South Esk – Great Lake Water Management Review

Scientific Report on Lake Augusta

August 2003

Prepared by
Hydro Tasmania

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LAKE AUGUSTA

1. PRELIMINARY REVIEW

Geomorphology

During the Environmental Review component of the South Esk – Great Lake catchment Water Management Review, it was noted that wind blown sand dunes (lunettes) of potential geoheritage significance border the eastern shore of the original Lake Augusta (see Figure 1). A brief study was carried out on the area by the Parks and Wildlife Service in 1994 (Bradbury, 1994). This report suggested that the frequent elevation of water level in Lake Augusta has resulted in erosion of the dunes, and that these may be degraded in part as a result of the raising of Lake Augusta. While the lunettes are not listed in the World Heritage Area, the lake and the land vested in Hydro Tasmania is surrounded by the World Heritage Area. The primary stakeholders affected by this issue are the Parks and Wildlife Service and people concerned with geoheritage issues.

The lunettes identified in the area surrounding Lake Augusta (referred to as the Nineteen Lagoons area), are derived from doleritic sand and are thought to have formed between 4,000-5,000 years ago. These lunettes are considered outstanding earth heritage features (Bradbury, 1994).

Bradbury (1994) assessed degradation of the landforms throughout the Nineteen Lagoons area and concluded that the integrity of many of the aeolian landforms in this region had been compromised, and some features had been completely destroyed as a result of human activities. The largest aeolian landforms in the Nineteen Lagoons area (dunes of up to 5 - 6 m in height) occur on the eastern shore of the natural Lake Augusta. Bradbury states that the formation of the present-day Lake Augusta and the periodic raising of the lake level have resulted in degradation of the lunettes through extensive lake-shore erosion. He listed activities such as earthworks associated with electricity infrastructure and roads, access to the lake for angling, physical trampling, fire, vegetation destruction from firewood collection for campfires, grazing and burrowing by introduced animals as also having some impact on the integrity of dunes.

The dunes are considered to be susceptible to wave attack as the soils are less than 5,000 years old and the fact that the alpine vegetation does not promote the development of a strong protective root mat. Soils developed on the Lake Augusta lunette and low lunettes around the Carter Lakes are uniform in texture with undifferentiated profiles (Pemberton, 1986:30). These are generally yellowish-brown, reddish-grey or greyish-brown. The soils of this lunette have been extensively burrowed by wombats and rabbits. Black organic soils are common in poorly drained locations at low elevations.

The raising of lake levels caused most vegetation and soils between the former shoreline and the new level to be lost. Bradbury suggests that the development of wave-cut scarps has allowed blowouts to be initiated. On the eastern shore of Lake Augusta, Bradbury (1994) identified at least 6 active blowouts, originating at the shoreline. At the time this study was carried out, some of these blowouts covered an area in excess of 2 ha, while the dune front was estimated to have advanced eastwards by at least 100 m.

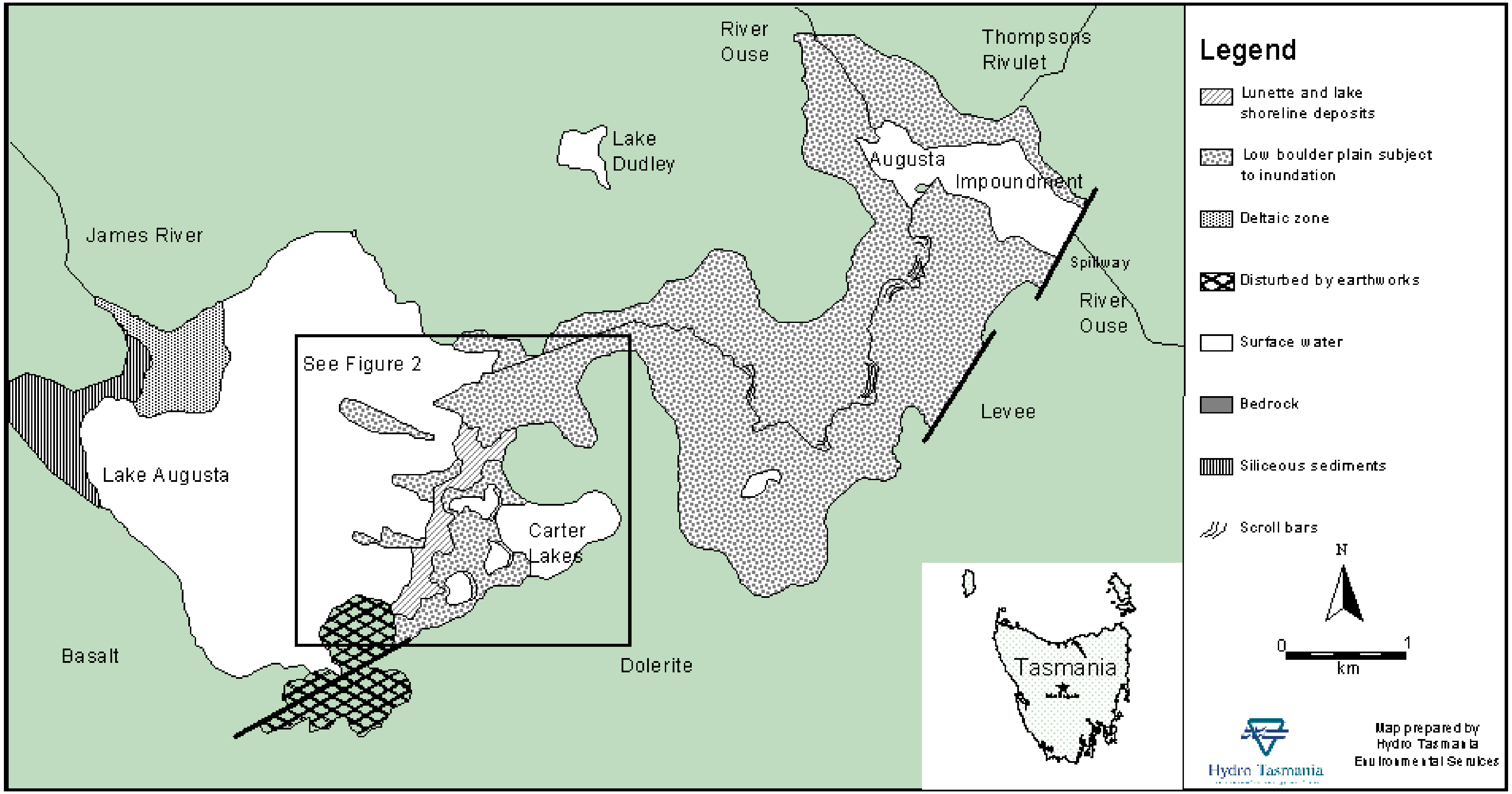

Figure 1: Area map of Lake Augusta showing general geomorphology

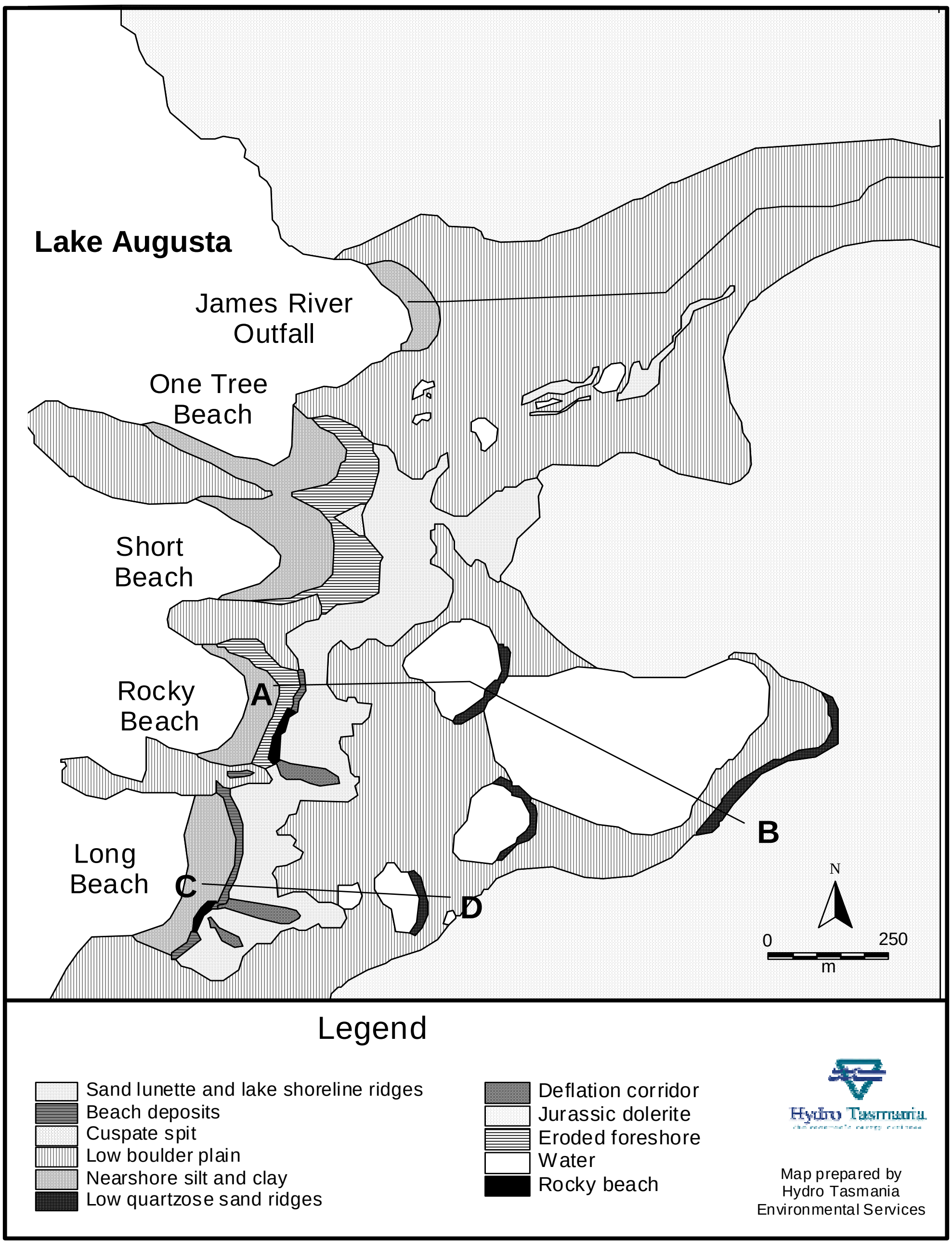

Figure 2: Geomorphic Units in the area to the east of the original Lake Augusta (figure also indicates location of cross-sectional profiles).

At the Augusta impoundment, Bradbury suggests that the intermittent raising of the lake level has resulted in loss of vegetation as a result of waterlogging and that the soil has then been removed by a combination of wind and wave action. He suggests that this has resulted in the underlying morainal material being exposed to wind erosion, creating a deflation lag, which is at least partially developed across the entire inundation area. In many areas of the Augusta impoundment, the deflation appears to have been complete and the lag now fully armours the bed of the impoundment.

A new lunette has formed just above the full supply level at the eastern end of the Augusta spillway. This substantial dune, up to 4 m in height has formed since the completion of the dam in 1953. This dune is well-vegetated and Bradbury (1994) indicated that it is in better condition that any other aeolian landform in the Nineteen Lagoons area. This dune gives some insight into the possible timeframe for formation of other dunes in the area, and although this dune may not be regarded as a geoheritage feature, it may be considered a cultural feature due to it having formed as a result of human influence.

Hydro Tasmania currently manages the lake above a minimum level to prevent sand blowing into the intake area. Bradbury (1994) suggests that the most effective rehabilitation would be to return the sand currently stored in the littoral zone back to the dune system. To do this, he suggests that there would need to be an increase in the low lake level events, exposing the littoral zone to desiccation and aeolian action. Sand fences may be necessary to trap sand remobilised in this manner in areas of active blowouts.

In his report, Bradbury also suggested that rehabilitation of the degraded Augusta dunes is likely to be impossible without Hydro Tasmania changing the operation of Lake Augusta to increase the number of low lake levels. He also recommended that a maximum lake level should be set for Lake Augusta and that the duration of high lake levels should be minimised to prevent further degradation of the Augusta dunes. No maximum lake level was suggested, however it would need to be below the current full supply level. It was recognised that a reduced maximum lake level may not present a long term management solution, but that increasing the capacity of Liawenee Canal to more quickly drain the lake may allow the same potential harvest of water resources without further serious impact on the Augusta dunes.

Hydrology

The original Lake Augusta is a relatively shallow body of freshwater estimated to be about 2 m deep. It is a permanent overflow system fed mostly by the James River. The fetch across the lake is approximately 2 km. Surface water is also contributed by local rainfall and run-off. The lake waters exit through the James River outfall. The James River continues to the Augusta Impoundment some 4km to the east where it joins the River Ouse.

Construction of Augusta Dam across the Ouse River to divert water into the Liawenee Canal produced a permanent body of water behind the dam (the Augusta Impoundment) and altered the hydrology of the original Lake Augusta. During high inflows, water is retained behind Augusta Dam causing Augusta Impoundment to fill. As the impoundment fills, it backs up, flooding back into the original Lake Augusta.

Hydrographic records kept by Hydro Tasmania since construction in 1953 show that impoundment levels have fluctuated between a low of 1142.35 metres above sea level and spills above full supply level at 1150.62 metres above sea level.

As expected, lake level is highly seasonal. High lake levels usually occur in winter and early spring coincident with seasonally high rainfall and snowmelt in the upper catchments of the James River and Ouse River. This is also when westerly winds are strongest. Conversely, lake levels fall in late summer when evaporation rates are high and water continues to be transferred to Great Lake via Liawenee Canal. The original lake remains relatively low (essentially within its natural boundaries) for months at a time during the summer and drier parts of the year. Therefore it is only during high lake levels (i.e. spill events) that the natural water level regime of Lake Augusta is modified.

Cultural Heritage

Another issue that was raised during the Environmental Review was the potential presence of sites of high Aboriginal Heritage significance in the area around Lake Augusta, particularly along the eastern shoreline. It was noted that this might be an issue in relation to the possible erosion of the eastern shoreline and sand dunes. This issue affects the Aboriginal community of Tasmania.

In the case of Lake Augusta, cultural heritage issues are intrinsically related to erosion issues. There are known Aboriginal sites in the Lake Augusta area, and several surveys have been carried out previously. However, there has been no assessment of the relative cultural importance of the area, or the susceptibility of the sites to erosion as a result of water level management.

The shoreline of Lake Augusta has been partially surveyed for Aboriginal sites and the state of existing knowledge has been summarised as part of a report by Smith (1998), from the Tasmanian Aboriginal Land Council. This report indicates that a significant proportion of the shoreline around Lake Augusta may contain Aboriginal sites. The report classified all areas that could potentially contain Aboriginal sites as areas of "high sensitivity". The remainder of the shoreline of Lake Augusta is lacking in information.

Other surveys that have been carried out around the shoreline of Lake Augusta include:

- Cosgrove (1984): this survey took in a small section of the north-west shoreline of Lake Augusta, however no sites were recorded. One site was recorded by Cosgrove at the mouth of the James River near Lake Augusta. Aboriginal sites at that time were also known to be on the edge of Howes Lagoon Bay and along Four Bays as the central southern side of the lake (from Tasmanian Aboriginal Site Index records).
- Du Cros (1992): Lake Augusta was surveyed as part of a report on the distribution of Aboriginal sites affected by erosion in the World Heritage Area - primarily the track across the dry middle of the lake and the northern and eastern margins. Sites were recorded along the north and north-eastern shoreline, especially around Worcester Bay and around the mouth of the River Ouse. The sites recorded were generally in already eroded areas as these were the areas targeted and with the best visibility.
- Tasmanian Aboriginal Land Council (1996a): During the Tana Trawna project, approximately 3 km of the track running along the western side of Lake Augusta was surveyed from the junction with Augusta spillway road to Little Blue Lagoon. Aboriginal sites were identified from this survey. Sections of this site were monitored following this and results showed that there is ongoing damage to the site and the artefacts themselves from vehicular traffic (Tasmanian Aboriginal Land Council 1996b; 1997).

All Aboriginal artefacts are protected under the *Aboriginal Relics Act* 1975. Section 4-(1) of this Act it states:

> "Except as otherwise provided in this Act, no person shall, otherwise in accordance with the terms of a permit granted by the Minister on the recommendation of the Director –
>
> a) destroy, damage, deface, conceal, or otherwise interfere with a relic;
>
> b) remove a relic from the place where it is found or abandoned."

This Act applies to Aboriginal sites anywhere in Tasmania, regardless of land tenure.

Threatened Species

Threatened species were not identified as an issue during the environmental review process. This is because *Paragalaxias julianus* was not listed as a threatened species until 2000. Following the listing of the species, the presence of *Paragalaxias julianus* in Lake Augusta was noted as an issue in relation to how the regulation of lake levels may affect the well being of this species and its habitat. The primary stakeholder in relation to this issue is the Inland Fisheries Service.

Electrofishing surveys and surveys on habitat preference for this species are required to better understand potential threats to the long-term survival of the species that may arise from lake level management.

Trout Fishery

During the community consultation stage, one stakeholder raised a concern in relation to the trout fishery (This is reported in the *Community Consultation Report: South Esk – Great Lake Water Management Review* in Section 3.2). The stakeholder was concerned that summer water levels in the Augusta Impoundment should continue to be managed so that the lake remained a productive trout fishery. This is an issue that potentially affects hundreds of trout anglers throughout the state.

Lake Augusta is generally referred to by anglers as two separate water bodies, Lake Augusta and Augusta Impoundment. When the lake level is down the lake recedes into the artificial impoundment behind Augusta Dam (Augusta Impoundment) and the original water body (Lake Augusta). This is generally the status of the lake for most of the fishing season (drier period of the year).

When lake level is low, Lake Augusta is essentially a natural lake and is the second most popular trout fishing water in the western lakes (Sloane & French, 1991). The lake and also the associated section of the James River (which is flooded during high lake levels) supports a very large population of wild brown trout and a significant number of wild rainbows (French, 1994; Sloane & French, 1991). Anglers generally believe that the native macrophyte beds in the natural Lake Augusta play an important role in the health of the trout fishery.

Augusta Impoundment is known to yield consistent bags of brown and rainbow trout (0.5 – 1 kg) and occasionally bigger. The angling theory is that the lower the storage the more concentrated the trout, resulting in better yields at lower lake levels (Sloane & French, 1991).

The fishing season for the Western Lakes is August to April inclusive. However, as part of the Western Lakes Fisheries Management Plan, developed by the Inland Fisheries Service, public opinion is being sought as to whether the season at Nineteen Lagoons area should be shortened to coincide with the opening and closing of the gate at Lake Augusta. The gate is generally shut during late autumn and is usually opened in the first week of October, although this can vary according to weather.

Fishery issues at Lake Augusta have not been examined as part of the Lake Augusta Assessment as no major change to the current lake level management is proposed. The Inland Fisheries Service has however developed a *Fishery Management Plan* for the Western Lakes, which includes Lake Augusta and the Nineteen Lagoons region. This process involved public consultation, including surveys and stakeholder workshops.

Public Access and Amenity

There was one response during the community consultation stage (and a general comment made later by another stakeholder) that related to public amenity and access. The concern was that vehicular access to the Western Lakes is cut off during parts of the fishing season as a result of high lake levels that cause spill over the spillway. This is an issue that could potentially affect hundreds of trout anglers.

The other concern related to access across the four-wheel drive track to Pillans and Julian Lakes, which crosses the dry section between the original Lake Augusta and the Augusta Impoundment. When the lake rises, this track is impassable.

The fishing season for the Western Lakes extends from August to April. Concerns regarding access specifically for fishing are not relevant outside the fishing season, as it is outside the legal period. The Parks and Wildlife Service presently restrict access to the Western Lakes area by closing a gate located on the road between Augusta Dam and Augusta Spillway during winter. The gate is closed in late autumn and is generally opened again in the first week in October. Reasons for the Parks and Wildlife Service restricting access include the protection of the Pillans – Julian Track and other 4WD tracks from undue degradation during wet periods. The closure of the gate is also important for safety reasons, as the lake spills frequently in winter. The lake is mostly very shallow and can rise quickly, therefore unless the gate is closed in winter, there may be a danger of people getting trapped on the other side of the spillway or being swept off if they attempt to cross.

Access Across the Spillway

An assessment of water level and spill records for Lake Augusta was carried out for the period 1990 to 2000 to determine how often during the fishing season the lake spills, and how often during the fishing season it is at a level where the lake is impassable. As the gate is closed by the Parks and Wildlife Service during the wetter winter and spring periods for safety reasons and for the protection of tracks and habitat, the main concern for this assessment has been the frequency with which the lake spills outside the period for which the gate is normally closed (i.e. October to April). These are the spill events that restrict access solely on the basis of the lake spilling.

In general, Lake Augusta is higher in the winter months and more likely to spill, and lower in the drier summer months, with spills being relatively infrequent during the ‘open gate’ period. Since January 1996, Lake Augusta has spilled on six occasions between the periods of October to April. The dates and duration of the spills are outlined in Table 1.

Year	Month	Dates	Duration (days)	Average discharge of spill (cumec)
1996	Jan	27th – 30th	4	5.35
	Feb	2nd	1	0.41
	Oct	1st – 4th	4	10.4
1998	Oct	2nd – 12th	11	8.52
1999	Mar	4th – 7th	4	2.80
2000	Oct	1st – 6th	6	6.36

Table 1: Dates and durations of significant spills over the Lake Augusta spillway between 1996 and 2000

The information suggests that the lake is relatively unlikely to spill during the majority of the ‘open gate’ period (October to April) and when it does spill during this period, the duration of the spill is on average, only 6 days. In terms of the overall picture, this is a relatively minor issue and is likely to inconvenience only a small number of anglers. No additional investigation of this issue is required.

Access Across Lake Augusta

According to ‘Western Lakes Fishery Management Plan’ (IFS 2002), the Pillans – Julian 4WD track is the most popular 4WD track in the Western Lakes. The main problems with the track across Lake Augusta are poor routing and a lack of maintenance. The track is presently closed by Parks And Wildlife Service during the early season (when conditions are generally still wet) to protect it from undue degradation, although wet conditions can occur throughout the year. This track can become impassable as a result of rising water levels before the lake itself reaches spill level, however if the lake is spilling, there is no access to this track (as the spillway needs to be crossed in order to reach the start of the track).

However the constraint to the passibility of the Pillans – Julian track is not the level of Lake Augusta itself, but the level of the James River, which follows its original course across the dry lake bed. A general ‘rule of thumb’ is that when the level of the James River reaches the iron supports on the footbridge which goes across the river, then it is too deep for four-wheel-drives to cross (M. Cousins, Parks And Wildlife Service, pers. comm.). This level in the river is obviously reached prior to the lake itself flooding. The James River is likely to have risen with high rainfalls in the catchment even under natural conditions (ie. pre-hydro development).

Although the lake level management of Lake Augusta can not influence the number of times the track is impassable as a result of the James River rising, management of lake levels may influence the duration for which the track is impassable.

To determine what influence the operation of the lake has on how frequently and for how long the lake is impassable, hydrological investigations, (probably including some modelling) would need to be carried out. However, as the level of concern that has been expressed regarding this issue was relatively low, no additional investigations were undertaken as part of this study.

Exotic Species

Canadian Pondweed (*Elodea Canadensis*) is an introduced aquatic weed that is found in Lake Augusta. It is a secondary prohibited aquatic weed introduced from North America. It prefers warm, shallow, slow moving water and forms fast growing, dense beds which out-compete native macrophytes. Elodea is known to clog canals and intake streams to the extent where regular removal is required. It has a wide-ranging distribution throughout Tasmania. It is likely to out-compete native macrophyte species, and is also believed to provide habitat for trout and possibly *Paragalaxias julianus* and/or some species of macroinvertebrates, however this is not supported by scientific evidence.

Canadian Pondweed was observed in Lake Augusta in 1998, washed up on the windward shoreline (D. Blühdorn, Hydro Tasmania, pers. comm.). No surveys of Canadian Pondweed in Lake Augusta have been undertaken, and so the distribution and extent of the aquatic weed in Lake Augusta is not known. However, it is likely that it is not a major environmental issue at present. The primary concern regarding its presence in Lake Augusta is the risk of it spreading into the Western Lakes. This is unlikely; as to do this it would have to migrate against the flow. There is no Hydro Tasmania influence upstream of Lake Augusta, so it is unlikely to have entered Lake Augusta via a hydro structure or operation. The most likely pathway by which the weed has entered the lake is regarded to be from boats and boat trailers transferring it from other water bodies.

This issue has not been further investigated as part of the Lake Augusta study.

Riparian Vegetation

Impacts on riparian vegetation around the shoreline of Lake Augusta resulting from periodic inundation was recognised as a potential issue, however there is little information on which to base this concern.

A wide variety of alpine plant species have been described for the Lake Augusta area by Pharo (1990). The major elements of this community include shrubs and graminoids. Other elements include cushion plants, herbs, grasses and a single tree species, the pencil pine, *Athrotaxis cupressoides*. Pencil pines are thinly dispersed along the shore of the Lake Augusta lunette.

A preliminary assessment of the riparian vegetation community was made to determine if fluctuations in water level were having a detrimental impact on the condition of this vegetation (Wild, 2001).

Alterations in water levels do not appear to be currently having a direct impact on the vegetation of the shoreline. Large trees and shrubs affected by inundation of root systems tend to show this impact by reduced growth, wilting, stunted root systems, stem base swelling, premature leaf fall or yellowing of older leaves (Crawley, 1986). Although no exhaustive investigations were undertaken, a brief visual survey did not find evidence of any of these symptoms. This is not unexpected because it is probable that since the dam was built inundation tolerant species have colonised the areas of frequent inundation. Therefore the plants that are currently found there are likely to be well adapted to inundation by water.

Further evidence for the plants being well adapted is the distinct change in vegetation at the high water mark. Most of the shoreline is dominated by a low growing fen of inundation tolerant species characterised by a high number of herbs, grass-like and cushion species. This community has a relatively high cover of vegetation and species diversity. The vegetation cover provides good protection for the soil against erosive forces such as frost heave, wind and wave action.

Above the fen, shrub communities that are not as tolerant of inundation dominate. These communities have a lower vegetation cover than the fen community and lower species diversity. The vegetation provides moderate protection against soil erosion when the lower strata are intact, but it is very susceptible to disturbance such as trampling.

Shrubs on the lunettes on the eastern side of the impoundment are being degraded by mobile dune systems. Aerial photo interpretation indicates that these processes have been occurring even before the dam was built, and the cause has been investigated through the geomorphological assessment.

The vegetation of the lunettes is being inundated by sand and is also dying back from soil erosion at the root zone. Few of the existing plants are able to tolerate the mechanical disturbance of moving sand and once areas are bare additional stress from factors such as frost heave, summer drought and exposure makes seedling establishment very difficult. Any steps that may help to stabilise the dunes would be beneficial to the vegetation.

2. Formulation of Study Objectives

Seven issues relating to the management of Lake Augusta were raised or identified through environmental review and stakeholder consultation. These are:

- erosion of the lunettes on the eastern shore;
- possible impacts from remediation of the lunettes on Aboriginal cultural heritage;
- environmental conditions for threatened species;
- the quality of the trout fishery;
- public access and amenity;
- the presence of Elodea; and
- impacts on riparian vegetation.

Following the review of existing information, a number of these have been considered minor issues and were not further investigated. The most significant issues are those relating to erosion of the lunettes, aboriginal heritage and the native fish species that presently occur in the storage. Additional information was required to clarify the facts relating to these issues in order for viable management options to be developed.

The main focus of the investigation was therefore to collect more detailed geomorphological information on Lake Augusta. The objective for this assessment was to determine whether there are areas that are susceptible to erosion, whether erosion is in fact occurring, and if so, whether it is a result of the regulation of lake levels in Lake Augusta or other processes.

An assessment of Aboriginal heritage is dependent on the findings of the geomorphological assessment. It is known that there are Aboriginal sites in the area, and therefore the affected areas will need to be surveyed if any interventive management activities are proposed following the completion of the study. No further survey work was therefore undertaken.

Surveys of population status and habitat requirements/preferences for *Paragalaxias julianus* were also undertaken to enhance knowledge of factors that may influence the long-term survival of this species.

3. DATA COLLECTION AND ANALYSIS

Geomorphic Survey

Separate independent consultants (Tim Stone and Dr Wayne Stephenson) were commissioned by Hydro Tasmania to provide an assessment of geomorphological issues at Lake Augusta.

The aims of the geomorphic assessment were to:

1. use morphological interpretation to identify landforms that may be susceptible to erosion processes, and specifically related to lake level management;
2. identify other possible processes that are contributing to erosion;
3. establish the geoheritage significance of these susceptible areas; and
4. propose potential options for management of issues or additional research.

Geomorphic Background

The Central Plateau is dominated by Jurassic dolerite (Pemberton, 1986:18). This intrudes deformed Palaeozoic basement rocks and Permian-Triassic sediments of the Parmeener Supergroup. The intrusion caused uplift of the Central Plateau along northwest and northerly of the lake.

Pleistocene glacial and periglacial events have shaped the surficial geology and geomorphology of the Central Plateau (Pemberton, 1986:23). Pleistocene ice-sheets once covered the western part of the Central Plateau reaching almost to Lake Augusta. The closest recognisable glacial deposits to Lake Augusta are glacial erratics and hummocky moraine. These features are developed west of Lake Augusta. The origins of Lake Augusta itself are unclear. Banks (1973) suggested that a recent northward tilting was responsible. However, the outline of the lake suggests that it is simply a product of structural jointing in the underlying dolerite.

The Lake Augusta lunette is located on the eastern shore of the original lake (Figure 1) and is one of a small number of large sand lunettes formed around lakes on the Central Plateau. Banks (1973) attributed these features to a Mid-Holocene Arid Period claiming that the sand was derived from the deflation of glacial outwash. The Lake Augusta lunette has been described previously by Pemberton (1986) and Bradbury (1994). Pemberton (1986:25) believed that the lunette was partly morainal in origin because of its location close to the eastern extent of the Pleistocene ice cap. Bradbury (1994) argued that the lunette formed from a lakebed source during an episode of major drought. He discounted a littoral sand source during a lake full phase because this seemed insufficient to account for the volume of sand in the lunette.

The proposed Mid-Holocene Arid Period is about 7,000 to 4,000 years ago (Pharo, 1990:13). However, the only known radiocarbon age relevant to the formation of the Lake Augusta lunette is a date of c.3,700 years BP (Before Present) obtained from an ‘organic palaeosol’ beneath a lunette at Lake Fergus located 10km south of Lake Augusta (Cullen, 1995). This organic horizon is manifest regionally and underlies most other lunettes on the Central Plateau including the Lake Augusta lunette. Pharo (1990:13) refers to it as ‘coffee rock’ and ascribes it to the downward leaching of organic material and iron oxides. On the basis of the date from Lake Fergus, the Lake Augusta lunette probably is mid-Holocene in age.

Bradbury (1994) describes the Lake Augusta lunette. Its indented shoreline comprises ‘Four Bays’ open to the prevailing westerly winds (Figure 2). These shallow embayments are separated by elongate promontories with bouldery headlands overlain by sand. Behind these embayments are parabolic dunes 5 m or more in height forming the main body of the lunette. East of the lunette is a group of smaller waterbodies known as the Carter Lakes. Some of these smaller waterbodies have low-lying lunettes developed on their eastern margins. Interestingly, these low lunettes are composed predominantly of quartzose sand whereas the sand in the Lake Augusta lunette is doleritic. Bradbury suggests that the reason is differential erosion of lakebed parent material.

Survey Methods

The geomorphology of the eastern side of Lake Augusta was mapped with the aid of an enlarged (1:42,000) colour aerial photograph taken in 1997 (Plate 1). Major landforms were traced from the photo and their exact boundaries and dimensions established by close field inspection. The survey focussed on the main Lake Augusta lunette and the landforms of the Carter Lakes area.

Subsurface sediments and soils were examined in dune blowouts, deflation corridors and along the eroded foreshore of Lake Augusta. A hand auger was also used where necessary. The sediments exposed were described with reference to soil development, texture and stratification. This field evidence was used to reconstruct a geomorphic history of the Lake Augusta lunette and subsequently to assess the geoheritage significance of the lunette.

Significant areas of erosion were also noted. Enlarged black and white aerial photographs taken of the lake in 1949 were examined to determine whether lake level management since 1953 was likely to have contributed to the erosion of landforms. Two profiles were constructed across the lunette and blowout surfaces to determine whether lake level heights might be related to erosional processes. The profiles were surveyed using a Trimble 4700 Real Time Kinematic GPS Surveying System.

Plate 1: Aerial photograph of Lake Augusta (17 Jan 1997, lake level at approx. 1147.3 m)

Geomorphic Characterisation

Nine geomorphic units were visually identified on the eastern shore of Lake Augusta and around the Carter Lakes (Figure 2):

1. Sand lunette and lake shoreline ridges
2. Beach deposits
3. Rocky beach
4. Cuspate spit
5. Nearshore silt and clay
6. Low quartzose sand ridges
7. Low boulder plain
8. Deflation corridor
9. Eroded foreshore

These units and their defining characteristics are described below. Particular reference is made to any erosion observed in these units.

Sand Lunette and Lake Shoreline Ridges

The Lake Augusta lunette and associated lake shoreline ridges near the James River outfall trend roughly south-west north-east. The main body of the lunette comprises a series of coalescing parabolic dunes (Plate 1). The long axes of these dunes are roughly aligned with the dominant wind direction and strike of the rocky promontories forming the ‘Four Bays’. Individual parabolic dunes run eastward for up to 250 m and rise up to 8 m above the lake. At the northern end of the lunette behind One-Tree Beach the dune sand has advanced up the side of a low rocky hill forming a climbing dune.

The sediments of the lunette and lake shoreline ridges are fine doleritic sand. A weakly developed dune podsol appears to have developed in the main body of the lunette whereas the lake shoreline ridges further to the north are reddish at depth. These soil profiles are observable in deep blowouts caused by wind erosion and the burrowing of wombats and rabbits. The lack of significant soil profile development accords with the assumed late Holocene age of the landform.

The windward side of the lunette is particularly susceptible to erosion. Most blowouts tend to occur on this side because of exposure to prevailing westerly winds. Burrowing animals can exacerbate this wind erosion particularly on slopes with a sunny northerly aspect. Reworking of the lunette by wind is evident in dune blow-out sections. On the windward side of the lunette these show a buried Holocene soil under about a metre of recently redeposited sand. The absence of soil in this uppermost unit suggests that it may date from the European historic period but because plant growth and soil formation is slow in cold climates it is possible that this unit actually pre-dates the European period.

The leeward side of the lunette adjoining the Carter Lakes is relatively stable. The noses of individual parabolic dunes comprise single or multiple slip faces at an angle of repose close to 45 degrees. These have edged onto the floor of the Carter Lakes and in some places present active slip faces. These active faces suggest some ongoing advance of dune sand onto the floor of the Carter Lakes but in general the sheltered side of the lunette appears well held by mature alpine vegetation.

Groundwater bevelling is a process that may be operating on lake margins that can erode lake margins down to the level of the watertable. The watertable acts as a base level to which deflation and weathering adjusts to produce a flat basin floor. Evidence of erosion or sand movement that may be caused by groundwater bevelling was suggested by the presence of ‘cliffing’ at the lake margin, although this effect may also be caused by wave-cut during high water levels. Ice formation and melting may cause further collapse of cliff-face sand and result in retreat of the cliffline. Cliffline retreat results in expansion of the basin floor, the end result of which is flattening of the land surface.

At Lake Augusta, all of these processes may be causing the shoreline to retreat, although during the survey there appeared to be some evidence that groundwater bevelling was active (Plate 2). In this instance, bevelling may be caused by a perched watertable and sand movement is expressed by extensive low cliffing along the lunette shoreline. As mentioned above, these cliffs may also have resulted from wave-cut, as well as groundwater pressure and frost heaving of wet sand. This erosion begins as a sand slump approximately 1 metre across. Older collapses are partially buried at the foot of the lunette and may also be impacted by wombat burrowing. Data on the local changes in groundwater level, and their relationship to surface water level changes in Lake Augusta, are needed to confirm that this bevelling is an active processes causing these erosional features.

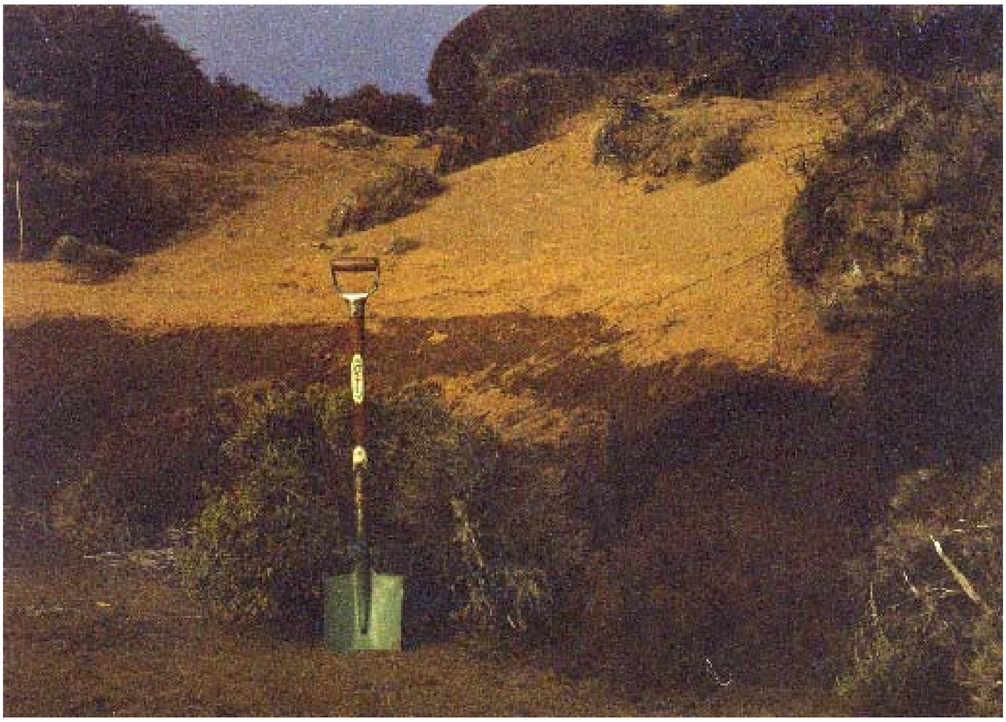

Plate 2: Fresh slump at the foot of the main lunette (to right of photo). This appears to be undermining the lunette, causing retreat of the lunette cliff line.

Beach Deposits

Beaches are an integral part of sand lunette systems because they supply sand for dune building. Beach deposits are present at Long Beach and Rocky Beach (see Figure 2 for locations) and comprise sand and gravel derived mostly from the underlying dolerite. The coarsest beach sediments have been worked by wave-action to the top of the beach forming low gravel berms. These berms are carpeted by wrackline vegetation indicating the highest levels reached by the lake. At Long Beach, a sequence of berms continues down the beach profile marking various lake levels as water rises and falls.

The processes that are undermining the base of the lunette also appear to be destabilising the beach deposits. The best example of this is a 1.5 m deep gully formed at the southern end of Long Beach (Plate 3). This gully has cut a neat 1m wide trench through Long Beach, and appears to channel groundwater flow and surface run-off through to the lake. The result is a loss of sand from the beach. This process is likely to be repeated at Rocky Beach where the watertable may be similarly exposed above a small beach deposit.

Plate 3: Gullying of beach deposits at southern end of Long Beach

Rocky Beach

Rocky beaches comprise outcrops of dolerite boulders. These protrude into the lake forming highly localised concave shorelines. In some places isolated or lightly clustered dolerite boulders stand in rows backed by beach deposits. Presumably these boulders act as a barrier to wave attack (Plate 4). The rocky beaches are favoured by pencil pines, which grow in small clumps above the high water mark.

Plate 4: Rocky Beach. Note groundwater seepage in background.

Cuspate Spit

Cuspate spits are triangular deposits of beach sand which have their apex pointing in the direction of the sea or lake from which they have emerged (Shepard, 1952). They are formed when spits or beach ridges approach each other from opposite directions owing to the action of two major wave sets or bi-directional currents. The sharp projection of a cuspate spit seaward or lakeward may be maintained by the presence of a nearby island, which protects it from direct frontal attack by destructive waves.

A good example of a cuspate spit protected by a nearby island (or, in this case, promontory) is located at the northern end of Short Beach (Plate 5). This deposit is triangular in planform and consists of doleritic beach sand and gravel. It is about 50 m wide at its base and more than 0.5 m thick. This formation may have been formed by reworking of beach sediments from One-Tree Beach and Short Beach. The cuspate spit is located at the same height as the full supply level of the modified Lake Augusta.

Plate 5: Cuspate spit looking east.

Nearshore Silt and Clay

This unit is best observed on aerial photographs. The silt and clay of the Lake Augusta near shore zone represents the lower shore face of the lunette. A comparable unit is absent from the Carter Lakes. The best surface expression of this unit is available at the northern end of One-Tree Beach. An eroded section shows yellow lacustrine silt and clay overlain by 30 cm of black organic soil and a cover of sedge.

Low Quartzose Sand Ridges

These are low lunettes formed on the downwind side of four of the Carter Lakes. The most easterly of these is the largest. It follows the outermost shoreline. The maximum height of this lunette was measured at 80 cm. At its widest it is about 40 m across. The other three low lunettes are probably no more than 60 cm high.

Unlike the main Lake Augusta lunette, these low lunettes are composed almost entirely of fine quartzose sand. Some dolerite grains can be observed but these represent only a small fraction of the total sediment population. These sediments are aeolian in origin and seem relatively unweathered. The soil profiles of the low lunettes are mostly undifferentiated and light brown in colour.

The Carter Lakes lunettes are in good condition. Wombat burrowing has disturbed the most easterly lunette but the vegetation is quickly recovering. Groundwater bevelling is a potential mechanism that may have caused the partial collapse of at least one low lunette in this area (Plate 6).

Plate 6: Partial collapse of low lunette in Carter Lakes.

Low Boulder Plain

A low boulder plain composed of dolerite dominates the eastern side of Lake Augusta and forms part of the lake floor when lake levels are raised. The Lake Augusta lunette has been built over the low boulder plain. On the lee side of the Lake Augusta lunette, the low boulder plain is well vegetated by thick alpine heath. The elongate promontories dividing the foreshore of Lake Augusta are outliers of the low boulder plain.

Deflation Corridor

Deflation corridors are erosion surfaces formed between the trailing arms of elongate parabolic dunes formed by wind (Plate 7). Three significant deflation corridors have formed in the Lake Augusta lunette and are likely to pre-date the raising of Lake Augusta. The largest is approximately 200 m long and 60 m wide. These deflation corridors are associated with the three longest parabolic dunes formed at Long Beach and Rocky Beach. Deep blowouts (depressions formed by wind erosion) behind Short Beach are also beginning to form deflation corridors as the parabolic dunes lengthen.

There is some visual evidence that the lower edges of the deflation corridor erosion surfaces are at the level of the watertable. The deflation corridors also have become small internal drainage basins redepositing sediment as fan deltas on the lake margin. Erosion of the deflation corridors through a variety of mechanisms (groundwater bevelling, sheet erosion, wave-cut, gullying, rainsplash, and wind erosion) has exposed a humicrete layer (an 'organic palaeosol') beneath the lunette and above the weathered dolerite of the underlying low boulder plain. The deflation corridors are likely to have been present prior to Hydro Tasmania development and therefore are unlikely to have been initiated as a result of raised water levels.

Plate 7: Long deflation corridor behind Rocky Beach looking west. Note watertable exposed at surface.

Eroded Foreshore

The eastern foreshore of Lake Augusta appears to be subject to erosion from factors such as groundwater seepage, surface water movements and wind. The net result appears to have been the removal of shoreface sediments and exposure of the underlying weathered dolerite.

Erosion of the Lake Augusta foreshore appears to progressively worsen in the direction of the James River outfall. At the southern end of the Lake Augusta lunette, Long Beach is in relatively good condition presenting a steep beach profile and an abundance of beach sediment. Northward, however, beach sediments gradually diminish in their extent until almost absent from Short Beach and One-Tree Beach. These last two beaches are likely to have been reworked to form the cuspate spit at the northern end of Short Beach. The timeframe over which this loss of sand has occurred is unknown, as are the processes that have been the main factors causing this to take place.

Some of the worst foreshore erosion can be seen at One-Tree Beach (Plate 8). Below the high water mark are small sand islands and pedestals of vegetation representing remnants of the original shoreline and lower shoreface. Stripping of the shoreface has also exposed the humicrete layer and underlying dolerite. The original beach has been reduced to a thin sand mantle. The extent of shoreline retreat at this location can be gauged by a lone large shrub (the One-Tree) clinging by its exposed roots to the edge of this sand mantle (Plate 9). This suggests the lunette shoreline may have retreated by at least 10m.

Plate 8: Eroded foreshore along One-Tree Beach. Beach sediments have been removed by wave action and currents exposing underlying weathered dolerite.

Plate 9: The "One Tree" on One-Tree Beach. Note shoreline retreat of about 10m.

Summary

Erosion at Lake Augusta appears to stem from six main processes. These are:

- lengthening of some parabolic dunes and maintenance of deflation corridors;
- the action of waves and currents during high lake levels;
- groundwater bevelling;
- aerial processes causing lunette blowouts;
- subaerial processes such as the action of frost and ice; and
- wombats and other burrowing animals such as rabbits.

Active management of water level in Lake Augusta has the potential to affect surface water processes for short periods of time and groundwater for longer periods. While wave action during artificially high water levels clearly has the capacity to initiate and progress erosion on the windward side of the lunette, there is also some potential that groundwater bevelling may contribute to this. It is possible that groundwater discharge associated with a perched water table in Carters Lakes may be the cause, although detailed hydrological modelling is required to confirm this hypothesis.

Post-1953 Erosion Processes

Comparison of aerial photographs taken of Lake Augusta in 1949 with present-day aerial photographs shows that construction of the dam in 1953 and subsequent lake level management did not initiate the large dune blowouts and long deflation corridors in the large sand lunette. Furthermore, analysis of the vegetation cover shown on these photos indicates that the size of these wind-eroded areas has not changed greatly in the past 50 years. This interpretation accords well with the observation that the leeward side of the lunette is relatively stable; although active slip faces in some areas suggest some ongoing advance of the dune sand.

Wind erosion may not be as significant as other processes operating on the lunette today. One reason may be that when the strongest westerly winds blow over the winter and spring months the sand is moist or waterlogged and difficult to entrain. Nonetheless, wind erosion is ongoing as indicated by the numerous blowouts of varying size on the windward side of the lunette. These blowouts appear to have been initiated by rabbits or possibly wombats. One possible trigger for the mobilisation of the long parabolic dunes was the rabbit plague of 1910. However, the formation of elongate parabolic dunes is a normal part of sand lunette construction (Lees, 1989; Lees and Cook, 1991).

Field observations made during this survey suggest that water and subaerial processes are likely to be causing erosion along the waterline. Lake level management since 1953 may have contributed to this erosion by causing levels in Lake Augusta to be increased. It is possible that such increases have resulted in destabilisation of the shoreline. Possible evidence of destabilisation by surface water is present at One-Tree Beach and Short Beach where beach sediments appear to have been stripped and reworked into a high-level cuspate spit. While the fact that the cuspate spit lies at about the full supply level supports the conclusion that this was formed following the construction of Augusta Dam, this interpretation cannot be supported by the pre-dam photo because of the poor quality of the enlargement.

Further evidence that water-related processes are resulting in erosion is the low cliffing on the windward side of the main lunette. This occurs about 3 m above the level that Lake Augusta was at during the field survey (between 1147.6 m and 1147.8 m), which coincides with full supply level (1150.6 m above seal level) as well as being at the same level as the Carter Lakes. The cliffing which occurs at this level on the lunette may therefore be caused by wave-cut during water levels associated with full supply, or by groundwater bevelling, when water from the Carter Lakes flows through the lunette and discharges above the water level in Lake Augusta following wet periods.

It has been hypothesised that the Carter Lakes are a surface exposure of the local watertable or 'groundwater window'. The low cliffing on the windward side of the lunette at the level of the watertable could be taken as evidence that groundwater discharge may be the cause. This process is more commonly observed in the playa lakes of the Murray Basin where it is known as groundwater bevelling (Bowler, 1986). The watertable acts as a base level to which deflation and weathering adjusts to produce a flat basin floor. It also causes lake basins to expand laterally. A graphical representation of this process for the Lake Augusta situation is presented in Figure 3. Groundwater bevelling of playa lakes is exacerbated by salt weathering in the zone above the watertable resulting in cliffing (Bowler, 1986). A similar effect may be caused at Lake Augusta by the action of frost and ice in the capillary fringe. This subaerial process has been described by Lawler (1989). When water in the capillary zone freezes, plant roots are attacked by needle ice causing the death of the plants and subsequent slumping of the soil. Prosser *et al,* (2000) observed that this process was most intense near areas of groundwater seepage. At Lake Augusta, the combined effect of groundwater seepage and heaving by frost and ice may be a factor causing lunette scarping.

Lake level management since 1953 may have contributed to this process. By raising lake levels, it could be assumed that the watertable and capillary fringe were also raised. Under original conditions, the watertable was likely to have been below the humicrete layer (located at 1150.9 metres above sea level). Assuming this layer is continuous and impermeable, this may have acted as a confining unit for local groundwater. Under the new water level regime, the watertable may now be perched above the humicrete layer in unstable aeolian sand. This perched watertable would be recharged by high lake level events, and when lake levels fall again the pressure of groundwater discharge and the effects of frost and ice may cause bevelling of the shoreline. Under this scenario, water levels in the Carter Lakes remain high after the levels of Lake Augusta fall because they are closed lakes maintained by local rainfall and run-off. It must be pointed out that this is a hypothesis only and that additional data on groundwater level changes in the area are needed to confirm or refine this idea.

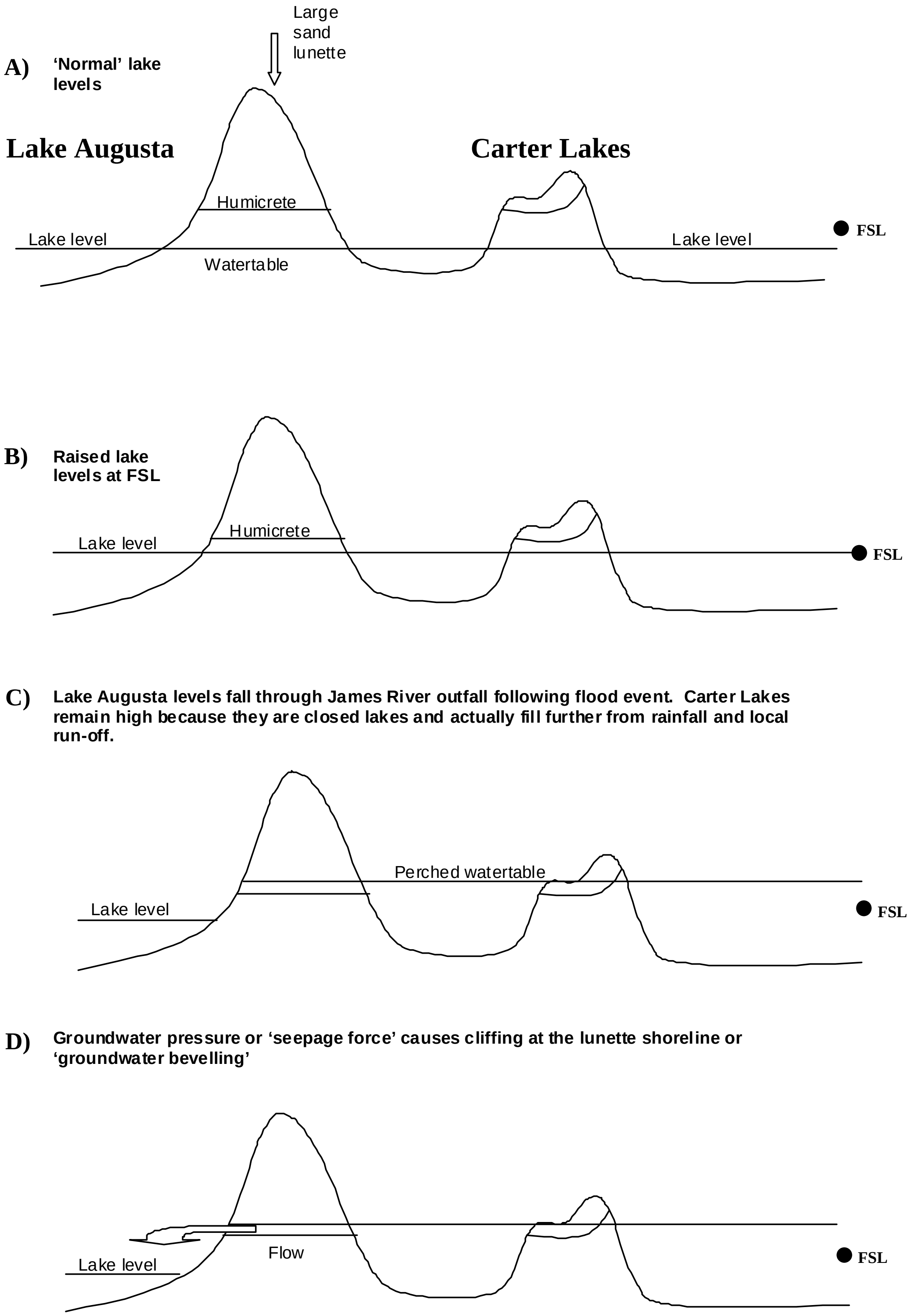

Figure 3: Possible influence of raised levels in Lake Augusta on the water table

Assessment of Geoheritage Significance

Geoheritage is recognised by the *Australian Heritage Commission Act* 1975 as any 'site', 'feature', 'geological monument', 'place' or 'area' that has 'aesthetic, historic, scientific or social significance or other special value for future generations as well as for the present community'. Criteria for assessing geoheritage significance in Australia were proposed by the Standing Committee for Geological Heritage of the Geological Society of Australia (Joyce, 1995). The term 'feature' best covers items of geological or geomorphological interest. Such features may be:

> 'an outcrop or natural section, a man-made exposure such as cutting, quarry or mine, an unconformity or fault-plane, or a landform, landscape or viewpoint. It may be a continuing geomorphological process such as coastal cliff erosion by waves' (Joyce, 1995:15).

Significant geomorphological features may be listed on the Register of the National Estate. The Australian Heritage Commission requires that the RNE ultimately contain:

1. a representative list of the places which demonstrate the main stages and processes of Australia's geological history; and
2. rare or outstanding natural phenomena, formations, features, including landscapes and seascapes (Joyce, 1995:16).

The level at which a feature is given significance may range from the local to international level. Assessment is based on the importance of the site in terms of similar sites elsewhere known to the person making the assessment (Joyce, 1995:A1.5).

Significance of Lake Augusta

Lake Augusta is likely to be significant at a regional level because it is one of only seven lakes on the Central Plateau known to have developed a sand lunette. This lunette is an example of sand lunette formation in a high alpine environment. Sand lunettes of this type are not known in any other part of the world.

Without dating of the Lake Augusta lunette and associated shoreline ridges, it is difficult to assess which particular stage of Australia's geological history these features represent. However, it is unlikely that the Lake Augusta lunette formed during a 'Mid-Holocene Arid Period' so the lunette has little palaeoclimatic significance. The possible aspect of Lake Augusta and its lunettes that may be significant is that they present an unusual example of Lees' (1989) and Lees and Cook's (1991) lake segmentation theory and its applicability to lunette formation. Furthermore, the Lake Augusta sand lunette formed over a rocky substrate rather than by shoaling which is a rare natural phenomenon not previously observed. For these reasons, Lake Augusta and its lunettes may be considered as significant, however the Lake Augusta lunette environment is not currently listed on the Register of the National Estate.

Native Fish Surveys

Population status of P. julianus

Surveys of native fish populations were conducted using backpack electrofishing equipment, sampling a variety of habitats around the margins of the natural lake and impounded areas of Lake Augusta. These surveys confirmed healthy galaxiid populations, with *Paragalaxias julianus*, *Galaxias brevipinnis* and *Galaxias truttaceus* captured in significant numbers and a range of size classes around the margins of the natural lake. Few galaxiids, however, were captured in the James River upstream of Lake Augusta during these surveys.

The surveys found that *Paragalaxias julianus*, *Galaxias brevipinnis* and *Galaxias truttaceus* were present in the Augusta impoundment and the Ouse River upstream of the impoundment, but all three species were captured in much lower numbers in these regions of the lake in comparison to the natural lake.

Habitat preference data for P. julianus

The electrofishing surveys conducted in the natural lake and impoundment provided a general indication of *P. julianus* habitat preferences. The rocky margins of the natural lake, particularly those located around its western half, appeared to be preferential habitat for *P. julianus.* Large numbers of fish were collected from in, around and from underneath the cobbles and boulders in these shoreline areas.

Macrophyte beds situated in the western half of the natural lake were also electrofished, however few paragalaxiids were observed or collected from these areas. No paragalaxiids were captured from the open sandy habitats around the lakes eastern shores.

The handful of galaxiids collected from the Augusta Impoundment also appeared to be associated with rocky marginal areas, with few fish captured from the open areas of silt that cover a significant proportion the lake bed, particularly at low water levels. The benthic habitat of the impoundment differs markedly to that of the natural lake. The majority of the rocky habitat around the impoundment consists of boulders that are imbedded into the substrate, with little interstitial refuge habitat available due to extensive siltation in the bed of the impoundment.

Formation of the Augusta Impoundment has modified the hydrology of the natural lake. When the impoundment fills, it backfloods into the natural lake, however the original lake essentially maintains its natural extent during the drier months and is elevated during spill events and high lake levels in the impoundment. The effects of the slightly modified water level regime in the natural lake on native fish populations is not clear, however large numbers of paragalaxiids were captured during the recent surveys, indicating that the existing water level regime in the natural lake is suitable for the maintenance of paragalaxiid populations. The Augusta Impoundment appears to marginal habitat due to large seasonal variations in benthic habitat availability, much of which appears sub-optimal due to heavy siltation.

Recreational Trout Fishery

Data collected by the Inland Fisheries Service from angler catch returns was collated in order to determine whether any relationship existed between lake level, angler visitation levels and catch rates, however there was insufficient data to allow meaningful analysis of this information. It should be noted that Lake Augusta and Lake Mackenzie are the only western lakes where bait fishing is permitted.

Analysis of aerial photos combined with visits to the lake have given indications that the aquatic macrophyte beds located in the western half of the natural lake may be decreasing in size. It is not clear whether the apparent decline is associated with normal inter-annual variability, or whether there is a long-term decrease in macrophyte cover within the lake. The relationship between recreational fishery productivity and macrophyte extent is also unclear.

4. ENVIRONMENTAL MANAGEMENT OPTIONS FOR LAKE AUGUSTA

Geomorphology

Through a process of visual interpretation, the geomorphic assessment identified and characterised 9 units in and around the Lake Augusta and Carter Lakes area. The assessment also identified those units that may be susceptible to erosion processes and posed some hypotheses regarding hydrologic mechanisms that may be influencing erosion. Unfortunately, the lack of detailed information on water movement meant that some of these hypotheses are unsubstantiated, and further work is required to resolve this situation. It is likely that the Lake Augusta lunettes have some geoheritage significance, at least at the regional level.

Regarding the erosion of landforms, it is likely that the artificially high lake level events cause wave-cut scarping on the windward side of the lunettes between Lake Augusta and the Carter Lakes, although there is an alternative hypothesis that this scarping has been produced by groundwater bevelling due to an artificially high watertable perched above the normally confining humicrete layer. Whether the watertable is artificially or naturally perched, it may be regularly recharged by high lake levels in Lake Augusta. Further data to resolve this situation is required.

Surface water erosion may also be responsible for changes at the northern end of the main lunette where two beaches may have been stripped and reworked by wave action into a high-level cuspate spit. This is less of an issue than the erosion occurring to the windward side of the lunette.

Another apparently significant issue may be the dune blowouts, particularly those exacerbated by rabbit and wombat burrowing. Remedial attention may be required to treat these blowouts, but this has not been identified as an issue arising from water level management.

A significant issue that was raised during the study was the mechanisms by which scarping is being caused at the base of the lunette. Further study and some monitoring is required to establish whether this is being caused by wave-cut or groundwater bevelling, as any remedial activities that are undertaken must target the cause and not the symptom.

In light of this, the following options for management might be considered:

- Establish groundwater monitoring devices to resolve the question regarding groundwater bevelling.

- Develop a foreshore protection strategy to address the issue of dimunition of sand for dune-building resulting from beach erosion. Sand replenishment, or sandbagging to reduce scarping may be worth considering, depending on the threatening process.
- Consultation with the Tasmanian Aboriginal Land Council to establish the significance of Aboriginal stone artefacts present in the dune blowouts and along the eroded foreshore, and develop appropriate measures to protect them if necessary.

Threatened Fish

Hydro Tasmania operations in Lake Augusta do not appear to be having a detrimental effect on populations of *P. julianus* in the natural impoundment, and so specific management prescriptions for the species have not been recommended. While the abundance of *P. julianus* appears relatively low in the Augusta Impoundment, initial assessments have indicated that the impoundment provides relatively poor habitat and is located on the outer extreme of the species distribution. At this stage no native fish management recommendations have been proposed for the impoundment. Hydro Tasmania will continue to support the recovery plan for the species through participation on the Tasmanian threatened galaxiid recovery team.

Recreational Fishery

Options to address recreational fishery issues include:

- Provide accurate public information on when the lake is spilling or about to spill.
- Manage maintenance activities associated with Augusta Dam so that impacts on angler access and the trout population are minimised where possible.

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