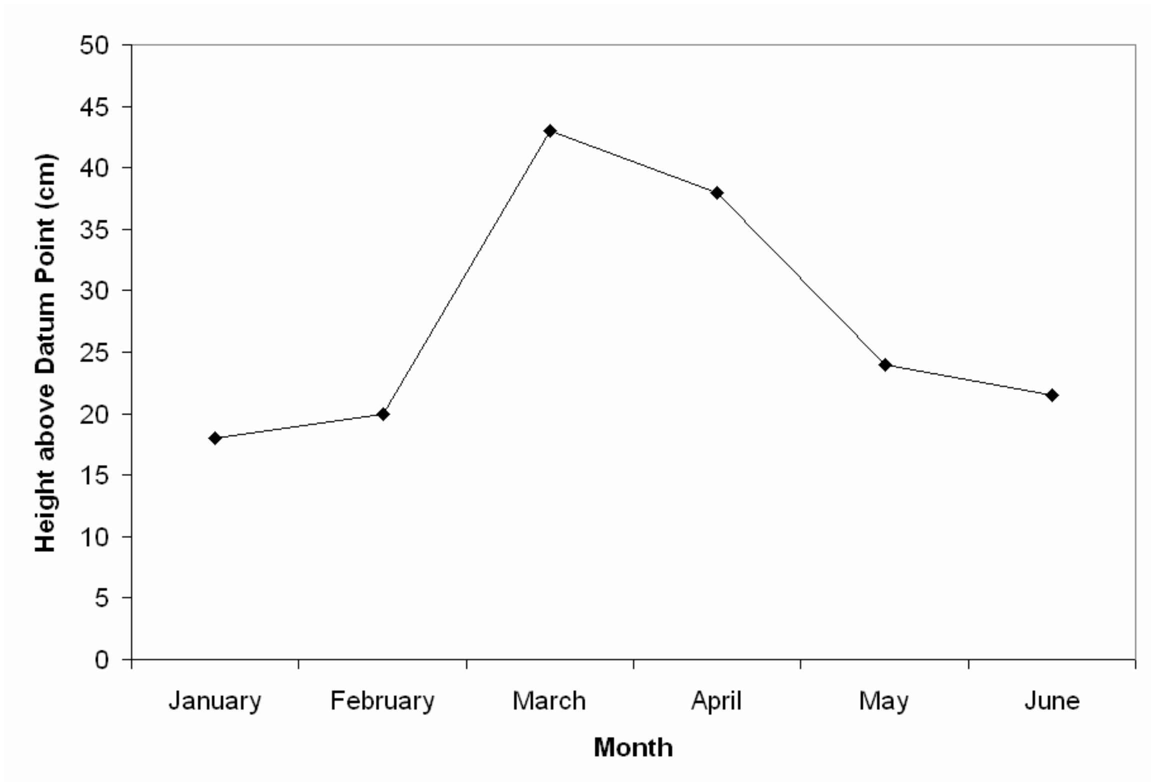
5.4.3 Water flows

Air temperature has a significant effect on the flow of streams in the Australian Alps and variations may be influenced by (Brown and Millner 1989):

- differing rates of evapotranspiration of riparian vegetation along small streams during day and night
- variations in the rate of snow melt
- variations in the ground water contribution to streams caused by overnight freezing of the surface layers of the soil.

During the period of snow cover (June to October) stream flow is very low and steady. When snow begins to thaw and there is also rain, the highest stream levels are observed. Stream flow in summer shows a diurnal pattern, with high flow during afternoons from melting snow. Water flow increases through late summer and autumn, reaching low winter levels by the end of May. Changes in the water level of Blue Lake were observed between January and June 1984 (Balmaks 1984) (Figure 13).

Three streams flowing into Blue Lake are the major source of water, with the stream at the north-western corner contributing approximately half of Blue Lake's water. The remaining streams contribute approximately 25% of water during periods of moderate flow, while the remaining 25% is provided by seepage and soil moisture (Raine 1974).



Source: Balmaks (1984)

Figure 13: Water level above an arbitrary datum point for Blue Lake

5.4.4 Thermal regime

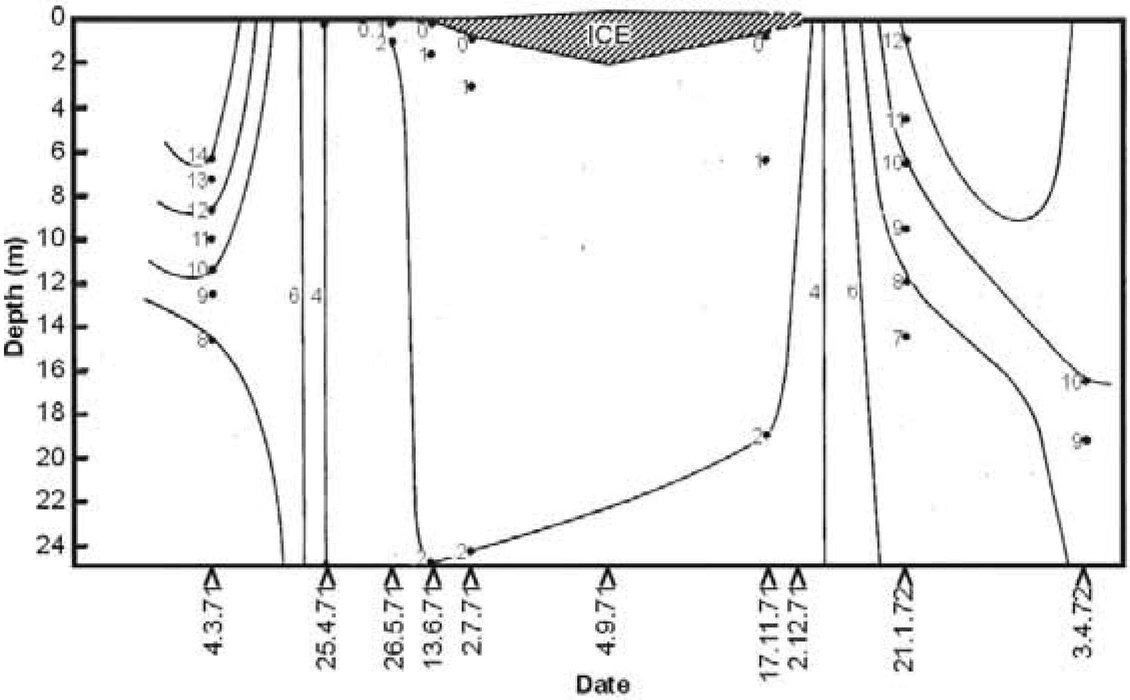
Temperature profiles at Blue Lake indicate a dimictic thermal regime (Figure 14). Raine (1982) reported complete mixing of Blue Lake waters in April 1971 and permanent ice formation from June when the lake temperature had dropped to 1ºC, except near the sediment-water interface. Ice thickness was almost two metres by September 1971 and may have been greater on the northern side of the lake near the headwall. Water temperature beneath the ice cap appears to have increased throughout the winter, possibly due to the release of heat from lake sediments or the influx of ground water. Ice cap melting began in November 1971 and disappeared entirely in early December, in response to the addition of water from melted snow. Summer stratification was complete by January 1972.

The persistence of stratification varies and appears to be a function of radiation input and windiness (Burgess et al. 1988; Cullen and Norris 1989). Blue Lake is the only dimictic lake on mainland Australia (Timms 1980). Suggested reasons for intense stratification at Blue Lake and its absence from the remaining four glacial lakes include the deep bathymetry of the lake, which minimises radiation input, and the protection from winds due to the steep topography on the northern and western sides of the lake (Raine 1982; Cullen and Norris 1989).

5.5 Physico-chemical environment

5.5.1 Water quality

The comparisons made with default trigger values (ANZECC and ARMCANZ 2000) are for general comparative purposes only. Strictly speaking these default trigger values would not be appropriate for Blue Lake and Hedley Tarn (see section 6.2).



Source: Raine (1982)

Figure 14: Generalised progression of isotherms at Blue Lake during 1971 and 1982

Dissolved salts

Blue Lake and Hedley Tarn have very dilute waters with a total salt concentration of 2.42 ppm and 2.35 ppm respectively (Williams et al. 1970; Table 6). Similarly low conductivities of 4.0–7.5 μScm^{-1} were measured in 1969 and 1984 (Williams et al. 1970; Balmaks 1984) (Table 6; Table 7). Conductivity appears to decrease between January and March and then steadily increases until June (Balmaks 1984). Conductivity lies well within the Australian water quality guidelines default trigger values for lakes and reservoirs (ANZECC and ARMCANZ 2000) (Table 8).

Ionic concentrations for the Kosciuszko glacial lakes are close to that of rainwater in the region, and the lakes' waters are among the freshest known in Australia (Williams et al. 1970) (Table 9).

pH

The pH values reported for Blue Lake are in the range 6.05–7.2 and decrease between January and April, coinciding with surface ice formation (Williams et al. 1970; Balmaks 1984). Some pH values were outside the lower limit default trigger value for freshwater lakes and reservoirs for south-east Australia (ANZECC and ARMCANZ 2000). However, this is likely to be caused by the granitic geology of the surrounding catchment causing natural site-specific conditions to be acidic (Balmaks 1984).

Water temperature

The temperature of Blue Lake waters can range between 0ºC and 14ºC (Raine 1982). As expected, temperature decreases between January and June, declining by more than 10ºC over a four month period in 1984 (Balmaks 1984). Both strong (Raine 1982) and weak (Balmaks 1984) thermal stratification has been reported for Blue Lake. The intensity of stratification appears to be dependent on climatic conditions during the year (Balmaks 1984) and varies according to windiness and the intensity of solar radiation (Burgess et al. 1988) within the Blue Lake catchment.

Dissolved oxygen

Dissolved oxygen (DO) in Blue Lake is 1.1–10.0 mg L^{-1}, and is characteristically higher in the inflow and outflow streams due to the flowing nature of the streams compared to the deep calm waters of Blue Lake (Balmaks 1984). In Blue Lake, DO measurements are highest at 1 m depth and then decrease with increasing depth (Balmaks 1984). This is to be expected since thermal stratification can influence the vertical distribution of gases in the water column (Boulton and Brock 1999). Mean DO estimates (Balmaks 1984) lie outside the default trigger limits for freshwater lakes and reservoirs in south-east Australia (ANZECC and ARMCANZ 2000); however, this may be an artefact of reported DO values being averages from the water column.

Turbidity

The waters of Blue Lake are extremely clear. Turbidity of 7.2–9.3 NTUs has been reported (Balmaks 1984), but based on quality control data these readings appear to overestimate considerably the true turbidity of Blue Lake. Not withstanding this, the measurements lie within the Australian water quality guidelines default trigger values for lakes and reservoirs (ANZECC and ARMCANZ 2000).

Table 6: Chemical composition of Blue Lake and Hedley Tarn

Locality	K_{18} (μmhos)[1]	Value [2]	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^- + NO_2^-	PO_4^{3-}	pH
Blue Lake	5.0	A	0.45	0.15	0.15	0.08	0.41	0.49	0.86	<0.005	0.009	6.05*
		B	52.3	10.1	20.0	17.6	30.9	21.3	47.7	–	–	
Hedley Tarn	4.8	A	0.46	0.12	0.12	0.06	0.55	0.61	0.41	0.018	0.001	6.1*
		B	58.8	9.1	17.6	14.4	45.3	29.4	25.3	–	–	

[1] μmhos = μScm^{-1} [2] A – ppm; B – equivalent percentage of total cations

* Values outside NWQMS water quality guidelines for freshwater lakes and reservoirs for southeast Australia (ANZECC and ARMCANZ 2000)

Adapted from Williams et al. (1970).

Table 7: Average chemical composition of inflow, outflow and Blue Lake waters

Location	pH	Conductivity (μmhos)[1]	DO (mgL^{-1}) (% sat.)	Temp. (ºC)	Turbidity (NTUs)[2]	NH_3 (ppm)[2,3]	NO_2^- (ppm)[2]	P (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Na^+ (ppm)	K^+ (ppm)	HCO_3^- (ppm)	Cl^- (ppm)	SO_4^{2-} (ppm)	Total coliforms (counts/100mL)
Inflow	6.32*–7.23	4.4–7.0	6.2(73%)*–9.2 (95%)	1.5–12.0	7.5–9.3	0.218–0.309	0.006–0.009	<0.02	0.33–0.51	0.05–0.26	0.78–1.51	0.09–0.63				3–800
Outflow	6.40*–7.00*	4.0–6.0	6.6(78%)*–9.5(84%)*	0.8–14.5	7.2–9.2	0.216–0.335	<0.006–0.008	<0.02	0.14–0.42	0.07–0.19	0.36–1.08	0.01–0.26	2.0–4.0	<1.0–1.2	<0.5–3.5	8–1000
Blue Lake	6.44*–7.39	3.9–7.5	5.1(49%)*–7.8(83%)*	1.5–13.7	7.9–8.8	0.214–0.322	0.006–0.009	<0.02	0.28–0.42	0.07–0.33	0.52–0.93	0.10–0.40	2.7–4.0	<1.0–1.3	<0.5	6–1200

[1] μmhos = μScm^{-1}. [2] Values appear anomalous. They probably overestimate typical values (P. Rendell 2006, pers. comm.). [3] Assumed to be total ammonia N.

At least some values are outside NWQMS water quality guidelines for freshwater lakes and reservoirs for south-east Australia (ANZECC and ARMCANZ 2000).

Source: Balmaks (1984)

Table 8: Default trigger values for freshwater lakes and reservoirs in south-east Australia

Salinity ($\mu S\ cm^{-1}$)	Turbidity (NTUs)	Chl a ($\mu g\ L^{-1}$)	TP ($\mu g\ P\ L^{-1}$)	FRP ($\mu g\ P\ L^{-1}$)	TN ($\mu g\ N\ L^{-1}$)	NO_x ($\mu g\ N\ L^{-1}$)	NH_3–N ($\mu g\ N\ L^{-1}$)[1]	DO (% saturation)		pH	
								Lower limit	Upper limit	Lower limit	Upper limit
20–30	1–20	5	10	5	350	10	10	90	110	6.5	8.0

[1] Total ammonia N

Source: ANZECC and ARMCANZ (2000)

Table 9: Average major ionic composition of glacial lakes and of rainwater

Sample	Sum of cations (m–equiv/l)	Value[1]	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}
Glacial lakes (average)	0.0418	A	0.48	0.12	0.13	0.07	0.41	0.79	0.56
		B	57.3	8.3	17.6	16.8	32.0	35.8	32.2
Rainwater[2]	0.0363	A	0.39	0.08	0.26	0.12	0.36	1.40	0.43
		B	40.7	4.8	31.1	23.4	24.0	54.6	21.4

[1] A – ppm; B – equivalent percentage of total cations. [2] From Hutton and Leslie (1958)

Source: Williams et al. (1970)

5.6 Habitats

5.6.1 Vegetation communities

The vegetation communities of Kosciuszko National Park, including the Blue Lake Ramsar site, have been mapped on numerous occasions. The most recent was broadscale mapping of vegetation provinces of Kosciuszko National Park between 1990 and 1994. This mapping was produced from aerial photographs and provinces were marked on 1:100 000 topographic maps. According to this map, the Blue Lake Ramsar site is classified as alpine vegetation complex.

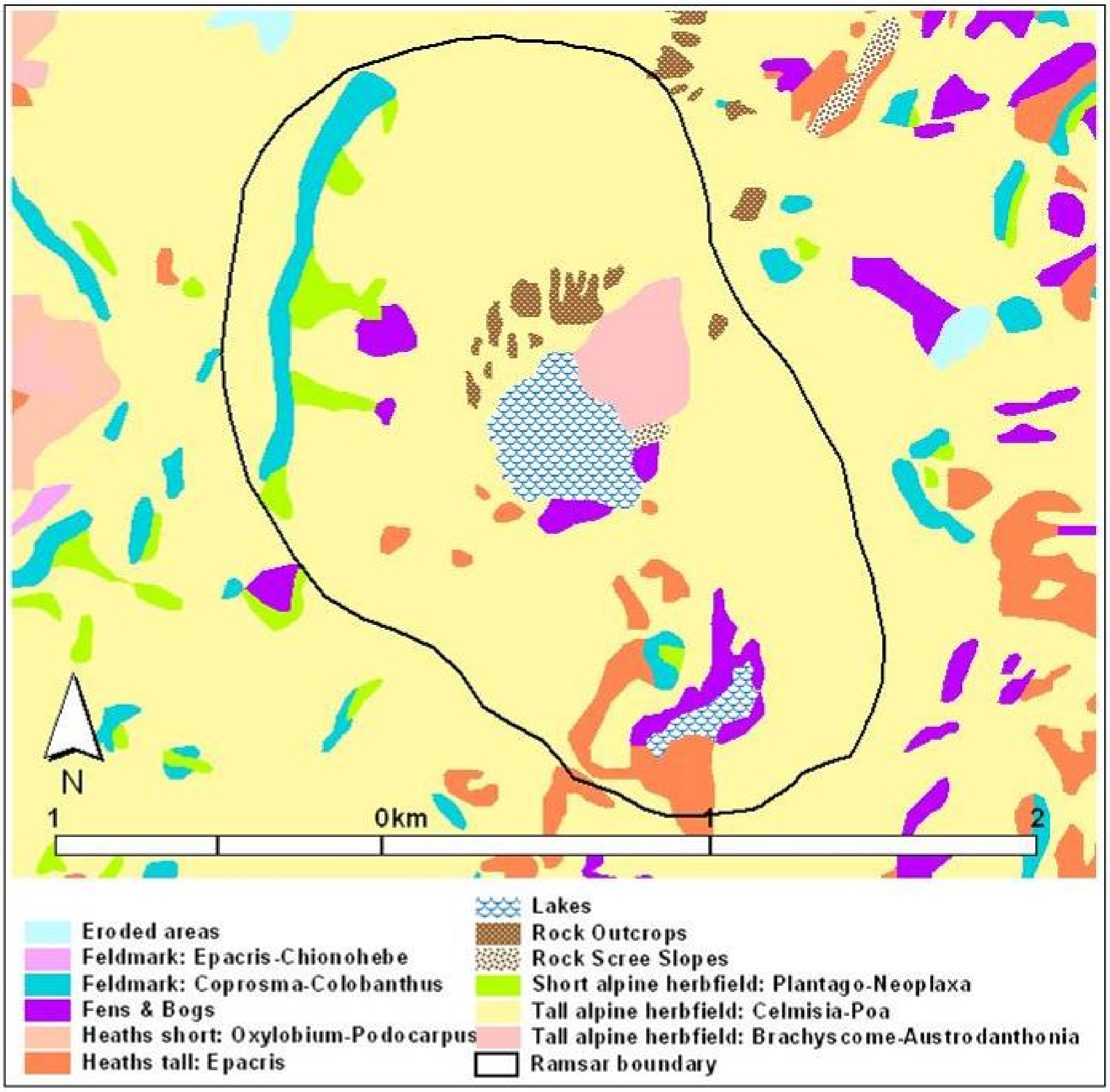
The vegetation of the Blue Lake Ramsar site is diverse and includes numerous communities. Communities within the catchment include tall alpine herbfields dominated by *Celmisia* and *Poa* species, tall alpine herbfields dominated by *Brachyscome* and *Austodanthonia*, feldmark dominated by *Coprosma* and *Colobathus*, short alpine herbfields dominated by *Plantago* and *Neopaxia*, tall heaths dominated by *Epacris glacialis*, and fens and bogs (Figure 15).

The Blue Lake Ramsar site is dominated by tall alpine herbfield communities characterised by species of *Poa* and *Celmisia* and with many other herbs including *Leucochrysum albicans alpinum, Chionochloa frigida, Aciphylla glacialis, Craspedia* species and *Euphrasia collina diversicolor*. The north-east margin of Blue Lake is characterised by tall herbfields dominated by *Brachyscome nivalis, Austrodanthonia alpicola*, *Alchemilla zanthochlora* and a number of ferns including *Blechnum penna-marina* and *Polystichum proliferum.*

The margins of Hedley Tarn and the southern margin of Blue Lake consist of heaths, fens and bogs. Tall heath communities, dominated by *Epacris glacialis* and *Poa costiniana,* are located on the southern margin and wrap around the western side of Hedley Tarn. The bog communities are characterised by the bog moss *Sphagnum cristatum* and include *Carex gaudichaudiana, Epacris paludosa, Richea continentis* and *Astelia* species. In the wetter, acidic fen areas, the *Sphagnum* disappears and the sedge, *C. gaudichaudiana*, dominates. Other species found within the fens of Hedley Tarn include *C. hypandra* and *Rytidosperma nudiflora*. Other heath, fen and bog species found along the shorelines of Blue Lake and Hedley Tarn include *Epacris microphylla, Oxylobium ellipticum, Podocarpus lawrencei, Kunzea muelleri, Phebalium ovatifolium* and *Prostanthera cuneata.*

The Blue Lake Ramsar site also includes feldmark communities and short herbfield communities. Feldmark communities occur in regions unfavourable for plant growth and commonly have a mat or cushion habit (Costin et al. 2000). Within the Blue Lake Ramsar site these communities are restricted to snowpatch areas. These regions are covered with snow for most of the year and when the snow melts they are exposed to intense solar radiation and freezing temperatures at night. Feldmark communities within the Blue Lake Ramsar site are dominated by *Coprosma niphophila, Colobanthus nivicola, Ranunculus anemoneus* and *Epilobium tasmanicum.* Short herbfield communities are located immediately below feldmark communities and are characterised by species such as *Plantago glacialis, Neopaxia australasica* and *Caltha introloba.*

Blue Lake does not have any macrophyte communities in the benthic or littoral zone. However the bottom sediments and littoral zone do create a habitat that supports macroinvertebrates and microinvertebrates. Bottom sediments and the littoral zone are discussed further below.



Source: Costin and Wimbush (1972)

Figure 15: Alpine vegetation

5.6.2 Endangered ecological community: montane peatlands and swamps

The montane swamps and peatlands within the Blue Lake Ramsar site include the heath, fen and bog communities (Costin and Wimbush 1972; section 5.6.1). The areal coverage of this ecological community is not large; it is not restricted to the Australian Alps and may be found in montane regions of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner and South Eastern Highlands (DEC 2005c).

This endangered ecological community is located on the margins of Blue Lake and Hedley Tarn. A large fen community is also located on the north-western side of the catchment and has been described as the largest fen community in Kosciuszko National Park (K. Green 2006, pers. comm.).

Montane swamps and peatlands are particularly threatened by land clearing, with estimates of current loss ranging between 20% and 75%. This community is also threatened by grazing, soil disturbance from feral and domestic animals, damage by off-road vehicles, peat mining, pollution and eutrophication, changes to watertables and surface water flows. The montane peatlands and swamps of Blue Lake Ramsar site are particularly threatened by climate change, fire, weed invasion, trampling, and sedimentation from nearby eroded slopes (DEC 2005c).

Due to the threats to this community, particularly from land clearing, montane peatlands and swamps have been identified as an endangered ecological community under the TSCA. Five priority actions have been identified to help recover montane peatlands and swamps in NSW (DEC 2005c).

5.6.3 Bottom sediments

Bottom sediments of post-glacial age have been measured from cores at a maximum depth of seven metres within the central basin at Blue Lake (Raine 1982). These bottom sediments are the habitat for numerous littoral invertebrates and other benthos (Table 12). Bottom sediments are largely sandy-grit or sandy-mud at depths of less than five metres within Blue Lake. In the deeper areas of Blue Lake sediments are fine organic muds with an organic matter content of 12.1%, carbon content of 5.21% and nitrogen content of 0.56%. Particulate input into the lake may be high as partly decomposed leaves and twigs were commonly recovered from grab samples (Timms 1980).

5.6.4 Littoral zone

The littoral zone (to a depth of one metre) of Blue Lake is dominated by bedrock and boulders. The littoral zone is narrow and shelves deeply. Bedrock is estimated to comprise 24% of the littoral zone while boulders and cobbles comprise 61% and 14% respectively. Rock size is important in the structure of macroinvertebrate communities, with species richness and abundance reportedly highest in alpine lakes with a dominant substrate of cobbles, rather than bedrock and boulders (Hancock et al. 2000) (Table 13).

5.7 Flora

5.7.1 Rare, endemic and noteworthy species

Particular reference is given later to the vulnerable anemone buttercup, *Ranunculus anemoneus;* however the Blue Lake Ramsar site supports many other rare, endemic and noteworthy flora species. The significance of these species is detailed in Table 10.

5.7.2 Phytoplankton

Phytoplankton has not been recorded within Blue Lake except for a small amount of green filament *Ulothrix*. In contrast, the following species were recorded within Hedley Tarn in order of descending abundance: *Staurastrum, Staurodesmus, Arthodesmus, Zygnema, Mougeotia, Rhizoclonium* and *Oscillatoria*. It is likely that the very dilute acidic waters of Hedley Tarn provide favourable habitat for the desmids, which include *Staurastrum, Staurodesmus* and *Arthodesmus* (Powling 1970).

Table 10: Rare, endemic and noteworthy flora species

Scientific name	Common name	Significance [1]	Habitat [1]
Oreomyrrhis brevipes	Rock caraway	Rare	Rocky areas in tall alpine herbfield and *Epacris-Chionohebe* feldmark
Oschatzia cuneifolia[2]	Wedge oschatzia	Endemic to alpine and subalpine tracts of Australian Alps	Damp sites in tall herbfield and bogs
Abrotanella nivigena[3]	Snow wart	Rare	Short alpine herbfield and wet areas near streams
Brachyscome stolonifera	Gwenda's daisy	Endemic to alpine tract of Kosciuszko	Short alpine herbfield and wet sites in tall alpine herbfield
Craspedia leucantha	–	Endemic to alpine and upper subalpine tract of Kosciuszko	Shallow running water, seepage areas, creek banks, below snowpatches
Erigeron setosus	Dwarf fleabane	Endemic to alpine tract of Kosciuszko	Short alpine herbfield and wet stream banks
Parantennaria uniceps	Snowpatch daisy	Rare	
Colobanthus nivicola[4]	Snowpatch cushion-plant	Endemic to alpine tract of Kosciuszko	*Coprosma-Colobanthus* feldmark and short alpine herbfield
Colobanthis pulvinatus	Feldmark cushion-plant	Rare	*Epacris-Chionhebe* feldmark and eroded tall alpine herbfield
Carex cephalotes	–	Rare	Wet sites in bog, fen and short alpine herbfield
Astelia psychrocharis	Kosciuszko pineapple-grass	Endemic to the alpine and subalpine tracts of Kosciuszko	Bogs and wet sites in tall alpine herbfield
Agrostis meionectes	–	Rare	Depressions in sod tussock grassland, short alpine herbfield, fen and bog
Deyeuxia affinis	–	Rare	Near rocks in short alpine herbfield
Ranunculus anemoneus	Anemone buttercup	Endemic to alpine and subalpine tracts of Kosciuszko Vulnerable: EPBCA Vulnerable: TSCA	Snow patches in short alpine herbfield, along snow-melt streams in tall alpine herbfield, rock crevices in *Coprosma-Colobanthus* feldmark.
Ranunculus niphophilus	Snow buttercup	Endemic to alpine tract of Mt Kosciuszko	Short alpine herbfield and in springs and flushes in tall alpine herbfield

[1] Costin et al. (2000). [2] Genus of two species, one mainland Australian, one Tasmanian. [3] Subantarctic in distribution. [4] *C. nivicola* and *C. pulvinatus* are main cushion plants.

5.7.3 Anemone buttercup (*Ranunculus anemoneus*)

The anemone buttercup (family Ranunculaceae) is a robust rhizomic perennial herb that grows to 35 cm or more. Its basal leaves are large (to 8 cm wide), leathery and deeply clefted; stem leaves are stalkless and clasping; flowers are creamy white and large (up to 6 cm diameter); and numerous fruits form in a densely clustered head (1.5 cm diameter) with a prominent beak (to 2 mm long) (NSW NPWS 2001). The anemone buttercup develops extensively while snow-covered and is therefore one of the early flowering herbs once the snow melts. It is described as one of the most spectacular buttercups in the world due to its showy white flowers (Costin et al. 2000).

The anemone buttercup is endemic to alpine and subalpine regions of Kosciuszko and is located within a narrow band of 32 km by 8 km along the Great Dividing Range which includes the Blue Lake Ramsar site. It is locally common near snow patches in short alpine herbfield and along snow-melt streams in tall alpine herbfield. It is also found in rock crevices in *Coprosma–Colobanthus* feldmark (Costin et al. 2000). Herbarium records indicate that the species may occur in environments with late melting snow or along watercourses in grassland, heathland (below snow patches) and on roadside batters (NSW NPWS 2001). Suitable habitat in the Blue Lake Ramsar site is extensive (Figure 15).

The anemone buttercup was seriously threatened by grazing until its cessation in Kosciuszko National Park in the 1950s; since this time the anemone buttercup has recovered significantly and is found in a range of habitats (Costin et al. 2000). While the species may also be palatable to native herbivores, large herbivores are not observed within the Blue Lake Ramsar site. However, rabbits and hares have been identified as a future threat, as are tourists picking flowers.

Due to its limited distribution and near extinction in the 1950s, the anemone buttercup has been scheduled as vulnerable under the EPBCA and the TSCA. A recovery plan has been developed in accordance with the recommendations in the TSCA (NSW NPWS 2001).

5.8 Fauna

5.8.1 Rare, endemic and noteworthy species

The Blue Lake Ramsar site supports a number of rare, endemic and noteworthy fauna species (Table 11).

5.8.2 Vertebrate fauna

Numerous vertebrate fauna have been observed within the Blue Lake Ramsar site (Appendix 2).

Table 11: Rare, endemic and noteworthy fauna species

Scientific name	Common name	Significance	Habitat
Burramys parvus	Mountain pygmy possum	Endangered: IUCN Red List 1996 Endangered: EPBCA Vulnerable: TSCA	Snow-covered alpine and subalpine regions above 1400 m altitude
Mastacomys fuscus	Broad toothed rat	Vulnerable: TSCA	Runways within wet alpine and subalpine heath and woodlands
Litoria verreauxii alpina	Alpine tree frog	Endemic high altitude subspecies[1] Critically Endangered: IUCN Red List 2002 Vulnerable: EPBCA Endangered: TSCA	Woodland, heath, grassland and herbfield at montane, subalpine and alpine altitudes
Gallingo harwickii	Japanese/Latham's snipe	Migratory bird listed under JAMBA, CAMBA, ROKAMBA and Bonn agreement	Fens, bogs, surface waters and littoral zone
Pisidium [Glacipisium] kosciusko	Bivalve	Likely to be restricted to Snowy Mountains [2]	Littoral zone and bottom sediments
Metaphreatoicus australis	Isopod	Restricted to highlands of south-eastern Australia [3]	Littoral zone and bottom sediments
Tasmanophlebia nigrescens	Mayfly	Restricted to highlands of south-eastern Australia [3]	Littoral zone and bottom sediments
Glacidorbis hedleyi	Gastropod	Restricted to highlands of south-eastern Australia [3], endemic to alpine lakes [4]	Littoral zone and bottom sediments

[1] Smith et al. (2003) [2] DEH (2006b) [3] Timms (1980) [4] Hancock et al. (2000)

5.8.3 Invertebrates

Benthic invertebrates

Of the 12 macrobenthic species recorded in Blue Lake, the dominant species recorded are *Antipodrilus davidis, Chironomus opposites* and *Pisidium [Glacipisium] kosciusko*. Two mesobenthic species, the ostracod *Candonocypris* and the mite *Oxus australicus*, also live in the bottom sediments. The sublittoral regions of Blue Lake exhibited the greatest number of species, abundance and biomass (Table 12).

Littoral invertebrates

Fifteen littoral invertebrate communities species have been recorded within Blue Lake (Table 13), with the bivalve mollusc *Pisidium kosciusko* the most common species, followed by the isopod *Metaphreatoicus australis*. The stonefly *Eusthenia venosa* and the larvae of the caddisfly Limnephilidae are also common (Hancock et al. 2000).

Invertebrate assemblages in Blue Lake Creek, immediately downstream from Blue Lake and Hedley Tarn, were also sampled as part of the National River Health Program in spring and autumn in 1994–1996. A total of 38 taxa were identified, mostly to the family level, including five taxa identified by Hancock et al. (2000).

5.8.4 Zooplankton

The following species of zooplankton were recorded at Blue Lake in order of descending abundance: *Asplanchna* spp., *Attheyela (Delachauxiella)* spp., *Alona* spp., *Camptocercus* spp.*, Eucyclops* spp. and *Chydorus* spp. Many rotifers were also present including *Keratella, Polyarthra* and *Monommata* (Bayly 1970).

The following species of zooplankton were recorded in a small shallow pool about 10 m^2, which was cut off from Hedley Tarn and is within the Blue Lake Ramsar site: *Boeckella montana* and *Macrothrix* spp. (Bayly 1970). At the time of sampling, Hedley Tarn was an essentially lotic habitat with moving water and lacking plankton.

5.8.5 Mountain pygmy possum: *Burramys parvus*

The mountain pygmy possum is the largest of Australia’s pygmy possums, yet weighs only 45 g and is small enough to fit in the palm of your hand. It has a total length of 250 mm, with over half of its length being tail. It is a mouse-like mammal, covered with dense greyish-brown fur above and creamy bright fawn fur under its body. It has a long tail, which is furred for 2 cm and then has short sparse, hairs; agile front feet enabling it to gather food, strong back feet to grip branches and enlarged front teeth to crack seeds (NSW NPWS 2002; DEH 2006a).

The possum feeds at night on Bogong moths (*Agrostis infusa*) during spring and summer to build up sufficient fat reserves to hibernate for up to seven months of the year; it is the only mammal to hibernate for prolonged periods under snow cover (Broome 2001). At other times of the year the possum supplements its diet with seeds and fruit from the mountain plum pine *Podocarpus lawrencei,* perennial blackberry *Rubus fruticosus L. aggregate* and snow beard-heath, *Leucopogon montanus*. Between April and October the possum hibernates and feeds on stored seeds and nuts (DEH 2006a).

Table 12: Benthic species

Scientific name	Common name	1 m	4 m	8 m	12 m	16 m	20 m	26 m
Unidentified large nematode	Nematode			11				
Antipodrilus davidis Tubificidae n. gen.	Oligochaeta	177	499	1232	965	810	1209	477
Metaphreatoicus	Isopod		11	399	11	11		
Procladius spp.	Midgefly		11	78	33	11	11	33
Polypedilum nr *tomnoiri*	Midgefly			11	22			
Chironomus ?opposites	Midgefly	1132	3274	3951	3152	3340	2642	2120
Tasmanophebia nigrescens	Mayfly		11					
Ramrheithrus dubitans	Midgefly	11	22			11		
Unidentified tipulid larva	Fly	22						
Glacidorbis hedleyi	Gastropod		11					
Glacipsium kosciusko[1]	Bivalve	44	1100	1643	1798	739	480	242
Total numbers (individuals m^{-2})		**1386**	**4939**	**7325**	**5981**	**4922**	**4342**	**2872**
Total biomass (g m^{-2})		**3.67**	**14.72**	**23.49**	**14.4**	**11.49**	**12.17**	**7.05**

[1] Now referred to as *Pisidium kosciusko.*

Adapted from Timms (1980)

Table 13: Littoral species

Species	Sweep[1]	Cobble[2]
Platyhelminthes Unidentified planarians	 –	 1.1
Annelida: Oligochaeta Unidentified tubificids	 0.2	 1.4
Mollusca: Bivalva *Pisidium kosciusko*	 1.4	 194.6
Mollusca: Gastropoda *Glacidorbis hedleyi* *Austropeplea tomentose*	 2.6	 1.4 6.4
Crustacea: Isopoda *Metaphreatoicus australis*	 0.4	 35.3
Insecta: Ephemeroptera *Tasmanophlebia lacascoerulei*	 0.1	
Insecta: Plecoptera *Eusthenia venosa* Notonemouridae nymph	 0.6 0.1	 21.7
Insecta: Trichoptera *Austrorheithrus* sp. Limnephidae larvae	 <0.05 <0.05	 3.1 21.2
Insecta: Diptera *Polypedilum* sp. Elmidae sp 2 adults Curculionidae adults	 0.1 0.1	 7.8 1.0
Insecta: Coleoptera *Sclerocyphon basicollis* larvae	 0.0	 2.0
Species richness	**12.0**	**12.0**
Total species richness	**15.0**	

[1] Mean number of individuals per m^2 of sweep in each lake
[2] Mean number of individuals per m^2 of cobble in each lake

The total population size of the mountain pygmy possum is less than 500 adults (Caughley 1986; NSW NPWS 2002); the possum was thought to be extinct until it was discovered in a ski chalet in 1966. It is the only Australian mammal with its distribution limited to alpine regions and it is physiologically intolerant of temperatures exceeding 28ºC (Osborne et al. 2000; Broome 2001). The possum's entire range covers less than 4 km^2 with populations scattered in small patches within an area of 30 km by 8 km; two of the four main subpopulations coincide with ski resorts in Kosciuszko (Caughley 1986; Broome 2001; NSW NPWS 2002). Unlike other possums, the mountain pygmy possum is ground-dwelling; it is found in snow-covered alpine and subalpine regions above 1400 m in Victoria and NSW and its habitat consists of rock crevices and boulder fields. It is frequently associated with the mountain plum pine (*Podocarpus lawrencei*), snow beard-heath (*Leucopogon montanus*), dusty daisy bush (*Oleaira phlogopappa*), alpine rice bush *(Pimelia ligustrina*), mountain backea (*Baeckea utilis*), alpine pepper (*Tasmannia zerophila*) and some *Epacris* species (NSW NPWS 2002; DEH 2006a). Mountain pygmy possums have not been recorded in the Blue Lake Ramsar site; however, mountain pygmy possum habitat is located in the site (Caughley 1986) and individuals often travel long distances between habitat patches to meet their daily and seasonal requirements (NSW NPWS 2002).

Since the mountain pygmy possum's habitat coincides with the ski resorts, it is particularly threatened by habitat destruction and fragmentation. Fox and cat predation is also a significant threat which is expected to increase with climate change increasing the habitat range favoured by these predators. Climate change is likely to allow the perennial blackberry, a declared noxious weed in NSW, to outcompete the mountain plum pine at high altitudes, thereby causing the mountain pygmy possum to lose its habitat niche to other small mammals such as the bush rat. Climate change is also likely to directly impact the mountain pygmy possum as it requires a snow depth of at least one metre for insulation during its winter hibernation. Fire also poses a potential threat as alpine vegetation communities are fire sensitive and often slow to regenerate (NSW NPWS 2002; DEH 2006a)

Due to the small population, limited distribution and significant threats, the mountain pygmy possum has been identified as an endangered species under the EPBCA and TSCA; a recovery plan has been developed in accordance with the recommendations in the TSCA (NSW NPWS 2002).

5.8.6 Broad toothed rat: *Mastacomys fuscus*

The broad toothed rat is described as a tubby, chubby-cheeked, compact rodent with a short, wide face and ears. It has long, dense, fine fur that is brown above with rufous highlights. Its tail is shorter than its head and body length and is ringed with very little fur. Broad toothed rats have a gentle demeanour and may be described as an 'Australian native guinea pig' (DEC 2005b).

The broad toothed rat is considered a specialised herbivore and its diet primarily consists of grass and sedge stems and is supplemented by seeds and moss spore cases. The broad toothed rat mostly collects food at night in summer and autumn and during the afternoon and early evening in winter (Carron et al. 1990; DEC 2005b).

The broad toothed rat lives in wet alpine and subalpine heaths and woodlands in Kosciuszko National Park (DEC 2005b). At alpine altitudes, it most commonly occurs near rock outcrops and boulder fields immediately adjacent to grassy sites. Other alpine habitats include dry heath dominated by *Nematolepis ovatifolium* and wet heath (Green and Osborne 2003). While the broad toothed rat has not been recorded in the Blue Lake Ramsar site, its distribution includes the Ramsar site. Its habitat includes complex runways through dense vegetation and under snow in winter (DEC 2005). Due to the relatively warm temperature (0 ºC to –2ºC) under the snow, it is able to remain active in winter (Happold 1998).

In a similar fashion to the mountain pygmy possum, the broad toothed rat is primarily threatened by loss, fragmentation and degradation of habitat; predation by foxes and cats; grazing of grass cover by rabbits and hares; invasion of habitat by weeds; and fire. Climate change also poses a significant threat as decreased snow cover and duration will increase the likelihood of predation by foxes and cats, increase competition from other climatically marginal species, increase the population of foxes, cats, rabbits, hares, and increase weed invasion and fire (Green and Osborne 2003).

The broad toothed rat was once considered extinct until rediscovered in Tasmania. Its known range was further extended into Kosciuszko National Park in 1973, however its distribution in NSW remains limited. For this reason, the broad toothed rat has been scheduled as vulnerable under the TSCA. A recovery plan has not been prepared for this species, however 18 priority actions have been identified to aid its recovery in NSW (DEC 2005b).

5.8.7 Alpine tree frog: *Litoria verreauxii alpina*

The alpine tree frog is a subspecies of the relatively widely distributed lowland whistling tree frog *Litoria verreauxii*. It is distinguished by dorsal green or olive markings, extensive dorsal warting and larger size (30 mm) than *Litoria verreauxii* (DEH 2006c). However, there is little difference between the call structure of the two subspecies (Smith et al. 2003).

The alpine tree frog occurs over an area of 3500 km^2 and was once wide-spread and abundant over much of the high country and south-eastern Australia (DEH 2006c). However, recent searches indicate that its abundance may have declined dramatically. The alpine tree frog’s habitat includes woodland, heath, grassland and herbfield at montane, subalpine and alpine altitudes. Populations breed on plains or open valleys where there are stream side pools, fens and bogs. Individuals may also be found amongst litter, under logs, beneath flat stones in stream beds or in rocky areas near streams (Gillespie et al. 1995). The frogs breed in deep pools in fens, stream cutoffs, lakes and reservoirs (Hunter et al. 1998). While the alpine tree frog has not been recorded, its habitat and breeding areas include the Blue Lake Ramsar site and the species *Litoria verreauxii* has been recorded at Charlotte Pass (Smith et al. 2003).

The alpine tree frog is suspected of being threatened by direct human interference through urbanisation and tourism; reduced water quality; exotic predators such as trout and gambusia; habitat modification, climate change and associated increased UV-B radiation (Frogs Australia Network 2005). Like many other amphibians, the alpine tree frog is also threatened by disease and pathogens. In particular, chytridiomycosis, which is caused by the chytrid fungus *Batrachochytrium dendrobatidis*, is potentially fatal to this species (Longcore et al. 1999).

Due to the marked drop in abundance, the alpine tree frog has been listed as critically endangered in the IUCN Red List in 2002, vulnerable under the EPBCA and endangered under the TSCA. A recovery plan has not been prepared for this species.

5.8.8 Japanese/Latham’s snipe: *Gallinago hardwickii*

Japanese/Latham’s snipe is a long-billed migratory shorebird with a brown base, dark-brown crown with cream centre, dark eye-stripe and pale cream face. The body is distinguished by a mottled black-brown buff, white belly and barred flanks (Simpson and Day 1986).

Despite having a reduced population, it is widely distributed throughout Australia, arriving in Queensland from August onward and migrating south to remain within eastern and southern Australia. Northward movement begins in February and continues to April in the north of Australia. It is well camouflaged and often flies at late dusk. Its habitat includes wet grasslands and open and wooded swamps (Blakers et al. 1984). It has been observed in the Blue Lake Ramsar site (K. Green 2006, pers. comm.)

The Japanese/Latham’s Snipe move in response to rainfall and may be observed at the Blue Lake Ramsar site, where they are able to feed on macroinvertebrates in response to drier wetland conditions elsewhere. Numbers have declined this century, presumably due to excessive hunting and the decline of suitable habitats (Blakers et al. 1984; Lane 1987). For this reason, the Japanese/Latham’s Snipe has been listed on the CAMBA, JAMBA, ROKAMBA and Bonn agreement.

6 Limits of acceptable change to key processes and components

6.1 Introduction

The ecological character of a declared Ramsar wetland is specified in the EPBCA as a matter of national environmental significance. The principle mechanism through which the EPBCA operates, including to protect Ramsar wetlands, is to prohibit actions that may cause a significant impact on matters protected by the Act unless assessed and approved under the Act. The 'limits of acceptable change' (LACs) system has been recommended for inclusion in the ecological character description of Ramsar wetlands to provide a basis for recommending thresholds in key components. These thresholds should be sensitive enough to be triggered when detrimental changes to a Ramsar wetland's ecological character occur.

For the Blue Lake Ramsar site, the main priority is to achieve the ecosystem quality equivalent to that at the time of listing of Blue Lake as a Ramsar site in 1996. However, this task is problematic due to the lack of comprehensive data of the current and 1996 quality of the Blue Lake Ramsar site. For this reason, LACs have only been provided for those components with adequate quantitative data to enable the detection of change. Therefore LACs have only been provided for water quality and vegetation communities.

The wetland risk assessment framework adopted by Resolution VII.10 of the Ramsar Convention recommends the use of biological responses as early warning systems to detect adverse change in a wetland. This framework also highlights the need to consider the ecological relevance of an early warning indicator. Due to a lack of comprehensive quantifiable information and natural variability within many components, LACs cannot be provided for many significant components within the Blue Lake Ramsar site. In particular, due to the natural variability in the occurrence and abundance of vertebrate fauna, invertebrates, phytoplankton and zooplankton, LACs have not been provided for these components. Based on the review of the critical components and processes that relate to the Blue Lake Ramsar site (section 5), monitoring initiatives at this site should focus on monitoring changes in water quality, the extent of vegetation communities, the water temperature of Blue Lake, and inflows and outflows of Blue Lake and Hedley Tarn.

6.2 Water quality

The waters of Blue Lake and Hedley Tarn are very soft and clear. Based on the results discussed in section 5.5.1 some water quality parameters of Blue Lake, namely DO and pH, may lie outside of the default trigger values provided by NWQMS for freshwater lakes and reservoirs in south-east Australia (ANZECC and ARMCANZ 2000). The default triggers are generic tools that do not address specific environments and have very limited relevance in unique environments such as Blue Lake and Hedley Tarn.

In addition, the default trigger values are provided by the National Water Quality Management Strategy (NWQMS) to assist in managing water resources to ensure that condition 2 and condition 3 aquatic ecosystems are adequately protected (ANZECC and ARMCANZ 2000). Condition 2 ecosystems are defined as 'slightly to moderately disturbed', while condition 3 ecosystems are described as 'highly disturbed'. Due to their location and the near-natural state of their waters, Blue Lake and Hedley Tarn are classified as a condition 1 ecosystem, which is a 'high conservation/ecological value system'. The objective of water quality management in condition 1 ecosystems is to 'ensure that there is no detectable change (beyond natural variability) in the levels of physical and chemical stressors' (ANZECC and ARMCANZ 2000). In such systems, the relevant guidelines are those that are developed from appropriate site specific investigations, such as those detailed in section 5.5.1, and are based around negligible change in the natural condition.

The aim of water quality LACs is to maintain Blue Lake and Hedley Tarn as a condition 1 aquatic ecosystem. In doing so, it is suggested that LACs be based on condition 2 and 3 default trigger values provided by the NWQMS and detailed in Table 8. Since the Blue Lake and Hedley Tarn catchment is granitic causing natural site-specific conditions to be acidic, pH should be excluded from analyses of LACs until the natural variability in pH at Blue Lake and Hedley Tarn is apparent. Similarly, site-specific factors, such as temperature and ice cover, may cause DO to vary and DO should also be excluded from analyses of LACs. Water quality LACs for Blue Lake and Hedley Tarn are detailed in Table 14.

In accordance with default trigger values provided by NWQMS a trigger for further investigation of water quality is recommended when the median concentration of *n* independent samples taken at a test site exceeds the 80th percentile of the same indicator at a suitably chosen reference site (ANZECC and ARMCANZ 2000, p 7.4-4). This is dependent on two years of contiguous monthly data at a suitably chosen reference site. While comparisons between test and reference samples may be applied based on one test site sample, the probability of performing a Type I error is reduced when sample size increases. For example the probability of performing a Type I error is reduced from 20% to 5% when the sample size is increased from 1 to 5. It is therefore recommended that monthly monitoring (Table 15) be instigated at both Blue Lake and a suitable reference site with a minimum of 5 samples analysed monthly.

6.3 Vegetation communities

The vegetation communities of Kosciuszko have developed in response to significant tectonic and glacial activity that has taken place since the Ordovician. However, the present-day distribution of vegetation communities has occurred in the context of relatively stable temperatures for the past 15 000 years, except for a brief period of slightly colder temperatures between about 3000 and 1500 years ago (Costin et al. 2000). Since the distribution of vegetation communities is largely a result of their interaction with climate, the natural variability within these systems is low.

Table 14: Water quality limits of acceptable change

	Salinity ($\mu S\ cm^{-1}$)	**Turbidity** (NTUs)	**Chl a** ($\mu g\ L^{-1}$)	**TP** ($\mu g\ P\ L^{-1}$)	**FRP** ($\mu g\ P\ L^{-1}$)	**TN** ($\mu g\ N\ L^{-1}$)	**NO_x** ($\mu g\ N\ L^{-1}$)	**NH_4** ($\mu g\ N\ L^{-1}$)
Freshwater lakes and reservoirs	20–30	1–20	5	10	5	350	10	10

Table 15: Water quality monitoring required to identify a trigger for further action

LAC indicator	Monitoring required to trigger management action
Water quality	Five water quality samples analysed monthly from both Blue Lake and a suitable reference site. A minimum of two years contiguous monthly data is required at reference site.

However, since European occupation of the region, which may have begun as early as 1834, the landscape has been significantly altered. Trampling and grazing of alpine vegetation and summer burning to promote fresh regrowth became well established practices by pastoralists. The domestic stock grazing at Kosciuszko, which spanned a period of 150 years, caused significant soil erosion, decline in habitat quality and decline in the abundance of many alpine flora. In particular, the anemone buttercup was almost grazed out of existence in the Kosciuszko region and its population has only recently increased to any extent (Costin et al. 2000; Pickering et al. 2004).

Coupled with this is the potential negative impacts from tourism. Blue Lake and Hedley Tarn are popular day-walk destinations for visitors and are reached by a hardened trail (Pickering and Buckley 2003) and, due to its unique geology, the Ramsar site is also favoured by rock climbers. The potential environmental impacts of tourism within the Blue Lake Ramsar site include soil compaction and erosion, introduction and spread of weeds, faecal contamination of lakes and creeks, and increased feral animals – all of which have negatively influenced the quality of vegetation communities.

It is in the context of relatively stable temperatures and impacts from grazing and tourism that LACs have been devised for the vegetation communities of Blue Lake (Table 16). The primary aim of these LACs is to have no decline from the 1996 condition and extent of vegetation communities or an improvement in the area and quality of vegetation communities. LACs specifically include:

- improvement or no decline in the area and quality of vegetation communities that were degraded during the period of domestic stock grazing – this primarily includes fens and bogs
- improvement or no decline in the area of vegetation communities supporting the endangered *Ranunculus anemoneus* – this primarily includes snow patches within short alpine herbfields, along snow-melt streams in tall alpine herbfields and within *Coprosma–Colobanthus* feldmark
- no further loss of vegetation community area and quality due to weed invasion and the impacts of tourism, such as trampling and creation of tracks.

Since reliable mapping of the extent of vegetation communities is unavailable for the time of listing, LACs have been devised using 1972 mapping by Costin and Wimbush. These maps are regarded as the best available surrogate for information on the extent of communities at the time of listing Blue Lake as a Ramsar site. Significant remediation work has been undertaken since this time and it may be likely that improvement in the extent of communities has occurred. Current details on the extent of communities is required to confirm quantitatively an improvement in the extent of vegetation communities.

6.4 Natural variability and recommended monitoring

6.4.1 Thermal regime

Temperature profiles at Blue Lake indicate a dimictic thermal regime (Raine 1982) (Figure 14). However, the persistence of stratification varies (Burgess et al. 1988) and appears to be a function of radiation inputs and wind (Cullen and Norris 1989). LACs for thermal stratification need to account for the natural variability in stratification that results from interannual climatic variation. However the nature of this variability remains unknown. Therefore it is recommended that the monitoring strategies detailed in Table 17 be undertaken so as to generate a scientifically robust LAC for the thermal regime of Blue Lake.

6.4.2 Water flows

Comprehensive data on inflows and outflows for Blue Lake and Hedley Tarn are lacking. In the absence of this data, identifying environmental water flow thresholds is problematic. In addition, climate change is predicted to alter the climate and hydrology of the Blue Lake Ramsar site (see section 7.2) and understanding natural water flows and their variability is necessary if the impacts of climate change are to be quantified. If this indicator were monitored over an extended period, appropriate LACs could be generated which would provide an indication of the environmental flows required to maintain the ecological character of the Blue Lake Ramsar site. Therefore it is recommended that the monitoring strategies detailed in Table 18 be undertaken so as to generate a scientifically robust LAC for water flows.

In the absence of measures of water flow at Blue Lake and Hedley Tarn, it may be appropriate to develop LACs based on a surrogate for water flow. Deviation from the natural variability in snowfall, depth and duration within the catchment of Blue Lake and Hedley Tarn may act as a surrogate indicator for changes in water flows.

Table 16: Limits of acceptable change for vegetation communities

Vegetation community [1]	Area [2] (ha)	LACs
Fens and bogs	9.71	Improvement or no decline in the area and quality
Tall herbfield: *Brachyscome–Austrodanthonia*	11.33	Improvement or no decline in the area and quality, particularly as *Ranunculus anemoneus* habitat
Tall herbfield: *Celmisia–Poa*	255.09	Improvement or no decline in the area and quality, particularly as *Ranunculus anemoneus* habitat
Feldmark: *Coprosma–Colobanthus*	10.32	Improvement or no decline in the area and quality, particularly as *Ranunculus anemoneus* habitat
Tall heath: *Epacris*	12.14	Improvement or no decline in the quality
Short herbfield: *Plantago–Neopaxia*	7.74	Improvement or no decline in the area and quality, particularly as *Ranunculus anemoneus* habitat

[1] Vegetation communities as described by Costin and Wimbush (1972)

[2] Areas of vegetation communities within the Blue Lake Ramsar site as mapped by Costin and Wimbush (1972) are approximate values.

Table 17: Potential water temperature indicator

LAC indicator	Monitoring required to develop a LAC	Triggers for management action
Water temperature	Measurement of water temperature within the water column of Blue Lake monthly for a minimum period of six years	Thermal regimes that cannot be attributed to natural variability

Table 18: Potential water flow indicators

LAC indicator	Monitoring required to develop a LAC	Triggers for management action
Inflow to Blue Lake, outflow from Blue Lake and Hedley Tarn	Measurement of flows using a flow meter over a minimum 12 month period	Water flows that cannot be attributed to natural variability

6.5 Conclusions

LACs have been developed for water quality parameters and vegetation communities as adequate information is available to develop default trigger values. Monitoring of these components has been included in Table 25 as a recommended action to be undertaken. In the absence of clear understanding of the natural variability in the thermal regime at Blue Lake and water flows at Blue Lake and Hedley Tarn, these components have been identified as a knowledge gap in Table 25 and monitoring is recommended to gain an understanding of the natural variability.

7 Key threats

7.1 Introduction

Threats, both real and potential, may significantly alter the components and processes of Blue Lake Ramsar site and therefore threaten the services provided by this wetland. Key threats to the Blue Lake Ramsar site are discussed in detail below, while Table 19 summarises the key threats and potential effects of these threats.

Table 19: Potential threats, effects and the status of threats

Potential threat	Some potential effects	Threat status
Climate change (Figure 16)	Climate: higher air temperatures, less snow cover and duration, increased rainfall Geomorphology: soil erosion, morphological changes Hydrology: earlier snow thaw, increased run-off, increased water flows, absent or shortened freeze/thaw cycle, loss of dimictic thermal regime Physico-chemical environment: increased sedimentation within Blue Lake, reduced water quality Biota: establishment of aquatic macrophytes, changes in species composition and abundance of flora and fauna, increased feral animal activity, loss of climatically marginal flora and fauna, earlier migratory bird arrival, weed invasion	Major
Cloud seeding (Figure 18)	Climate: increased precipitation, increased rainfall, less snow cover and duration, increased atmospheric AgI Hydrology: increased run-off, increased water flows, increased sedimentation, increased AgI and Ag^+ in water column Physico-chemical environment: increased AgI in water column and sediments, release of Ag^+ to water column and sediments Biota: increased Ag^+ in cellular tissue, impacts unknown, loss of snow reliant species and communities, loss of endemic, vulnerable or endangered species and communities, change in species assemblages, increased exposure of fauna to predation, freezing	Unknown
Recreation and tourism (Figure 19)	Geomorphology: compaction of soil, erosion, reduced visual amenity Hydrology: increased sedimentation and litter Physico-chemical environment: reduced water quality Biota: compaction of soil and vegetation, erosion, increased weed invasion, reduced habitat quality and quantity, increased disturbance, increased feral animal activity, loss of endemic, vulnerable and endangered species and communities	Minor
Bushfires	Hydrology: increased run-off, increased sedimentation Physico-chemical environment: reduced water quality Biota: loss of vegetation cover	Minor
Erosion and sedimentation	Hydrology: increased sedimentation Physico-chemical environment: reduced water quality Biota: loss of species and communities	Minor

7.2 Climate change

Since alpine ecosystems are largely influenced by low temperature conditions, they are considered to be particularly sensitive to climate change (Pickering et al. 2004) and they have been identified as being amongst the most vulnerable systems in Australia (Basher et al. 1998). There is little chance for the alpine zone to respond to climate change as the opportunity for species to retreat upward is limited by the relatively low altitude of the Australian Alps (maximum of about 2000 m) (McCarthy et al. 2001). Alpine and subalpine ecotones are temperature dependent and, due to sharp altitude changes within the Snowy Mountains, ecotones are narrow. Observations of biota changes within these ecotones may provide a good ecological indicator of climate change. Furthermore, since human impact is less within alpine environments, the ability to differentiate between climate-related changes and other human impacts is enhanced. For these reasons, alpine ecosystems and impacts on related components and processes would be important indicators of climate change.

Records from the Australian Bureau of Meteorology indicate that predictions of climate change are not unfounded due to the consistently drier and hotter conditions occurring since the 1970s. The three hottest decades last century were the 1970s, 1980s and 1990s (DEC 2006). This decade is likely to follow this trend with 2005 being the warmest year on record (BOM 2006b). Early predictions of climate change on snow conditions in the Australian Alps indicate a dramatic decline in the total area receiving snow and the total amount of snow (Pickering et al. 2004). The Intergovernmental Panel for Climate Change (IPCC) predicted warming of 0.7ºC to 2.5ºC by 2050 (Houghton et al. 2001). According to the best-case scenarios of temperature increases of 0.6ºC by 2050, CSIRO models indicate a 27% reduction in the area that receives 30 days of snow per year in the Snowy Mountains and Victorian Alps. Similarly, according to worst-case scenarios of temperature increase of 2.6ºC, a 97% reduction in the area that receives more than 60 days of snow cover a year is predicted by 2050 (Hennesy et al. 2003). Alpine climate change projections are provided in Table 20.

Decrease in the total area receiving snow and the total amount of snow is likely to have direct and indirect impacts on the key services, components and processes at Blue Lake Ramsar site. Potential ecological effects on key components and processes at Blue Lake and Hedley Tarn have been summarised in Figure 16 and include (DEC 2006):

- alterations to catchment hydrology and geomorphologic processes
- possible extinction of flora and fauna whose climatic ranges are limited to alpine and subalpine regions
- uphill migration of biota from lower altitudes
- expansion in the distribution of some plant communities
- reduction in the extent and species composition of some plant communities
- change in the composition and abundance of fauna
- increase in the diversity, abundance and distribution of weed species
- uphill extension in the range of feral animals
- increase in wildfire incidents.

Table 20: Projected changes to Australian alpine temperature and precipitation

Scenario (year)	Projected change in temperature (ºC)	Projected change in precipitation (%)
Low impact (2020)	+0.2	+0.9
High impact (2020)	+1.0	-8.3
Low impact (2050)	+0.6	+2.3
High impact (2050)	+2.9	-24.0

Projected changes are relative to 1990 conditions.
Source: Hennesy et al. (2003)

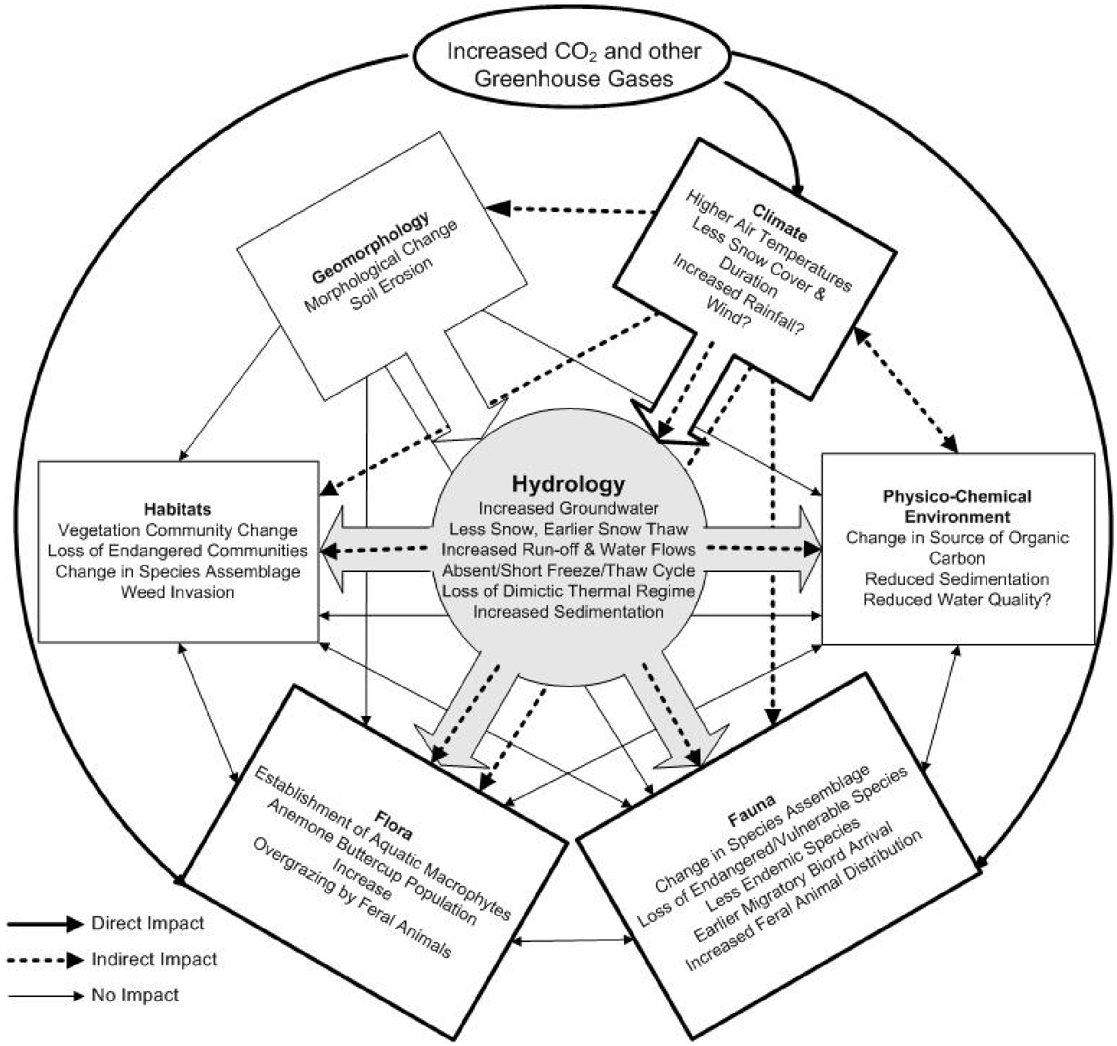


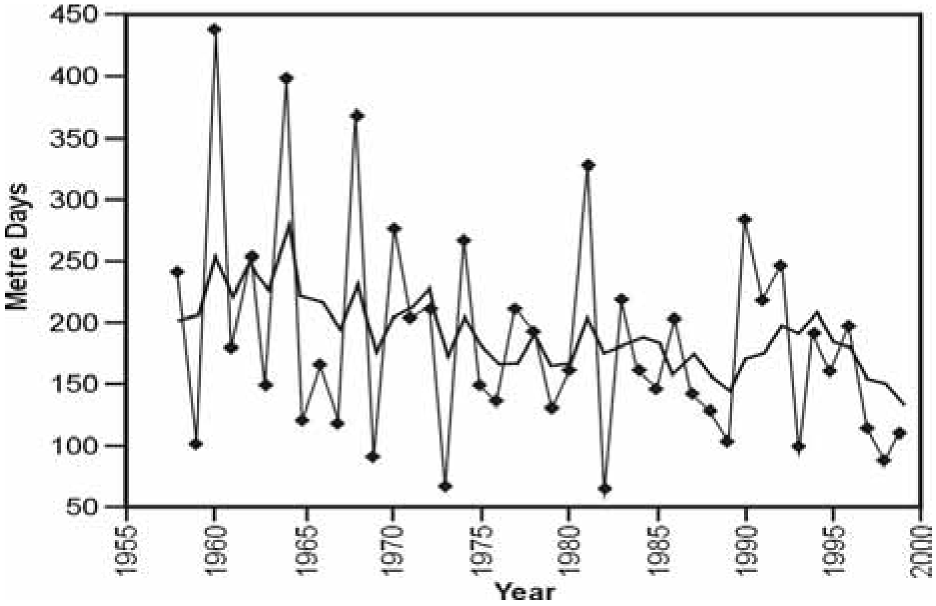
Figure 16: Conceptual model of the potential impacts of climate change

7.2.1 Alterations to hydrologic and geomorphologic processes

Based on snow data from the Snowy Mountains Hydro-electric Authority, it is evident that climate change is already having a negative influence on annual snow cover at Spencers Creek (Figure 17) (Green and Pickering 2002). Based on the climate projections detailed in Table 20, CSIRO has predicted the total area with an average of at least one day of snow cover to decrease by 22–85% by 2050 and the area with at least 60 days of snow cover to decrease by 38–96% by 2050 (Hennesy et al. 2003) (Table 21). The reductions in precipitation and snow cover projected to occur in response to increases in air temperature are likely to have significant impacts on the hydrology and geomorphic processes occurring at Blue Lake Ramsar site.

7.2.2 Potential effects on fauna

Based on data of mammal distribution within the Australian Alps, it is estimated that 35 mammals, six of which are feral, generally decline in abundance with increasing altitude (Table 22). Evidence indicates that some of these mammals have increased altitudinal distribution over the 30-year period prior to 1999, thereby highlighting the potential extension of these species with continued climate change. Since feral and introduced animals may reduce the ecological value of the Blue Lake Ramsar site, it is noteworthy



Source: Green and Pickering (2002)

Figure 17: Annual snow cover in metre-days at Spencers Creek

Table 21: Percentage change in area of snow with a least 1, 20 or 60 days simulated annual-average snow-cover duration

Snow Duration	2020 Low Impact	2020 High Impact	2050 Low Impact	2050 High Impact
At least 1 day	–9.9	–39.3	–22.0	–84.7
At least 30 days	–14.4	–54.4	–29.6	–93.2
At least 60 days	–17.5	–60.3	–38.1	–96.3

These numbers are relative to 1990 conditions.

Source: Hennesy et al. (2003)

Table 22: Mammals that decline in numbers with increasing elevation

Declining Species	Reason for decline
Group 1: Decline not snow-related in the short term	
Bats (11 species)	Reduction in flying insects
Possums (7 species)	Require trees
Koala	Absence of food tree species
House mouse	Lack of food for a specialist granivore
Group 2: Longer-term changes indirectly relate to snow	
Dog	Absence of large prey/competition with fox
Agile antechinus	Competition with dusky antechinus
Swamp rat	Competition with broad toothed rat
Eastern pygmy possum	Competition with mountain pygmy possum
Spotted-tail quoll	Competition with fox
Group 3: Decline likely to be snow-related	
Kangaroos and wallabies (3 species)	Mobility in snow/access to food
Wombat	Access to ground-based food
Echidna	Access to ground-based food
Bandicoot	Access to ground-based food
Cat	Hunting method
Rabbit, pig, horse	Access to ground-based food

Source: Green and Pickering (2002)

that an increase in the altitudinal distribution of feral animals, including cats, rabbits, hares, pigs, feral horses and dogs, has been observed (Green and Pickering 2002).

Three native animals – the dusky antechinus, broad toothed rat and mountain pygmy possum – have habitat niches within the alpine zone (including Blue Lake Ramsar site) and show increases in population with altitude. The mountain pygmy possum relies on snow cover to provide the stable, low temperatures for torpor. It also shows lower recruitment during periods of lower snow cover (Green and Pickering 2002) and it is estimated that a 1ºC temperature rise and accompanied changes in precipitation would eliminate its habitat range (DEC 2006). Meanwhile, the dusky antechinus and the broad toothed rat are active under snow conditions, using snow cover for protection from predation by foxes. Reductions in the population of the dusky antechinus and broad toothed rat are evident during periods of low snow cover. Furthermore, there is a potential decrease in areas of suitable habitat for the broad toothed rat with climate change (Brereton et al. 1995).

There is also evidence that the first arrival of migratory shorebirds observed within the Blue Lake Ramsar site has been earlier in decades after 1970 (Table 23) (Green and Pickering 2002). The Australian kestrel (*Falco cenchroides)* is largely dependent upon snow-free ground for foraging and its earlier arrival, while the flame robin (*Petroica phoenicea*) and Richard's pipit (*Anthus novaeseelandiae)* arrive in early spring to feed on insects immobilised on the surface of the snow. The earlier arrival of these species may indicate a shorter snow cover period, thereby enabling them to forage at an early period (Green and Pickering 2002).

7.2.3 Potential effects on flora

Climate change may affect the distribution of plant communities directly through changes in temperature and precipitation. Changes may also be observed indirectly through changes in the depth and distribution of snow cover, longer growing seasons, changes in prevailing soil moisture and changes in vegetative competition (Good 1998; Pickering 1998; Pickering et al. 2004). The extent of change is dependent on the rate and degree of change in temperature and precipitation, but it is likely to involve changes in community distribution and species composition. Predicted changes in the distribution of plant communities within the Blue Lake Ramsar site are controlled by reduced snow cover and associated increased diurnal freezing and thawing of soils, increased moisture stress, which will favour plants adapted to moisture deficits, and potential soil and vegetation degradation (Table 24) (Pickering et al. 2004).

Since the cessation of grazing, new populations of the anemone buttercup have established in sites drier than the isolated refuge sites. If the drier sites are the typical habitat for the anemone buttercup, it is predicted that this species may respond to climate change by increasing its abundance and extent (Pickering et al. 2004).

Table 23: Time of first arrival of migratory shorebirds at or above 1500 m

Species	1970–1979	1980–1989	1990–1999
Flame robin	2 Sep	17 Aug	21 Aug
Australian kestrel	5 Nov	20 Sep, 26 Oct	30 Aug, 8 Sep, 23 Sep, 28 Sep
Richard's pipit	16 Sep	5 Sep	28 Aug

The earliest record for each decade is given and all other dates earlier than the earliest record in 1970–1979.

Source: Pickering et al. (2004)

Table 24: Predicted changes in the distribution of plant communities as a result of climate change

Plant community	Current climatic range	Predicted change
Short Alpine Herbfield	Alpine	The reduction in late-lying snow patches may result in colonisation of some remnant areas of short alpine herbfield by tall alpine herbfield species. For smaller snow patches there could be complete loss of community, while for larger patches there will be a reduction in area occupied by this community.
Snowpatch Feldmark	Alpine	Reduced area as windswept feldmark species will colonise the area in response to the reduction in the area of late-lying snow patches.
Tall Alpine Herbfield (*Brachyscome–Austrodanthonia*)	Alpine	Unlikely to be greatly affected while snow cover remains adequate, as this specialised community is restricted to areas that are subject to relatively rapid natural erosion.
Tall Alpine Herbfield (*Celmisia–Poa*)	Alpine	Likely to increase in areas while adequate (3–4 months) snow cover continues to occur. The community potentially could expand into areas currently occupied by mesic communities. They may be affected by increased herbivory, including grazing by feral animals, if rising temperatures cause changes in dominance of species within the community. Some areas currently with tall alpine herbfield may be colonised by shrubs.
Fen	Alpine Subalpine Montane	Decreased precipitation and increased temperature may result in decreased run-off into fens leading to changes in competitive advantage of fen species, potentially resulting in replacement by sod tussock grassland species in drier sites.
Bog	Alpine Subalpine Montane	A reduction in soil moisture associated with climate change is likely to promote the replacement of valley bogs by sod tussock grassland species. If the reduction in snow cover is to the level experienced by subalpine vegetation, then valley bogs could be colonised by tussock grassland and heath communities.
Heath (*Epacris–Kunzea*)	Alpine Subalpine Montane	Heath may colonise other communities, particularly replacing fen and bog species if conditions become warmer and drier.

Adapted from Pickering et al. (2004)

7.3 Cloud seeding

Cloud seeding is a way of trying to increase rainfall from clouds by artificially adding raindrop nuclei to clouds. Commonly, silver iodide particles, which have a crystal structure similar to ice particles, thereby enabling water to deposit and accumulate on the silver iodide particle, are fired into the atmosphere from generators (Holper 2001).

Upon the implementation of the *Snowy Mountains Cloud Seeding Trial Act 2004* (NSW), Snowy Hydro Limited commenced a six-year cloud seeding trial in the Snowy Mountains region of NSW. The trial, referred to as the Snowy Precipitation Enhancement Trial (SPET), involves cloud seeding winter storm systems and undertaking monitoring and analysis to determine the socioeconomic and ecological feasibility of cloud seeding (Snowy Hydro 2004). The cloud seeding targets the alpine and subalpine zone of Kosciuszko National Park and includes the catchment of Blue Lake and Hedley Tarn. Operations involve the dispersal of silver iodide from 12 pairs of ground-based generators.

Snowy Hydro Limited claims that there have been 'absolutely no adverse impacts of cloud seeding' observed in Tasmania in 40 years (Searle 2004). Snowy Hydro Limited also predicted that the SPET will (Snowy Hydro 2004):

- not have a significant impact on the environment
- not have a negative impact on precipitation in areas downwind of the target areas
- not impact the conservation values of Kosciuszko National Park
- be in accordance with the principles of ecologically sustainable development and the precautionary principle
- have no adverse consequence on the outstanding scientific values of Kosciuszko National Park and its potential listing as a World Heritage area
- potentially act as a benchmark for future scientific and environmental initiatives consistent with global climate change initiatives.

However, cloud seeding over Kosciuszko National Park still remains controversial. The primary concern is the unknown impact of silver iodide within these ecosystems, the high conservation value of alpine and subalpine ecosystems in Australia, and the impact of cloud seeding on snow dependent fauna, such as the mountain pygmy possum (Figure 18).

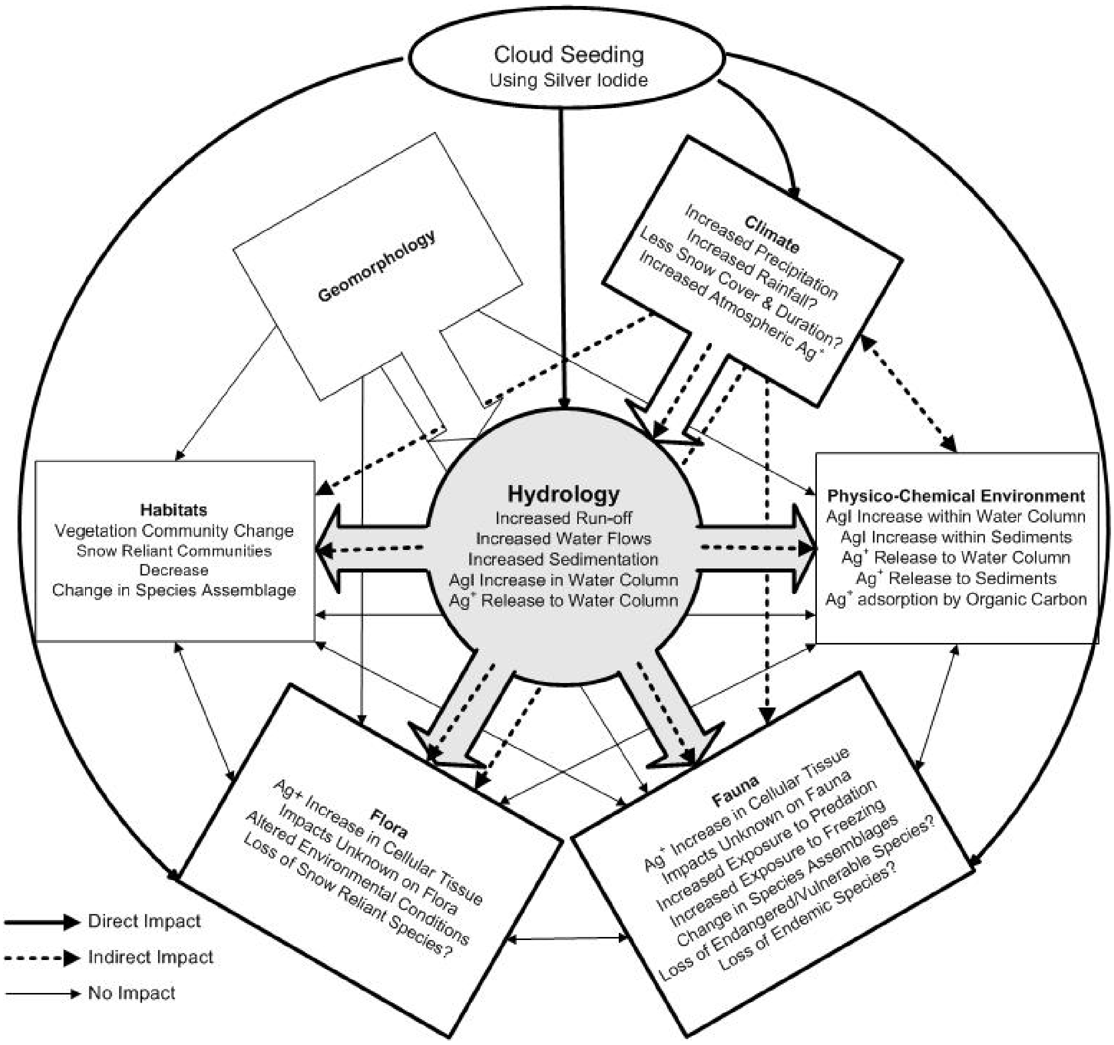


Figure 18: Conceptual model of the potential impacts of cloud seeding

The silver ion is a highly toxic heavy metal ion, particularly for micro-organisms and fish (Cooper and Jolly 1970). While silver iodide is regarded as ‘insoluble’ from a broad perspective, it may be slightly soluble to levels that may cause significant environmental effects (i.e. 1 μg/L). Since the water quality of Blue Lake exhibits extremely low conductivity and ionic concentrations, and has been described as among the freshest in Australia, even small increases in silver ions may significantly influence the near-natural nature of water quality and have significant impacts on the highly sensitive alpine flora and fauna. Due to the near-natural state of its water quality, Blue Lake is best described as a condition 1 ecosystem, which is expressed as a ‘high conservation/ecological value system’. The objective of water quality management in condition 1 ecosystems is to ‘ensure that there is no detectable change (beyond natural variability) in the levels of physical and chemical stressors’ (ANZECC and ARMCANZ 2000).

The Blue Lake Ramsar site has high conservation value and is identified as internationally important. It forms part of the UNESCO Biosphere Reserve, is part of a world centre of biodiversity, is listed as a Ramsar wetland of international importance and, in conjunction with Kosciuszko National Park, fulfils the criteria for World Heritage listing. Any addition of silver iodide to the Blue Lake Ramsar site may alter its high conservation value.

It has been hypothesised that changes in precipitation over Kosciuszko National Park may negatively impact snow dependent mammals, such as the mountain pygmy possum and the broad toothed rat (Colong Foundation for Wilderness 2004). Precipitation, which may fall as rain at lower altitudes, may decrease snow cover in marginal snow cover areas. Reduction in snow cover increases threats of predation on these species and removes the insulating winter blanket of snow, thereby exposing the mammals to freezing air temperatures and ultimately may cause the extinction of these endangered and vulnerable species.

7.4 Recreation and tourism

There is increasing awareness that tourism and recreation within Kosciuszko National Park has a significant impact and may reduce the sustainability of this industry. Approximately 70 000 people visited the alpine area during the snow-free period in 1999–2000 and about 21 000 of these people had a day walk to the summit of Mt Kosciuszko. Visitation to Mt Kosciuszko has increased considerably from the 20 000 visitors in the 1970s and is expected to continue to rise (Pickering and Buckley 2003; Pickering et al. 2003).

Blue Lake Ramsar site can be reached by a hardened trail from Charlotte Pass and is a popular destination with tourists and rock climbers. Visitation to the site has had considerable environmental impacts such as increased litter, compaction of soil, erosion, vegetation trampling, faecal contamination, disturbance to wildlife, noise pollution, reduction of visual amenity, introduction of alien plants and increased feral animal activity (Pickering and Buckley 2003) (Figure 19). While direct tourist visitation to the Blue Lake Ramsar site has potential environmental impacts, the impact of ski resorts and associated infrastructure may also have a significant impact on the site. For example, native fauna and flora may be impacted through tourism activities that caused increased numbers of introduced species and habitat fragmentation and reduction (Pickering et al. 2003).

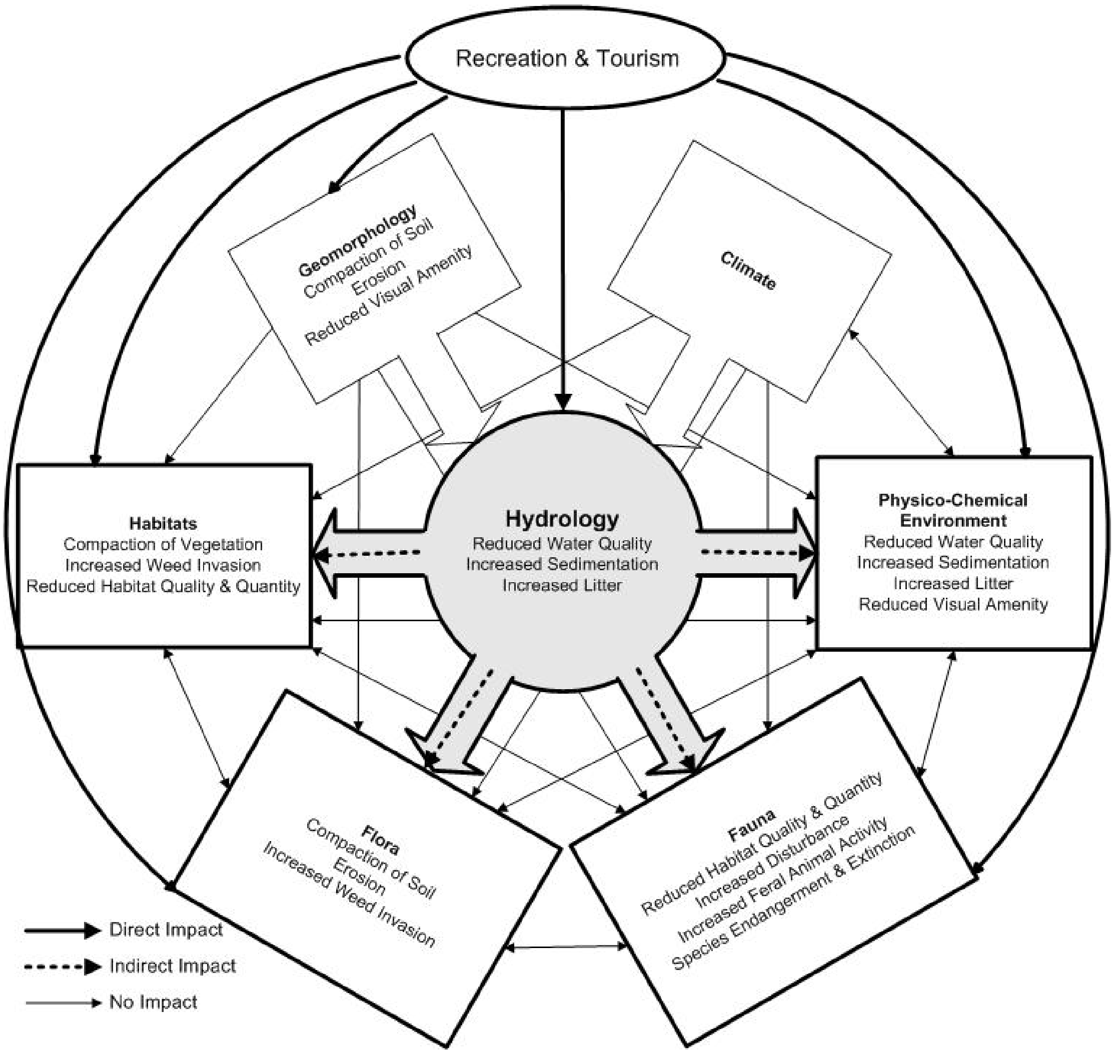


Figure 19: Conceptual model of the potential impacts of recreation and tourism

The impacts of visitation to the Australian Alps has already become evident. Over 175 alien plant species have been recorded above 1500 m. These species are predominantly associated with disturbance and may be a direct result of tourism with 78% of weeds identified being associated with roadsides or paths and 58% of weeds associated with ski resorts (Johnston and Pickering 2001).

7.5 Bushfires

Bushfires in Australia are a natural and periodic event. However, in extreme drought years environmental conditions change from non-drought conditions. Fuel is increasingly dry and available in drought years, thereby making conditions favourable for bushfires. Despite being a natural event, bushfires still remain a threat to alpine vegetation.

The Australian Alps experienced its largest bushfires in over 60 years in the summer of 2003. Fires spread across Victoria, NSW and the Australian Capital Territory and originated from 140 small, individual lightning strike fires resulting from wild electrical storms in south-eastern Australia on 8 January 2003; a total area of 1.73 million hectares was burnt across three states. Despite special efforts by the NSW NPWS, numerous mountain huts were destroyed. While the main range and the alpine zone acted as a firebreak, the fire did progress up to 50 m into the snowgrass area in the Mt Carruthers–Twynam area and included some of the Blue Lake Ramsar site (Worboys 2003). An isolated patch on the southern slope of Blue Lake and within 50–200 m of the waters of Blue Lake was burnt (T. Greville 2006, pers. comm.). While the burnt area now shows signs of recovery, impacts on the catchment include loss of vegetation, increased run-off and erosion, increased sedimentation, and addition of ash and burnt material to the lake (K. Green 2006, pers. comm.). The impact of the fire on the water quality of Blue Lake and Hedley Tarn remains unknown.

7.6 Erosion and sedimentation

In the mid- to late-1800s summer alpine grazing became a common undertaking by pastoralists in the Kosciuszko region. Overgrazing, particularly of the grasslands in the alpine zone, became apparent by the late 1880s (Maiden and Helms, cited in Good 1992). However, grazing was not restricted until 1943 when snow leases were revised and 1944 with the establishment of Kosciuszko State Park. The degradation brought on by grazing was evident, particularly near Mt Kosciuszko and including the Blue Lake Ramsar site, through severely eroded soils, entrenched flow lines, deep and active gully erosion, and the destruction of important vegetation communities and formations (Good 1992).

Rehabilitation and revegetation was initially undertaken in 1959 with limited success. Stabilisation was eventually achieved by sowing exotic grasses and legumes which provided a protective cover for the establishment of native species (Good 1992). However, it is apparent that recovery of alpine vegetation from degradation caused by grazing can take long time (Scherrer and Pickering 2005) and may be unsuccessful over extended periods. Observations at the Blue Lake Ramsar site indicate that past rehabilitation may be starting to fail. In particular, it is apparent that heavily grazed areas on Mt Twynam and Carruthers Peak are beginning to erode, with sedimentation likely to be occurring within Blue Lake and the alpine fen located in the upper regions of the Blue Lake Ramsar site. This fen may be the largest alpine fen located within the Australian Alps and is therefore of great significance (K. Green 2006, pers. comm.).

8 Recommendations and conclusions

8.1 Introduction

The primary function of describing the ecological character of a Ramsar wetland is to document the living and non-living components, how they interact and the natural variability of the wetland, thereby enabling LACs to be identified. As a result of doing this, other outcomes are achieved, including the identification of knowledge gaps and recommendation of actions to deal with these knowledge gaps, and updating the Ramsar Information Sheet (RIS).

8.2 Knowledge gaps and recommended actions

The availability of baseline data, which establishes the range of natural variation in components, processes and services in a wetland within a given time frame against which LACs can be assessed, is essential for sound management of a Ramsar site. Furthermore, a clear understanding of the impact of key threats is also necessary for adequately adapting management to deal with threats. For the Blue Lake Ramsar site there are considerable gaps in knowledge relating to the climate, geomorphology, hydrology, physico-chemical environment, habitats, flora and fauna, particularly with regards to potential threats arising from climate change, cloud seeding, recreation and tourism, bushfires and past grazing activities. The key gaps in knowledge and recommended actions for addressing these gaps are summarised in Table 25. A priority level has been assigned to each knowledge gap by site managers according to the degree of necessity or urgency in which the recommended actions should be undertaken.

8.3 Updating the Ramsar Information Sheet

This document is appended to the updated RIS for Blue Lake Ramsar site. The recommendations for updating the RIS are:

- translate the Ramsar criteria for which the site was listed in 1996 from the pre-1999 criteria (1a, 1d, 2b, 2d) to the current criteria used by the Ramsar Convention and the EPBCA (1, 3)
- include Ramsar criterion 2 due to the occurrence of nationally vulnerable, endangered or critically endangered species or endangered ecological communities within Blue Lake Ramsar site
- include the alpine tree frog (*Litoria verreauxii alpina*) and Japanese/Latham's snipe (*Gallinago hardwickii*) as noteworthy fauna
- update section 26 on factors adversely affecting the site to include:
    - climate change as a major factor affecting the ecological character of the site
    - cloud seeding as an unknown factor affecting the ecological character of the site
    - bushfires as a minor factor affecting the ecological character of the site – include rehabilitation work undertaken in the 1960s as a conservation measure taken to reduce erosion within the Blue Lake Ramsar site
- update conservation measures proposed but not yet implemented to include measures documented in the Kosciuszko Plan of Management (DEC 2006)
- update current scientific research and facilities to include the research undertaken by DECC
- update jurisdiction to include DECC
- update management authority to DECC and current contact information
- update reference list to include this report and recent research.

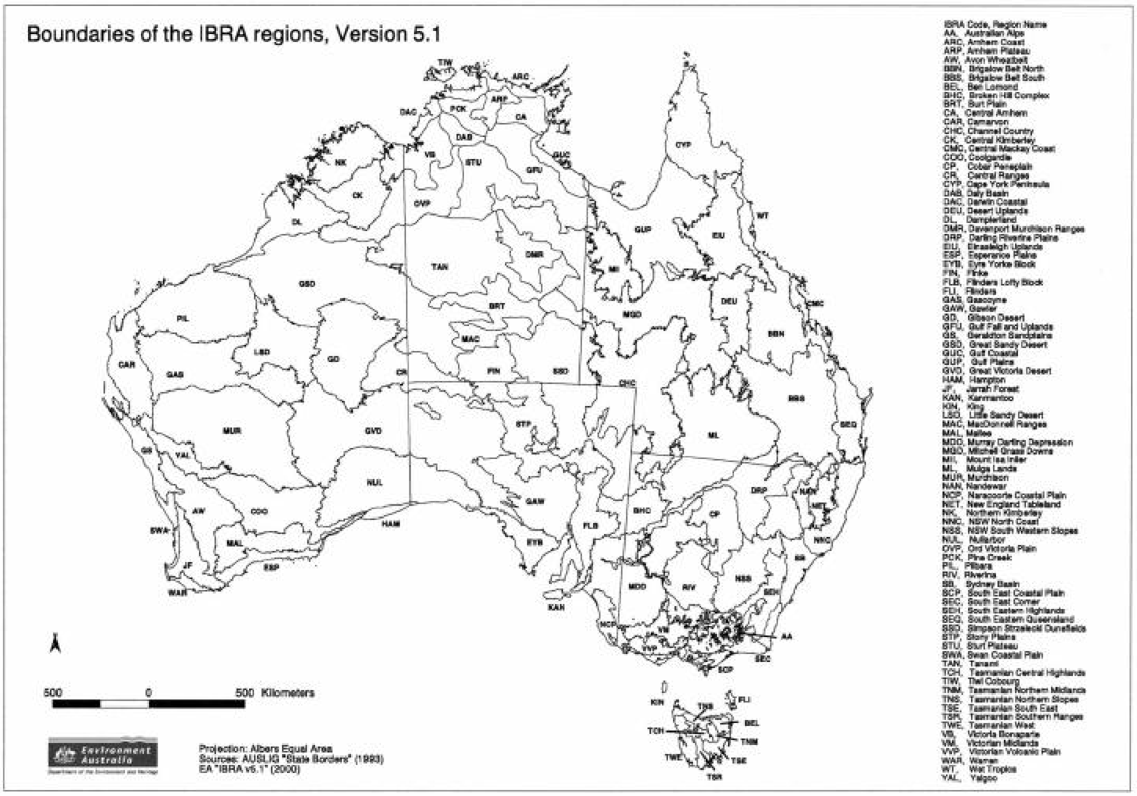
Table 25: Summary of key knowledge gaps and recommended actions

Component affected	Knowledge gap	Recommended actions	Current actions	Priority Level
Climate	Impacts of climate change	- Monitor changes in alpine air temperatures, snowfall, snow depth and rainfall	Undertaken by CSIRO	High
	Impacts of cloud seeding	- Monitor changes in snowfall, snow depth and rainfall	Undertaken by Snowy Hydro	High
Geomorphology	Impacts of climate change Impacts of recreation and tourism	- Monitor soil erosion within the Blue Lake and Hedley Tarn catchment	Needed	High
Hydrology	Impacts of erosion and sedimentation	- Rehabilitate the affected areas - Monitor sedimentation regimes within Blue Lake	Needed To be undertaken by DECC in summer of 2006–07	Very High High
	Impacts of climate change	- Monitor the break-up of ice on Blue Lake - Monitor thermal regime within Blue Lake	Currently undertaken by DECC Currently undertaken by DECC	Medium Medium
	Detailed water flow data	- Detailed monitoring of water inflows and outflows from Blue Lake and Hedley Tarn for at least one year	Needed	Low
	Detailed ground water data	- Determine the contribution and quality of ground water to and from Blue Lake and Hedley Tarn	Needed	Low
Physico-chemical environment	Impacts of bushfires	- Monitor post-fire water quality to identify whether there is a significant change from pre-fire water quality	Post-fire water quality undertaken by DECC No pre-fire water quality available	Low Low
	Impacts of cloud seeding	- Monitor water quality to identify concentrations of AgI and Ag^+	Needed	Low
	Temporal changes in water quality	- Monitor water quality and identify changes from Balmaks (1984) and Williams et al. (1970)	Undertaken by DECC	Low
	Detailed limnological data	- Collect detailed limnological data	Needed	Medium
Habitats	Impact of erosion and sedimentation	- Rehabilitate the affected areas - Monitor sedimentation on the affected alpine fen using quadrats and photoplots	Previously undertaken but requires further work. Needed	Medium Medium

	Impacts of climate change Impacts of cloud seeding Impacts of recreation and tourism	- Monitor changes in species assemblage, establishment of weed species and compaction of vegetation using quadrats and photoplots	Currently being undertaken in nearby areas	Low
		- Monitor changes in extent of vegetation communities from recent and historic aerial photography	Undertaken by Pascal Scherrer. May require more detailed work.	Medium
	Temporal changes in extent of vegetation communities	- Map extent of vegetation communities from recent and historic aerial photography to identify changes	Undertaken by Pascal Scherrer. May require more detailed work.	Medium
	Impacts of climate change	- Implement study on impacts of increased UV radiation on alpine flora	Undertaken for entire alpine area by Roger Good.	Medium
		- Monitor (lack of) aquatic macrophytes within Blue Lake	Needed	Medium
	Baseline data of productivity of phytoplankton	- Collect baseline data on productivity of phytoplankton	To be undertaken by DECC.	Medium
Fauna	Impacts of climate change	- Implement study on impacts of increased UV radiation on alpine flora	Undertaken by DECC	Medium
		- Monitor arrival of migratory birds to Blue Lake and Hedley Tarn	Needed	Low
		- Monitor changes in visitation patterns of mammals to Blue Lake and Hedley Tarn	Needed	Low
		- Establish the physiological requirements for vertebrates, invertebrates and zooplankton	Undertaken by DECC	Low
		- Monitor the upstream altitudinal migration of mammals frogs, crustaceans and fish, e.g. trout	Partly undertaken by DECC	Medium
	Impacts of cloud seeding	- Establish the effect of AgI on fauna	Needed	Low
	Food web	- Describe food webs within Blue Lake and Hedley Tarn	Needed	Low
	Baseline data on productivity of zooplankton	- Collect baseline data on productivity of zooplankton	Needed	Low
	Detailed fauna census	- Collect detailed fauna data including species assemblage and sightings	Needed	Low

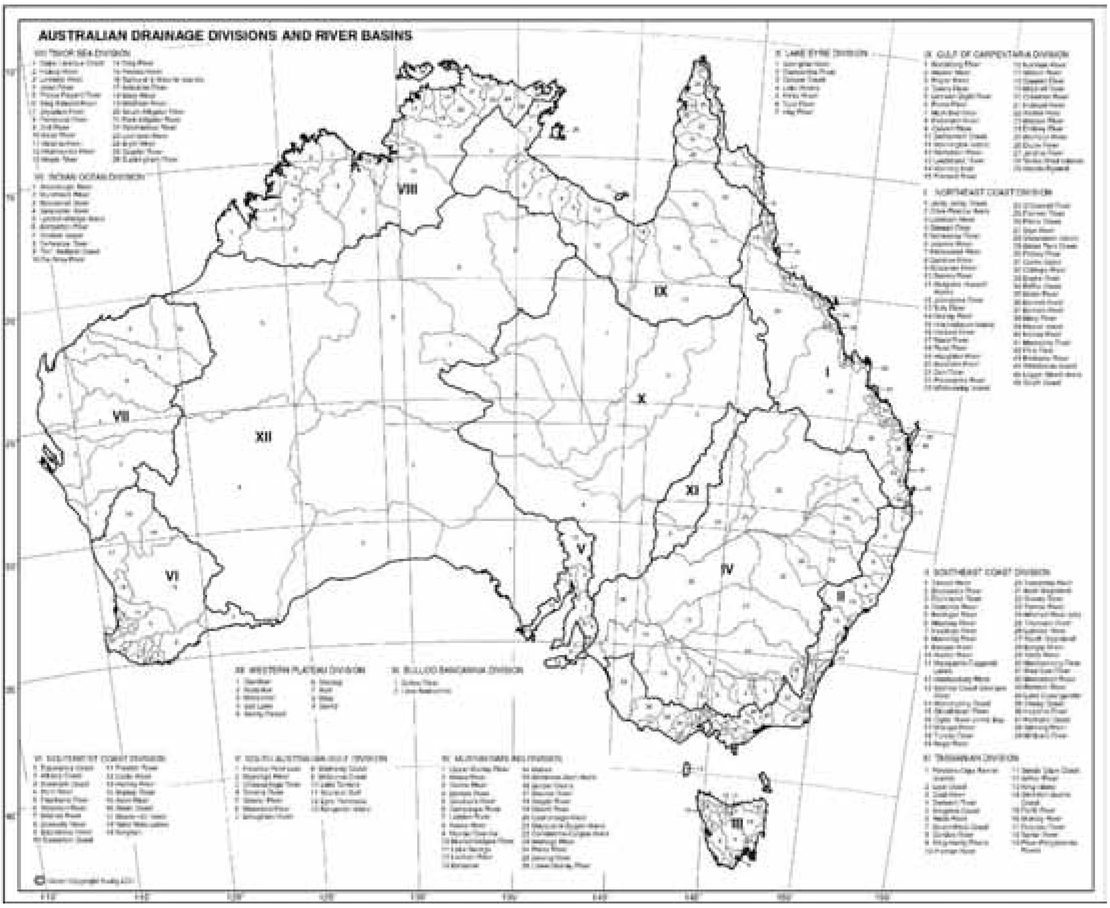
Appendix 1: Australian regionalisation schemes

IBRA



Source: DEWHA (2000)

ADDRB



Source: Auslig (2001)

Appendix 2: Animal species

Scientific Name	Common Name
Birds	
Anas superciliosa	Pacific black duck
Phalacrocorax carbo	Great cormorant
Phalacrocorax varius	Pied cormorant
Hirundapus caudaclitus	White throated needletail
Egretta novahollandiae	White faced heron
Aquila audax	Wedge tailed eagle
Falco cenchroides	Nankeen kestrel
Falco peregrinus	Peregrine falcon
Elanus axillaris	Black shouldered kite
Vanellus miles	Masked lapwing
Petroica phoenicea	Flame robin
Anthus novaeseelandiae	Richard’s pipit
Sericornis frontalis	White browed scrubwren
Strepera graculina	Pied currawong
Corvus coronoides	Australian raven
Corvus mellori	Little raven
Gallinago hardwickii	Japanese/Latham’s snipe
Mammals	
Vulpes vulpes	Fox
Lepus capensis	Hare
Mastacomys fuscus	Broad toothed rat
Rattus fuscipes	Bush rat
Burramys parvus	Mountain pygmy possum
Tachyglossus aculeatus	Short-beaked echidna
Antechinus swainsonii	Dusky antechinus
Reptiles	
Drysdalia coronoides	White-lipped snake
Austrelaps superbus	Copperhead
Eulamprus kosciuszkoi	Alpine water skink
Eulamprus tympanum	Southern water skink
Pseudemoia entrecasteauxii	Mountain log skink
Amphibians	
Crinia signifera	Eastern common froglet
Litoria verreauxii alpina	Alpine tree frog
Fish	
Galaxias olidus	Mountain galaxias

Source: RIS (1998)

Glossary

Acceptable change is based on the work of Phillips et al. (2005), as 'the variation that is considered 'acceptable' in a particular measure or feature of the ecological character of a wetland. Acceptable variation is that variation that will sustain the component or process to which it refers'.

Aestivate is to pass the summer in a dormant or torpid state. Similarly to a winter hibernation.

Assessment as defined by Resolution VIII.6 of the 8th Conference of Parties to the Ramsar Convention is: 'The identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities.'

At a given point refers to the ecological character of a site at the time of designation for the Ramsar list.

Attributes as defined by the 6th Conference of Parties to the Ramsar Convention, include 'biological diversity and unique cultural and heritage features. These lead to uses or derivations of products, but they may also have intrinsic, unquantifiable importance' (Annex A to Resolution VI.1).

Baseline is defined as ecological condition of the wetland at a starting point, usually the time of listing.

Bathymetry is the measurement of the depths of oceans, seas, lakes or other large water bodies and the data derived from such measurements.

Benchmark is defined as a pre-determined state (based on the values which are sought to be protected) to be achieved or maintained.

Benefits, as they relate to Ramsar wetlands and to ecological character and change in that character, are defined by Ramsar (9th Conference of Parties, Resolution IX.1) as the benefits that people receive from ecosystems.

Biodiversity is the variability among living organisms. It includes diversity within and among species and diversity within and among ecosystems. Biodiversity is the source of many ecosystem goods, such as food and genetic resources, and changes in biodiversity can influence the supply of ecosystem services (Millennium Assessment 2003).

Change in ecological character as redefined by Resolution IX.1 of the 9th Conference of Parties to the Ramsar Convention are 'the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service.'

Character is a descriptive snapshot which lists the constituents at a site and their relationships. It is a 'value free' statement. (Contrast with condition.)

Cirque is a steep bowl-shaped hollow occurring at the upper end of a mountain valley, formed by the rotational ice action at the head of a glacier.

Components are the physical, chemical and biological components of the system, with the latter being defined as habitat, species and genes.

Condition (ecological condition) refers to the health or quality of a site. It involves analysis, assessment and value-based judgment. The assessment is made comparative to other sites.

Criteria used in Ramsar specific context refer to the nine criteria for listing of a site as internationally significant under the provision of the Ramsar Convention (as amended at the 9th Conference of Parties), namely a wetland that

1 contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region;
2 supports vulnerable, endangered, or critically endangered species or threatened ecological communities;
3 supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region;
4 supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions;
5 regularly supports 20,000 or more waterbirds;
6 regularly supports 1% of the individuals in a population of one species or subspecies of waterbird;
7 supports a significant proportion of indigenous fish subspecies, species or families, life history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity;
8 is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend;
9 regularly supports more than 1% of the population of a non-avian species of animal.

Desmid are any of various green unicellular freshwater algae of the family Desmidiaceae, often forming chainlike colonies.

Dimictic is a term used for a lake having two seasonal periods (autumn and spring) of overturn with free circulation so surface and deep waters mix and the thermocline is disrupted. Dimictic lakes normally go through two stratifications and two mixing cycles annually.

Dissolved oxygen (DO) is the amount of oxygen dissolved in a body of water, used as an indication of the degree of health of the water and its ability to support a balanced aquatic ecosystem. Usually expressed in milligrams per litre, parts per million (ppm), or per cent of saturation.

Ecological character as redefined by the 9th Conference of Parties to the Ramsar Convention, is 'the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time' (Resolution IX.1 Annex A).

Ecosystem is a dynamic complex of plant, animal, and microorganisms.

Ecosystem indicator can be any biological, chemical or physical characteristic of the wetland for which long term data exists.

Ecosystem service In the Millennium Ecosystem Assessment (2003) (MA), ecosystems are described as the complex of living communities (including human communities) and non-living environment (ecosystem components) interacting (through ecological processes) as a functional unit which provides inter alia a variety of benefits to people (ecosystem services). Included in MA ecosystem services are provisioning, regulating, and cultural services that directly affect people, and supporting services which are needed to maintain these other services. Within this context, ecosystem benefits are defined in accordance with the MA definition of ecosystem services as 'the benefits that people receive from ecosystems' (Resolution IX.1 Annex A, 9th Conference of Parties to the Ramsar Convention).

Erosion is the group of natural processes, including weathering, dissolution, abrasion, corrosion and transportation, by which material is worn away from the Earth's surface.

Erratic is a piece of rock that has been eroded and transported by a glacier to a different area; it is left behind when the ice melts. Glacial erratics give us information about the direction of ice movement and distances of transport. Glacial erratics can be any size from small pebbles to large boulders the size of a house.

Feldmark is a community of prostrate plants growing on a stony pavement in an extreme alpine environment.

Functions as defined by the 6th Conference of Parties to the Ramsar Convention are activities or actions, natural, a product of interactions between ecosystem structure and processes, for example flood control, sediment retention, food web support. Functions include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilisation and erosion controls; storm protection; and stabilisation of local climatic conditions, particularly rainfall and temperature (Annex to Resolution VI.1).

Ground water is water occurring below the ground surface.

Lotic refers to moving water.

Monitoring as defined by Resolution VIII.6 of the 8th Conference of Parties to the Ramsar Convention is 'collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management.'

Moraine is an accumulation of boulders, stones, or other debris carried and deposited by a glacier.

Nivation is the process of alternative freeze and thaw by which fallen snow gets converted into a mass of ice or névé.

Orographic effect occurs when a moist air mass is forced from a low elevation to a higher elevation as it moves over rising terrain. As the air mass gains altitude it expands and cools, creating clouds and frequently precipitation on the windward side or top of a mountain.

Podsolisation is the process by which soils are depleted of bases and become acidic.

Processes as defined by the 6th Conference of Parties to the Ramsar Convention are 'changes or reactions which occur naturally within wetland systems. They may be physical, chemical or biological' (Annex A to Resolution VI.1). Biological processes are the dynamic biotic and abiotic interactions within an ecosystem such as primary production, decomposition, carbon and nutrient cycling, sedimentation and provision of habitats for other biota. These may or may not provide benefits or services to humans.

Rain shadow is a dry region of land that is leeward or behind a mountain with respect to the prevailing wind direction. A rain shadow area is dry as the orographic effect causes precipitation on the windward side or top of the peak.

Service *see* ecosystem service

Solifluction is the down slope movement of unconsolidated rock debris by freeze–thaw processes, interstitial ice and snow melt.

Talus is a sloping mass of rock debris at the base of a cliff or incline.

Tarn is a small mountain lake, especially one formed by glaciers.

Thermocline is a layer in a large body of water, such as a lake, that sharply separates regions differing in temperature, so that the temperature gradient across the layer is abrupt.

Turbidity is the cloudy appearance of water due to suspended material.

Values as defined by the 6th Conference of Parties to the Ramsar Convention are the perceived benefits to society, either direct or indirect, that result from wetland functions. These values include human welfare, environmental quality and wildlife support (Annex A to Resolution VI.1).

Water quality is a general term to describe the suitability of water for a given use (such as for drinking or vegetation growth).

Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth which at low tide does not exceed six metres (Article 1.1.) and may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands (Article 2.1).

Abbreviations

ADDRB	Australian Drainage Divisions and River Basins
ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australian and New Zealand
asl	above sea level
BOM	Bureau of Meteorology
CAMBA	China–Australia Migratory Bird Agreement
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation (NSW)
DECC	Department of Environment and Climate Change NSW
DSE	Department of Sustainability and Environment (Vic)
EPBCA	*Commonwealth Environmental Protection and Biodiversity Conservation Act 1999* (Cwlth)
IBRA	Interim Biogeographical Regionalisation of Australia
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
JAMBA	Japan–Australia Migratory Bird Agreement
LAC	limit of acceptable change
NPWS	NSW National Parks and Wildlife Service
NWQMS	National Water Quality Management Strategy
RIS	Ramsar Information Sheet
ROKAMBA	Republic of Korea–Australia Migratory Bird Agreement
TSCA	*Threatened Species Conservation Act 1995* (NSW)
UNESCO	United Nations Educational, Scientific and Cultural Organization

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