BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT

POTENTIAL EFFECTS OF CHANGES TO HYDRO POWER GENERATION

APPENDIX 5:

GORDON RIVER KARST ASSESSMENT

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June 2001

Prepared for

Hydro Tasmania

the renewable energy business

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ACKNOWLEDGEMENTS

The karst hydrology team wish to extend sincere thanks to Ben Martin and Cameron McCarthy (Water Resources, Hydro Tasmania) for all their help in installing equipment and acting as coxswains throughout the project. Ian Houshold (Department of Primary Industries Water and Environment) provided technical advice. Stephen Bresnehan (Environmental Services, Hydro Tasmania) helped source information from the archives. Dave and Rick brought in the helicopter after cold days out in the field.

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1 INTRODUCTION

This report is part of a series of studies commissioned by Hydro Tasmania to investigate the environmental implications of water management changes in the Gordon River predicted to occur if a Basslink cable were operational. It focuses on the possible implications of Basslink on the karst features in the middle Gordon River area.

1.1 Background information

Karst is a type of terrain, characterised by distinctive hydrology and landforms, which develops in rock types which readily dissolve in water. The degree of karstification depends mainly on the chemical susceptibility of the rock to solution, but the degree to which the bedrock is fractured by bedding planes, joints, or faults, and the interconnectivity of these fractures, also plays a major role. The more common karst landforms include caves, dolines, collapses, channels, springs, and solution features such as karren and runnels. Some or all of these landforms may be found in combination, or may be absent altogether.

The majority of karst is found in carbonate rocks such as limestone ($CaCO_3$) and dolomite ($Mg\text{-}Ca(CO_3)_2$) although it is also found in less widespread carbonate and sulphate substrates such as magnesite ($MgCO_3$) and gypsum ($CaSO_4.2H_2O$). Given enough time and the right conditions, karst phenomena may develop in non-carbonate rocks such as quartzites and sandstones.

Caves have been long been a focus for human activity providing shelter, places of ritual and galleries for art (Kiernan, 1995). Archaeological investigations in the caves on the nearby Franklin River, for example, have yielded some important information on their inhabitation by Aborigines. Caves and karst systems provide unique habitats for specifically adapted flora and fauna, and offer important sites for research in the fields of geology, geomorphology, zoology, botany, ecology, hydrology, archaeology and climatology. More recently caves have been used for recreation, tourism and education, and as sites of important cultural, archaeological and historical heritage.

Karst areas represent an important facet of the earth's geodiversity. Cave sediments often provide a unique record of landscape evolution, of environmental and climatic change, and of biological evolution on both the local and regional scale; particularly when analysis of the actual constituents of the sediments are combined with morphological studies. One of the unique values of cave sediments is that the subsurface environment provides protection from erosional and depositional processes occurring at the surface which can otherwise obliterate or obscure the record. Caves also support remarkably diverse faunas which, having developed in specific restricted environments, are of special significance in understanding evolutionary processes.

The karst environment is highly dynamic and is potentially very sensitive to disturbance. Its integrity depends on a complex interactive relationship between land, water and air (Watson et al., 1997). A minor change in any one of the variables can have a significant impact on the balance of the entire system. In practice, the maintenance of the characteristics of a karst system often hinges upon the retention of natural water flows and water chemistry (Kiernan, 1995).

In terms of land area, Tasmania holds a relatively large proportion of Australia's karst. Tasmanian karst is especially significant as it is relatively undisturbed, and has been found to contain locally and globally significant cave fauna, rare chemical deposits and evidence of Aboriginal exploitation. The presence of karst in the World Heritage Area (WHA) requires special consideration.

1.2 Scope

The study area is located in the middle Gordon River, between the Gordon Dam and the Franklin River tributary (Fig. 1). Within this area, karst rocks crop out along the Gordon River channel in three principle areas:

1. The Nicholl's Range karst which is identified as SW43 in the Tasmanian Karst Atlas (Kiernan, 1995). This area comprises approximately a 3 km stretch along the Gordon River, from the Denison River confluence, downstream.
2. A dolomite karst area extending for approximately 3 km on the Gordon River, just downstream of the Albert River confluence and above the Second Split. This karst had not previously been identified and is referred to here as the Gordon–Albert karst area.
3. The Gordon–Sprent karst area located between the Olga River tributary and the Franklin River tributary (Kiernan, 1995).

There is also an outcrop of dolomite present upstream of the Albert River which the team was not able to inspect, although there are no known caves or features associated with it.

The Gordon Power Station controls the majority of the flow in the Gordon River in the upper catchment area. Additional natural pick up is provided by the major tributaries in the system, which has the effect of reducing the ratio of power station discharge to natural flow in the river, with distance downstream.

The Nicholl's Range karst and the Gordon–Albert karst were given a higher priority than the Gordon–Sprent karst in this study, as they are located closer to the Gordon Power Station and are therefore considered more susceptible to the effects of station operations. The Gordon–Sprent karst is located downstream of a number of large tributaries which essentially diminish the effects of the power station flows. This area was also not specifically highlighted for investigation in the work brief, and was to be reviewed to see whether further work might be required.

The study has focussed specifically on karst which is influenced by the dynamics of the Gordon River. Any issues identified which relate to the effects of the current Gordon Power Station operations compared to pre-dam conditions are separated from Basslink issues. Cave fauna and flora are assessed in a separate report by a different study group (refer to Appendix 10 of this report series – Gordon River Cave Flora and Fauna Assessment (Doran *et al.*, 2001)).

1.3 Objectives

There were two main objectives for the study:

- Identify and assess the significance of karst landforms, cave contents and geo-hydrological processes which may be affected by Basslink.

- Investigate interactions between karst and fluvial processes, particularly with reference to river bank stability and the effects of repeated drawdowns in karst groundwater in response to stage in the Gordon River. This objective refers primarily to the role of karst groundwater in mobilising unconsolidated sediments in the river banks to cause erosion, and relates specifically to two common features found throughout the areas: backwater channels and sediment flows. These features have also been researched by the geomorphology team and are reported on in more detail in Appendix 4 of this report series – Gordon River Geomorphology Assessment (Koehnken *et al.*, 2001).

In addition, the karst hydrology team was to identify sites of interest for the cave fauna assessment team, and to liaise with the geomorphology team in trying to understand any potential links between karst hydrology and geomorphological processes.

1.4 Constraints

Twelve days of field work, amounting to approximately 45 hours work, were carried out by the authors, between the beginning of July and the end of September 2000, over six different field visits including one overnight stay in the bush. Due to the remoteness of southwest Tasmania, access to the study area was solely by helicopter, and once airlifted in, by boat along the river channel. Access was generally only possible when the power station was turned off, as the safe helicopter landing sites occur mainly in the Gordon River bed.

There were several constraints on the actual available working time in the field, and the methods by which data could be collected. These were due primarily to short working days, poor weather, complicated logistics, safety considerations and the general inaccessibility of the area. The high density of vegetation also meant that ground coverage behind the river banks was difficult and slow, and was an inefficient use of the available time. As a consequence, work was focussed mainly in the river channel, and on the caves recorded in the literature.

2 METHODOLOGY

2.1 Literature review

The remoteness of the area has essentially protected the karst areas from economic or recreational exploitation. The majority of the previous exploration work in the Gordon River and surrounding rivers was undertaken by HEC investigators, and subsequently by recreational cavers and speleologists. The latter's interest was primarily in response to HEC dam site investigations in the area and therefore certain areas have received more intensive investigation than others, particularly those parts of the river which were potentially suitable for dam sites and associated impoundments, i.e. the Gordon–Sprent area and the Nicholl's Range karst. The Gordon–Albert karst area has only recently been identified as dolomite (it is marked as undifferentiated metamorphic rocks on the recent geological maps of the area) and it has not received much attention from cavers and speleologists to date.

Several caving expeditions to the Nicholl's Range and Gordon–Sprent karst areas were conducted by the Tasmanian Caverneering club and the Sydney Speleological Society in the late 1970s and early 1980s. Middleton (1979) details the early exploration history of the area including works carried out by HEC investigators and by speleologists.

The early HEC reports from the Nicholl's Range area mention the presence of caves and sub-surface cavities in borehole logs, however, no special reference was made to other karst features. Cavers from the Tasmanian Caverneering Club visited the Lower Gordon area (which is downstream of the present study areas) in 1959 and 1961, and found a total of 8 small caves. The failure to find any spectacular or extensive caves, together with the remoteness of the location, impeded any further exploration attempts at that time. Later attempts by members of the Sydney Speleological Society in the early and middle 1970s proved more fruitful and extended the knowledge of the area. These expeditions used combinations of canoes, rafts, small aluminium boats and jet boats to access karst areas in the middle Gordon, as far upstream as the First Split. This allowed access to the Nicholl's Range karst which was first visited by speleologists in 1974. Detailed cave surveys were carried out by the speleologists for publication in the society journal and these reports have provided invaluable information with which to begin the current project.

2.2 Field investigations

Field investigations were carried out on the following dates under various power station operations:

- July 10–11 station on; 2–3 turbines; low discharge over the previous week

- July 22–23 station off; full gate flow previous day
- July 29–30 station off; full gate flow previous day
- Aug 19–21 station off on 19–20th; 6-h on-off cycle on full gate 21st (Basslink simulation)
- Sept 2–3 station off on 2nd; reduced flow on 3rd
- Sept 28 station off; extended maintenance period

The Basslink simulation continued on a 12-h on-off cycle for the following two days, during which time water level data were recorded.

While basic observation was the primary form of investigation, the following techniques were also employed.

2.2.1 Mapping

Reconnaissance geological mapping was carried out while travelling throughout the study area by boat. Dips and strikes of the bedding were taken where possible, and brief notes on the degree of karstification, and the presence of springs or seepages in the river banks were recorded. Grid references were obtained using a Garmin GPS and are all recorded with UTM Australian Map Grid 1966, Zone 55G projections. Details of non-karstic rocks were not recorded.

A slightly more thorough approach was adopted in the Gordon–Albert karst area as these rocks had not previously been mapped. In the interests of saving precious time, outcrops elsewhere were primarily just checked against maps drawn by speleologists during the late 1970s.

2.2.2 Cave and backwater channel surveying

Similar methods were used to survey the caves and the backwater channels. Hand-held magnetic compass and clinometer (Suunto brand) were used to measure azimuth and zenith angles to the nearest 0.5° between successive pre-selected stations. Distances were measured with a fibreglass tape to the nearest centimetre. The Australian Speleological Federation Karst Index (1985) Surveying Standards gives a survey conducted to this accuracy a designation of ‘Survey Grade 5’. These methods are expected to yield an accuracy of 2%. In practice, closure loops show that accuracies of approximately 0.5% (i.e. a mis-close of 0.5 m over a 100 m traverse) or better are regularly obtainable. A zero RL level was selected as an arbitrary level within the cave to which all levelling measurements could then be related.

The level of information recorded about the morphology of the cave (e.g. passage shapes, dimensions, materials, deposits etc.) is assigned a Map Grade: data for this study were collected to ‘Map Grade 4’. Passage and channel widths were estimated, but distances to the floor of the features were measured with the tape to the nearest centimetre. These surveys are therefore ascribed an accuracy of ‘Grade 54’, with the first number representing the Survey Grade, and the second, the Map Grade.

Very low gradients were measured in the backwater channels which can lead to significant errors in the overall survey. However, a check on the data was possible by noting the direction of water flows.

2.2.3 Surveying to the nearby hydrological station

A more accurate surveying technique using a WILD level head with a PENTAX tripod and staff, was utilised to correlate the cave (and the cave survey) with the nearby hydrological station (No. 2405 at site 61). This station had been installed with a slightly longer term, more sophisticated water level probe (refer to Appendix 2 of this report series – Gordon River Hydrology Assessment (Palmer *et al*, 2001)) and was also the location for one of the groundwater monitoring sites. The terrain was difficult to negotiate but nevertheless, a closure loop with an accuracy of 295 mm over approximately 1 km was obtained.

2.2.4 Water level recording

Temporary water level recorders were installed at three different sites within the Bill Neilson Cave (Section 3.1.2.1.2). Two lightweight capacitive water level type probes with 392 DATAFLOW loggers (DATAFLOW SYSTEMS Pty Ltd) with ranges of 0.5 m and 1.5 m were installed, one towards the rear of the cave to monitor the flow in the cave stream, and the other towards the middle of the cave in an effort to record the degree of flooding due to power station operations. A third, much more crude system was set up adjacent to one of the major daylight holes. Four 2 m stakes with sections of survey tape attached to them, were installed and levelled in relative to the cave survey. Water soluble paint was applied to each of the stakes and the survey tape, to gain an absolute high level water mark during the Basslink simulation, and the period immediately following it.

Water level recorders were installed using jamming techniques and string rather than bolts, with consequent minimal damage to the cave walls. In addition to the recorders installed by the team, there were a number of natural high water level markers in the cave such as scum marks and moss growth lines which proved extremely useful as data controls.

2.2.5 Water sampling

Water samples were taken where appropriate and were analysed by Analytical Services Tasmania for anions, cations and alkalinity. Sample bottles, which were supplied by the laboratory, were completely filled to exclude air bubbles and were delivered for analysis as soon as possible (within 3 days). The primary purpose of the sampling program was to identify potential karst groundwater signatures in the water.

2.2.6 Aerial photography analysis

Two sets of aerial photographs, dated 1974 and 1999, were viewed for surface evidence of karstification in the Nicholl's Range karst. The smaller scale, black and white prints from the earlier set showed some evidence of sinking streams and enclosed depressions along the line of the distinct change in slope at the eastern geological boundary. The thicker vegetation present in the area today obscured these features from view on the recent photos.

2.2.7 Erosion pins

Two erosion pins were positioned in the sediments in Kayak Kavern and Bill Neilson cave to provide a preliminary estimate of whether erosion or deposition of the cave sediments is occurring. The pins are 0.5 cm diameter steel rods which are approximately 1 m in length. They were inserted into the sediments leaving approximately half to one third of the rod exposed. The tops of the rods have been taped for easy identification. Measurements are taken by observers from the tops of the rods to the surface of the sediments using whatever measuring tool is available. In most instances, the cave surveying fibreglass tape was used with an accuracy of up to 0.5 cm.

3 CURRENT CONDITIONS

This section describes the current status of the karst systems in each of the three areas in turn. The sub-headings are structured to include:

- A brief description of the geology of the area.
- A summary of the degree of karstification with reference to the first main objective.
- Discussion on the karst hydrology in light of the second main objective which focuses mainly on the role of karst in unconsolidated deposit instability. This topic is most fully described, with the conclusions drawn, in the section on the Gordon–Albert karst as this area has the highest density of the specific features under investigation. (It would appear that the alluvium in this area is largely controlled by the presence of the underlying carbonate rocks.) Evidence from the other two

study areas, which is in support of the conclusions, is also summarised in this section for the sake of continuity. Some cross referencing between the relevant sections under each of the study area headings is therefore unavoidable. This section also has a distinct overlap with the geomorphology work and further information can be found in their report (Koehnken *et al.*, 2001).
- A brief description of karst landforms which may be influenced by the dynamics of the Gordon River.

An additional section is added, where appropriate, to highlight any other interesting features identified which are not specifically related to the Basslink issue.

3.1 Nicholl's Range karst

3.1.1 Geology

The Nicholl's Range karst is located in a north-south trending band of limestone which occupies the relatively small low lying area, to the west of the Nicholl's Range. The rocks comprise a series of light to dark grey limestones, which are interbedded to the west of the area with non-calcareous and calcareous, dark, fine grained argillite. At the eastern extremity of the low lying area, an outcrop of what may be weathered dolomite is exposed in the river channel at the mouth of the Denison River. Outcrop is limited in the main, to the right hand bank of the river. Borehole records from a drilling program carried out by the HEC in the 1970s show that the low-lying area on the left hand bank at Grid ref 403250, 5271000 is underlain by up to 20 m of gravel, sand and silt which is now partially cemented. Roberts and Naqvi (1978) report that the drainage is relatively poor in this area which suggests that the cementation may be reasonably extensive. Borehole logs also show that the rocks in the topographically higher area to the west is comprised of sandstones and siltstones. While the published geology maps show a simplistic structural interpretation of the general area, the HEC borehole logs give reasonable control in the immediate study area. A report by Middleton (1982) also shows preliminary geological boundaries for the karst area.

Field investigations in this area were focused mainly in the river channel. The bedding strikes approximately north-south, with vertical to subvertical dips. The rocks are part of the Gordon Group, which is the most extensive carbonate sequence in Tasmania and contains some of the State's most important and well known karst, e.g. Mole Creek Karst National Park, the Mt. Cripps karst, the Junee-Florentine Valley karst and Ida Bay karst. The rocks were subjected to folding and faulting during a deformation event in mid-Devonian times (the Tabberabberan Orogeny) which has greatly facilitated the degree of karstification. It is reported that the limestone unit has been faulted into contact on all sides (Roberts and Naqvi, 1978) which would suggest that the rock has been subjected to major stresses and strains. Joints and cracks formed under these stresses provide the initial openings for water movement, allowing the dissolution process to begin.

3.1.2 Karstification

Conditions for karstification in the Nicholl's range area are highly favourable with its high rainfall, dense vegetation cover and organic soils which ensure that percolating waters are relatively acidic with good capacity for dissolving carbonate. The karst features in the area include a number of caves, karst springs, limestone cliffs and solutional features such as notches, karren and scallops. Several previously unknown caves of variable sizes were found on high ground above the limestone cliffs but as these were dry and were located high above the zone of fluctuation of the Gordon River (approximately 8–12 m above low water level), they were not further pursued.

The majority of the karstification is seen to the east of the low-lying area where the limestones are significantly purer. Mud particles in shales and shaly limestones, such as those identified in the borehole logs, tend to prevent extensive karstification occurring by clogging potentially developing conduits.

The primary issues for consideration for the study were:

- how far back into the caves at river level the Gordon River water reaches;
- whether there are karst features present within this zone of inundation, or within any additional zone, if any, which may be created by Basslink operations; and
- what the vulnerability and significance of any affected karst features might be.

The two biggest river level caves identified from the literature, Bill Neilson Cave (NR1) and Kayak Kavern (NR2), were the main focus of the field investigations.

3.1.2.1 Bill Neilson Cave

The biggest known cave in the area, the Bill Neilson cave, is approximately 500 m in length and has developed in a north-south direction parallel to the strike of the beds, along what also appears to be a fault plane. The entrance chamber adjacent to the Gordon River is approximately 8 m high by 5 m wide, and the passageway remains big enough to comfortably walk through to the end of the cave (Fig. 2a). Smaller, higher level passages are present in places, one of which was investigated. There are several large daylight holes in the roof which have facilitated limited vegetation encroachment into the passageways directly underneath.

3.1.2.1.1 Cave survey

The cave was surveyed to the end of the main passage using the methods described above (Fig. 2a,b). Approximately 175 m from the Gordon river, the passageway bends sharply to the right, and folds back on itself before continuing onwards for a further 200 m. A relatively large cave stream (Section 3.1.2.1.4) flows along the full length of the passageway, and is fed by at least two small tributaries in the vicinity of the major bend. The average gradient of the cave floor is very low (<0.015), although there are some short steeper sections in places. An arbitrary reference level (0 m RL) was selected at the base of a protruding section of rock, 1.41 m above the cave floor on the west wall close to the entrance. All height and inundation measurements are relative to this point.

Calcite formations are not common in the cave. Of particular note are: (a) a large stalactite located approximately 200 m from the entrance which is the same formation recorded by Middleton (1977); and (b) a large number of smaller straws in the upper level passage.

3.1.2.1.2 Inundation levels

The evidence for the limits of inundation in the cave by the Gordon River is shown in Fig. 2b and is summarised as follows:

- The water level recorder, which was installed approximately 135 m into the cave with its base at 0.78 m RL, did not register any flow between 20/8/00 and 2/9/00, despite the power station operating on full gate several times during the period.
- The soluble paint on the 4 wooden stakes showed a maximum water level of approximately 0.82 m RL between 19/8/00 and 2/9/00.
- Several ‘scum’ lines were found on the cave walls and on a fallen log at various distances from the entrance which appear to record the high water marks during previous high level events (Plate 1; Fig. 2b). They include:

Location	**Date**	**Level**
Log at entrance	2/9/00	0.73 m RL
Log at Station 6	19/8/00	0.71 m RL
East wall at station 11	19/8/00	0.81 m RL
East wall at station 15	19/8/00	0.76 m RL

- Three additional scum lines were also present on the wall of the cave at station 13. The upper line was obviously much drier and presumably older than the others and was located at a level of approximately 2.1 m RL. The freshest line visible on 19/08/00 was situated at 0.76 RL.

- The log at the entrance to the cave is covered in moss down to a distinctive 'limit of growth' level at approximately 0.78–0.83 m RL.
- There are steep banks of fine silt present at the major bend 175 m from the entrance which have been very dry for some time. The base of the sediment bank is decimeters above the cave floor.
- Glow worm colonies were found in the roof of the cave, directly above the stream, at distances of 30–50, 90, 220 and 300 m from the entrance. The colony at 90 m is located at approximately 5 m RL, and the one at 220 m is in the region of 5.5 m RL. This suggests that inundation levels do not reach higher than 5 m RL at present. (Refer to Section 3.1.2.1.8 for discussion and comparison with the old survey).
- All speleothems in the cave are located above approximately 6–7 m RL. They appear to be relatively old, are no longer actively growing and show no signs of any inundation, suggesting that water levels have not reached that height for some considerable time.

The data suggest that the maximum inundation level reached in the cave during the investigation period was no more than approximately 0.76 m RL[1], or as far back into the cave as station 16 (~180 m). The power station operated at full gate for part of this period and there was little rainfall. It is not known how long the scum line at 2.1 m RL has been in place but it is likely that it represents full gate station discharge coincident with high rainfall conditions with a reasonable contribution from the River Denison.

3.1.2.1.3 River level fluctuations

The cave survey data have been levelled in to the hydrography station (No. 2405) at Site 61 approximately 1 km upstream of the cave, in order to try and relate the river fluctuations to inundation levels. The river water levels were also levelled in at both sites on the day of the survey (20/8/00), and were recorded on two other occasions at the cave to provide extra control. While the river fluctuation data from Site 61 (Fig. 2c) are not directly comparable with fluctuations at the cave due to differences in the river profile, the hydrography station data can be used to give an indication of the effects of the power station flow this far down in the system.

Using the water level data at the cave and at Site 61, the inundation observations, the cave survey, and the levelling in data between the cave and the hydrography station, it is estimated that the 0 m RL level in the cave is equal to approximately 2.18 m (±0.11 m) on the gauge board at Site 61 (Fig. 2c). From the available data for Site 61 between 6/3/00 and 23/9/00, it is clear that the river levels reached during the fieldwork period were not particularly high. The average water levels in April 2000 for instance were at least 0.2 m higher, with a peak of +1.65 m occurring during an extended period of full gate discharge in conjunction with moderate rainfall (72 mm of rain at Strathgordon in the previous week). If similar rates of fluctuation were assumed at the cave, this peak would be equivalent to 2.4 m RL. The extent of this fluctuation suggests that the 2.1 m RL scum level in the cave could have been emplaced sometime in the preceding few months representing inundation to station 23 or approximately 270 m back into the cave. Further monitoring inside the cave is necessary to correctly ascertain the inundation levels.

The hydrology data also suggest that rainfall events have a significant effect on the river levels, presumably due to the relatively large catchment area contributing to the River Denison and the additional Orange and Albert River flows. The rainfall events between 14/4/00 and 23/4/00, and between 29/4/00 and 4/5/00 for example (Fig. 2c), are reflected in the river level data as 0.9 m and 0.8 m increases respectively, despite the power station's output being reasonably consistent. Rainfall in the few days leading up to the 10/8/00 ensured that river levels at Site 61 on that day were similar to the levels on 30/8/00 and 31/8/00, although the power station was output was considerably higher during the latter.

[1] The variability in the recorded levels is due to the inherent errors in measurements of this accuracy level.

3.1.2.1.4 Cave stream flow

The water level recorder to the rear of the cave measured stream flow levels every 10 minutes from 29/07/00 to 2/09/00 (Fig. 3). During this period, three marked events were recorded which can be related to relatively major rainfall events. Two stream gaugings carried out at moderate to low levels returned flows of 0.04 and 0.086 cumecs. The hydrograph shows the stream has a very flashy regime, with steep sided, short duration peak flows.

While the stream flows may reach relatively high peaks at times (e.g. 0.4 cumecs estimated on 30/7/00) they are unlikely to last for any significant length of time after a rainfall event as the catchment area is so small. This is confirmed by the water chemistry results which show low concentrations of dissolved minerals suggesting short residence times (Section 3.1.2.1.6). It is not expected that the cave stream flow has a significant effect on flood water levels in the cave created by the Gordon River.

3.1.2.1.5 Cave sediments

Cave sediments are found throughout the cave and are of varied composition including poorly sorted pebble to cobble gravels, fine sands and silts. They can be subdivided into wet sediments and dry sediments.

The wet sediments are variable in composition. The cave floor, where visible, consists of bars of gravel, cobbles and boulders in a coarse sandy matrix. Sediments reaching up to approximately 0.5 m from the base of the cave floor in the entrance chamber, consist of poorly to moderately well sorted pebble to cobble gravel, with rounded and angular clasts in a silt/clay matrix, which grades upwards to fine gravel. The coarse sediments are then overlain by fine sands and silts which vary in thickness and are seen directly overlying bedrock in places. The fine sediments are present in banks, and in thin coatings on the bedrock walls of the cave. A section through a sediment bank in the entrance chamber exposed thin sandy partings laid down parallel to the surface, in the upper few centimetres of the deposit. A high level water mark appears at a height of approximately 2.2 m above the cave floor, above which the sediments are somewhat drier and more weathered than those lower down.

A distinct wash line (between 0.5 and 1 m above the cave floor, depending on the width of the cave) separates the coarse sediments from the overlying fine sediments, and where there are none present, it is reflected on the bedrock surface. Below this line, the sediments (or bedrock) are well washed, and it would appear that it marks the limit of the active cave stream zone. Scour by the cave stream is likely to be the dominant sediment transport process. This theory is supported close to the cave entrance, where a tree trunk has breached part of the channel floor, and sediment has accumulated on its lee side (Plate 2). Between this line and the high water level mark there is evidence of deposition, erosion, slumping and collapse taking place and it is considered that this zone is dominated by processes related to the Gordon flood water. The following evidence was found in the main entrance chamber:

- Small, parallel vertical grooves known as ‘rills’ are present in the sediments close to the cave entrance where the banks are relatively steep. These are common features in silt and clay banks steeper than 40º where frequent flooding and draining occurs (Bogli, 1961).
- Small, delicate, fine sediment depositional structures can be seen accumulating beneath the overhanging rock features on the cave walls.
- Small fresh green leaves and other flood debris were found incorporated in the fine sediments on the cave walls on 2/9/00.
- Sediment collapse has occurred in the left bank of the major entrance chamber (Plate 3).
- Sediment cracking is evident on the right bank (Plate 4).

Based on the water level recorder information, the cave survey, and the natural water level indicators observed throughout the cave, it appears that the wet sediment banks described above are inundated with Gordon River water on a regular basis, during normal power station operations. While the power station is on and the river water is ponded in the cave, it is probable that fine sediment falls out of suspension onto the cave walls. When the station is turned off and the river water recedes out of the cave, the saturated sediment may be destabilising causing the slumping and collapse as the inundation flood waters are drawn down. The sediment cracking may be due to desiccation of the sediments once the flood waters have receded. When water levels have dropped sufficiently, the scouring action of the cave stream becomes the predominant process and any fines deposited close to the cave floor are washed away.

There is a possibility that the particles which are deposited are reworked materials from the existing sediment banks, and that no additional sediment is being introduced into the system. However, an overall net accumulation of sediment is thought to be more likely, from particles entering the system through the numerous daylight holes, and possibly also from the Gordon River through the cave entrance. Comparison with the 1976 pre-dam cave survey supports this view although caution must be exercised in directly comparing the surveys (Section 3.1.2.1.8).

An erosion pin was installed in the wet sediments, approximately 30 m from the cave entrance, above the active stream level, to further assess sediment movement in the cave during the period of investigation. The height of the pin above the sediment was 0.480 m at the time of installation on 20/8/00, and again on 24/9/00 when checked by the cave fauna team. The pin is still located in the cave and if it is to be useful in the longer term additional pins should be installed for better statistical analysis and to reduce the risk of interference in the results due to damage to the pin by moving debris etc.

The dry sediments can be divided into two different groups. The first group are silts located on the walls of the cave above the high water level mark. They are particularly evident in the entrance chamber where they have weathered to a white colour. The weathering and the moisture content of the deposits suggest that they are not part of the same inundation regime as the wet sediments. The second group are located in a steep bank which reaches the upper level passage at the large bend, approximately 175 m into the cave. The base of the bank is just above the active stream level and the sediments are composed of very dry, fine, powdery silts. A jaw bone, presumed to be that of a wallaby[2], was found in the deposits in the upper level passageway, along with a small speleothem currently forming from a drip in the ceiling onto the sediment base. The dryness of these sediments suggests that they are outside the present zone of influence of the Gordon River.

3.1.2.1.6 Water chemistry

Three water samples (Attachment 1) were taken from the cave. Two samples were from the same location at the entrance to the cave, the first on 11/06/00 when the power station was on (Lois's sample), and the second on 30/7/00 during a period of heavy rain when the power station was off (sample no. KW005). The third sample was water from an intermittent tributary to the main cave stream in the vicinity of the bend (sample no. KW006), which was also taken on 30/7/00.

Comparison of the two cave entrance water samples show that there were much fewer dissolved minerals present following the heavy rain. This suggests that the cave stream has a rapid response time to rainfall with little time for reactions with the carbonate rock minerals to occur. The intermittent tributary had higher calcium levels of 22 mg/l suggesting a slightly longer residence time in the carbonate environment. These values, however, are all relatively low for a carbonate source.

3.1.2.1.7 Conclusion

Taking all the available evidence into consideration, the extent of the flooding in the cave under full gate power station flow and low rainfall conditions, is not more than approximately 0.76 RL at Station 16, or 180 m from the entrance, just before the major bend. High flows in the Denison River are likely to increase this distance somewhat, although the extent of the increase is not known. There is evidence

[2] The jaw bone will be further discussed in the cave fauna assessment report (Appendix 10).

for an older, high flow level of 2.10 m RL, which corresponds to a distance of approximately 270 m into the cave, as far back as Station 23.

The only features located within this zone of fluctuation are the cave sediments, which are regularly inundated by Gordon River flow. There appears to be deposition of fine sediments occurring with the inundating waters, although scouring at lower levels in the cave associated with the cave stream is maintaining a sediment balance. A recently installed erosion pin may provide quantitative evidence in the future although it would need to be supported by additional erosion pin information. With the exception of the sediments, it is considered that the cave is relatively robust at the present time as all speleothems and glow worm colonies are located high above the estimated maximum inundation levels.

3.1.2.1.8 Pre-dam conditions

Comparison with the pre-dam cave survey from 1976 suggests that there may have been some small changes in the caves since the Gordon dam came into operation. Fig. 4 shows an enlarged version of the critical part of the cave. The 1976 survey was conducted to CRG Grade 5C, while the present survey is to ASF Grade 54. These two survey grades are equivalent and thus the two surveys are in theory directly comparable. However, as with any cave survey there may be some differences in the surveyors' styles and interpretations. Nevertheless, the surveys indicate the following:

- In the first 50–60 m of cave passage, the 1976 survey shows that the streamside and streambed were both composed of river gravels. The 2000 survey however, shows that while the streambed is still river gravel, the streamside is composed of fine sediment banks. These sediment banks are quite thick (~30–40 cm) and there is evidence of layering parallel to the surface. This suggests that long term deposition may be occurring.
- The massive formation in the streamway approximately 200 m from the entrance of the cave, which was photographed in 1976 (Middleton, 1977), appears unchanged in July/August 2000.
- The two glow worms colonies mentioned in the 1976 survey are still present in 2000, and a third colony closer to the cave entrance has now been found (The colonies are further described in Doran *et al.*, 2001). It is likely that the Gordon Dam has reduced the exceptionally high flood peaks, which means that flooding of riverside caves is now less extreme. Perhaps this has allowed the glow-worms to colonise areas of the ceiling that in the past have been too flood prone to provide a suitable habitat.
- The 1976 survey mentioned that there was a fern growing close to the stream just inside the entrance which is now no longer there.

3.1.2.2 Kayak Kavern

Kayak Kavern is a much smaller cave located immediately upstream of Bill Neilson cave, also on the right bank of the river. It is essentially a major undercut in the carbonate cliff, which has been partially closed off to the front by a large block of limestone that has slipped into position (Fig. 5).

The cave is approximately 25 m long and has a silt floor which dips steeply down to the Gordon River level when the power station is off. No speleothems of any sort were observed. Distinctive shallow channels approximately 1 m in width were evident on top of the sediment bank on 2/9/00, where water had been moving on the surface. In addition, our footprints from the previous trips had been washed away.

Comparison with the 1976 survey shows a significant difference in the size and orientation of the sediment bank at the entrance to the cave (Fig. 5). It should be noted however, that as the previous survey is equivalent to ASF Grade 2, and the recent survey is ASF Grade 54, they are not comparable in a quantifiable way. Nevertheless there are some differences between the two that suggest that there have been some changes since the power station came into operation. Some of these apparent changes could be due to the different river levels at the times the surveys were done, so some caution is required.

Currently the silt bank extends at least 21 m from the 'constriction' at the eastern side of the cave, whereas in 1976 the silt was estimated to extend to around 16 m, leaving an obvious 'bay' at the shoreline in the cave (Fig. 5). In addition, in 1976 the silt mound supported a growth of ferns, but today there is no vegetation at all within the cave. One hypothesis is that these changes are due to a greater total inundation time due to the presence of the dam, hence making the silt mound no longer a viable flora habitat. Alternatively, this may be due to additional vegetation growth at the cave entrance restricting light penetration into the cave. The more regular flooding may have resulted in increased amounts of silt deposition in the comparatively still water of the cave 'bay'. An erosion pin was installed on 2/9/00 with a height of 0.325 m exposed, to try to quantify any rates of change. A height of 0.330 m was estimated by the cave fauna team on 24/9/00, although it is still too early for conclusive results. Additional pins would be useful if longer term data are required.

All the available evidence, including comparative levels in Bill Neilson cave, suggests that Gordon River water inundates the cave on a regular basis under current power station operations and that significant sediment deposition is occurring.

3.1.2.3 Other caves

Fieldwork for this project focussed on assessing the caves known in the area from the literature. There are nine caves recorded in the Nicholl's Range area (Australian Speleological Federation, 1985). The two caves described above are NR1 and NR2 respectively. NR3 and 4 are small caves on the banks of the river, one of which is impenetrable, while the other is associated with a cave stream, is not decorated and is not thought to be vulnerable. NR6–8 are extensions of the Bill Neilson cave system and are located 660 m north of the Gordon River along the same stream system. Due to the relatively shallow gradient of the stream, the low-lying topography in the area, and the limited extent of inundation of the river along the stream in the Bill Neilson cave, it is considered unlikely that the caves as far back as 660 m would be affected by the power station river fluctuations.

NR5 is located approximately 275 m from the river and is described as a dry cave although there was a 'pool' of water in a canyon 7 m below the main cave floor during the survey in 1981 (Middleton, 1982). It is not known whether there is a direct hydrological connection between this pooled water and the river, such that it might be affected by fluctuations in the river level. However, as the cave is poorly decorated, and the area which is recorded as being important for archaeology is approximately 7 m above the water table, it is considered unlikely that it would be affected by fluctuations due to the power station. The last cave, NR9, is 50 m long and is located further upstream on the right bank, a few hundred metres back from the river. This cave was not visited but it is recorded as being poorly decorated, and as it is a wet environment with an active cave stream at an extended distance from the river, it is considered unlikely that it would be significantly affected by Basslink fluctuations.

Further investigation for new caves was relatively brief. Several previously unrecorded holes and a small cave were found on the right bank, on top of the limestone cliff upstream of Bill Neilson cave. These are however, located approximately 8–12 m above the low river level and almost all were dry during the investigation. One small vertical cave had water flowing at the bottom of it approximately 4–5 m below the entrance but was too small to further investigate. There was no decoration visible from the entrance. These features were not considered further as they are considered to be located above the zone of fluctuation of the river under power station operations.

3.1.3 Karst hydrology and bank stability

The catchment area to the Nicholl's Range karst is relatively small at approximately 2 km^2. Recharge occurs diffusely where rain falls within the carbonate rock area (autogenic), and also as point recharge where streams running off the adjacent lower permeability hills sink when they reach the carbonate rock boundary (allogenic). While these sites were not visited, they were identifiable on the aerial photographs.

Solution in the limestones is well developed and it is probable that the large majority of the groundwater in the area is transported to a discharge point in the Gordon River via concentrated conduits in the rock. A simple water balance for the catchment area suggests that the large cave stream in the Bill Neilson cave is the primary drainage outlet for groundwater in the area.

Some isolated sediment flows were identified in this general area by the geomorphologists, the largest of which was further investigated to determine whether there was a karst groundwater influence on its development. (This topic is more fully discussed in Section 3.2.3.3 below). Brief investigation inland of the feature highlighted an absence of any bedrock. There are backwater channels present however, in the same form as seen elsewhere with a sandy base, steep sides comprising the vegetation and soil layer, small surface water flow divides, and a network of channels which eventually join to flow towards the river. The channel eventually cut the river bank approximately 5 m downstream of the sediment flow feature, and was of the order of 5 m above the water level on 2/9/00 which was a few metres higher than the sediment flow. Based on the available evidence, which is further discussed in Section 3.2.3, it is proposed that the sediment flows are not specifically related to karst or the channels, and that the latter are surface water runoff features.

3.1.4 Surface landforms

From the limited investigations on the surface in this area, it would appear that the primary karst landforms of note are the few small dolines which were found in the vicinity of the cave, and the limestone cliffs in the river channel. As the dolines are higher than the zone affected by the river they were not considered further. The limestone cliffs reach a height of 15–20 m and are present on the right bank on the outside bend of the river. They are approximately 500 m in length and are undercut in places within the active river zone, e.g. at Kayak Kavern. A rock platform of 1–2 m in width is visible towards the upstream end of the outcrop. On 11/7/00, while the power station was operating at 1–2 turbine discharge levels, the platform was approximately 1 m above the level of the water. Well developed scallops are also common on the cliff face, at heights above and below the high water level mark.

The scallops, undercuts and rock platform are all solution features which are formed by the chemically erosive nature of the river over long periods of time. While these processes are almost certainly active today, the height of the scallops above the current water levels suggests that either larger volumes of water have been present in the past, or that the river is incising the rock. This is a natural process and it is unlikely that these features are susceptible to effects of power station operations.

3.1.5 Other interests

While it is not of specific relevance to the Basslink issue, some leaf litter was found on the ceiling of Bill Neilson Cave, over 150 m from the entrance and approximately 6–8 m above the present stream level, which suggests that the cave has experienced episodes of flooding at some point in time to that height. Dating of this material by high precision radiocarbon techniques may provide information about very high level floods, perhaps from before the Gordon River was regulated. This information may be of interest in further understanding the hydrology of the system.

A piece of saturated wood was found approximately 50 m from the entrance of Bill Neilson Cave, in situ, at the junction between the gravel and the silts. Dating a sample of the wood may provide an approximate age of emplacement of the sediments which may help to understand the sediment transfer processes occurring in the cave. However, the wood is expected to be relatively recent, and as it is saturated and located in the active cave stream zone, it may not be a particularly good sample.

The large dry sediment bank in the Bill Neilson cave that reaches the upper level passage has not been disturbed for some considerable time. Further examination of these sediments may find some material which could be used to date the deposits. This would provide useful information for reconstructing the palaeoenvironment of the area.

From the number of previously undescribed holes above the limestone cliffs found with an hour or two of exploration, it is anticipated that there might be potential for further inland discoveries in this area. These are unlikely to be of consequence to this study but will be of interest to speleologists.

3.2 Gordon–Albert karst

3.2.1 Geology

The geology of the Gordon–Albert karst area is not well understood, due in part to the remoteness of the area and also to the lack of outcrop exposure. The area is mapped on the regional geology maps as Precambrian metamorphic quartzites and schists, and was only recently confirmed to include carbonate rocks during the initial geomorphological investigations for the Basslink impact assessment.

The majority of dolomite in Tasmania is of Cambrian age (Brown, 1989) and is known to contain significant karst landforms, for example at Mt. Anne where some of the deepest vertical caves in Australia are found. There are also localised and relatively small outcrops of Precambrian dolomite found in various locations in the western part of Tasmania (Turner, 1989), but karst is known at only a few of these localities. The age of the rocks in the Gordon–Albert karst area is not known.

Field investigations have shown that the area is characterised by a sequence of organosols and vegetation, overlying grey-white sands and silts or orange sand and gravels, which are overlying the dolomite. In some instances the soil and vegetation layer overlies the dolomite directly. In the downstream part of the reach, the rock was overlain by a weakly lithified sequence of fluvial deposits (sand and pebble gravel) which were not mapped in detail (e.g. Grid ref 409772, 5266327). The dolomite primarily outcrops around the major bend in the river, immediately downstream of the Albert River confluence (Map 2). A relatively thin band of dolomite was also found further downstream (Grid ref 408745, 5266830) between non-carbonate rocks although the contacts were not observed.

The full extent of the dolomite is not known as investigations were limited to the river channel and the immediate surrounding area. Experience from the other dolomite areas north of the site in the Maxwell River Valley (SW35, SW36 and SW37 in Kiernan, 1995) has shown that these relatively soluble rocks usually occupy the lowlying plains between hills of more resistant quartzites and schists. Small residual towers are common in the plains where a capping of more siliceous rock has resisted weathering processes. The study area is directly south of this valley along the regional strike, and with the continuous low lying topography between them, and the relative absence of surface streams shown on the 1:100,000 map, it is possible that the dolomite may extend further northwards towards the Maxwell river.

3.2.2 Karstification

Field observations were carried out in the Gordon River channel with additional limited inland investigation. Significantly more time was spent searching in this area as it had not previously been described. The following evidence for karstification was found:

- The general topographic expression of the dolomite as a broad valley of relatively subdued relief.
- The presence of scallops, notches and small pinnacles.
- Some well developed solution features, reaching up to 0.5 m in diameter and extending back into the rock up to, and perhaps greater than, 1.5 m in places.
- Solution features which are filled with loose sediment (Grid ref 410331, 5266753; Plate 5).

- A number of dolines inland, the largest of which reaches 15 m in diameter and is 4–5 m deep (Map 2).
- A number of small springs discharging from the dolomite, both at river level and inland.
- Three stalactites, the largest of which is approximately 20 cm long and 5 cm wide at the base, preserved in a distinctive air pocket at the high water level mark in the river channel.
- A small hole which we have named Middle Landing Hole and assigned the proposed code GA-X1.

None of the karst features, including the small cave, is big enough to enter, however, the dolines, the springs and the degree of solution observed suggest that significant karstification has taken place in this area. The most extensive solution features were noted in the easterly corner of the bend in the river.

The dolomite dissolution processes are likely to be still active, but as they occur on the scale of geological time, they are not particularly relevant in discussing the potential effects of the Gordon Power Station. No significant karst formations were found, with the exception of the three stalactites which are naturally preserved in an air pocket.

3.2.3 Karst hydrology and bank stability

The effects of karst hydrology on the bank stability as stated in the objectives (Section 1.3), refers in this study, to the role of karst groundwater in mobilising unconsolidated sediments in the river banks with the effect of bank erosion, a subject which is also being researched by the geomorphology team. There are two separate elements in the system which required investigation: (a) backwater channels (Plate 6); and (b) sediment flows (Plate 7) at or below the high water level mark. Further discussion of these features can also be found in the geomorphology report (Koehnken *et al*, 2001).

3.2.3.1 Issues

The following issues were considered pertinent to these investigations:

- Whether the backwater channels are in themselves a karst feature, or whether there is a correlation between the location and structure of the channels and any karst features which may contribute to their development such as springs, dolines, solution features, etc.
- Whether karst groundwater is implicated in the development of the sediment flows, and hence the bank erosion, and whether it is the source of water for the sediment transfer.
- Whether there is a relationship between the backwater channels and the sediment flows.

These issues were also investigated in the broader sense by the geomorphology team and further discussion may be found in their report.

3.2.3.2 Backwater channels

The backwater channels were found to occur throughout the three karst areas although none were found to have karst bedrock in the floors or walls, or in the immediate vicinity. They run perpendicular, parallel and obliquely to the main river channel. Some channels contained water during the investigations while others did not. Some channels are of the order of a metre or two wide, while some are much larger, perhaps 5–10 m wide, reaching depths of up to 4 m. Some are devoid of vegetation in the channel base, some contain small plants in a muddy substrate, and some contain abundant leaf and twig litter. Most are of a relatively shallow gradient, although some in the lower regions of the Gordon River were found to have vertical drops of up to 1 m in places where two channels came together (see Section 3.3.3). Two channels in this area were selected for further investigation and a third, which is discussed in Section 3.2.3.3, was observed adjacent to a sediment flow.

3.2.3.2.1 Channel network 'Ben'

The first is a large channel in the middle of the bend downstream of the Albert confluence (Grid ref 410260, 5266510; Fig 6). The channel varies in width from 3 to 10 m and reaches a maximum depth of approximately 4 m (Plate 6). The survey of the channel showed that it winds away from the river with an average slope of 0.026, to reach a height of 5 m above the level of water in the river on the 19th Aug 2000[3]. It must be noted however, that with such a low gradient, this preliminary survey method using the tape and clinometer can incur relatively large errors: the error for this survey at this site is estimated as ±1%.

In contrast to the tannin stained Gordon River water, a very small flow of clear water was observed seeping into, and flowing in the channel as far back as 194 m from the river. A sample of the water was taken for chemical analysis approximately 50 m from the beginning of the channel (or approximately 144 m from the river). Beyond this distance, the channel splits into two and was dry on 19/8/00, but it was evident from the mud and lack of vegetation that there had been water present relatively recently. Several side tributaries enter the channel throughout its course. The base of the channel is located at the junction between the thick organosol and vegetation layer, and the underlying white sand. In several places it was evident from the gaps at the interface (approximately 5 cm) that there had been significant sand and water movement beneath the organosol/vegetation layer.

While the channel is located in the dolomite karst region, there was no evidence of any bedrock cropping out over its entire, ~200 m, length. Moreover, the catchment area within the two limbs of the bend is relatively small for a continuous supply of karst conduit water to be recharging the channel. The height of the top end of the channel (5 m ±1% above the river water level) is too high for high river level flows to be providing residual water which would have then been draining back out of the channel during the site visit. In addition, the water chemistry of the channel water shows low levels of dissolved minerals, particularly calcium and magnesium, which suggest that it is not karst groundwater providing the flow in the channel (sample no. KW007; Attachment 1).

It is likely that the channels are essentially surface water creeks, with their waters derived principally from rain seeping vertically through the high permeability organosol and vegetation layer, and then flowing horizontally down the channel at the interface with the sands. The sands themselves are probably fairly well saturated being also of relatively high permeability. High flows in the Gordon River are likely to back up into the lower part of the channel in the wider stretches but are unlikely to completely flood it.

There are no data from pre-dam times for comparison with the system today to isolate what the effects of current power station operations might be. It is probable that natural processes are governing the most distal parts of the channel, and that only the lower reaches of it may be affected by the power station. These processes are beyond the scope of this report.

3.2.3.2.2 Channel network 'Cam'

A second channel was investigated in the same general area but on the other side of the Gordon River between two creeks (Fig.7a). It is much smaller (approximately 25 m in length) with a steeper gradient, and is located parallel to the river, approximately 20–25 m behind the bank. It lies at a distinct break in slope in the river bank and appears to have very slight surface divides at either end. An active sediment flow, which will be further discussed in the next section, was identified in the river bank between the two creeks.

The preliminary survey showed that the base of the channel was 3.3–3.5 m above the level of the river on 19/08/00[3] (Fig. 7a,b). This survey is considered to be more accurate than at Channel network 'Ben' as the gradients are higher, the distances shorter and the survey loop was closed. The sediment flow

[3] The water level was relatively low as the station had been off for the previous 12 hours. Previous operation had been at full gate.

was 1.8 m above the river level and therefore 1.5 m below the base of the channel. The floors of the channel are composed of fine silts and mud and there was an absence of any well established vegetation on 19/8/00. In two areas, the channel widened to form two small very shallow depression type features and while there was no standing water present in them, the sediments were relatively wet.

Fluctuations from the water level recorder located within approximately 100 m of the site show that the river can vary by approximately 4 m in this reach. The height of the surface divides at either end of the channel are 3.4 and 4.2 m above the river level. The water level recorder data show that the full gate power station flow on the day before the survey was high enough to flood the channel via the western entrance. Natural water level conditions were also low at this time as there had not been significant rain in the previous few days. It is likely that the channel is occupied on a fairly regular basis, whether by full gate station discharge in dry conditions, or by a combination of lower power station discharges plus heavy rainfall. Note that the higher divide was still channel shaped but there was vegetation present suggesting that if it is breached on occasion, it is not as frequently as the rest of the channel.

3.2.3.3 Sediment flows

Sediment flows are a common feature throughout the Gordon–Albert karst area. They occur in areas where the river banks are composed of sand, and they are typically found at the high water level mark at, or close to, the junction between the organosol/vegetation layer and the underlying sediment. They range in size from a few centimetres to holes large enough to crawl into, and are expressed as distinctive orange layers of sediment, typically overlying lighter coloured sands. They are a relatively temporary feature, and are most frequently seen immediately after the power station has shut down following an extended period of operation at full gate.

These features are described in more detail in the geomorphology report (Koehnken *et al.*, 2001) but in summary, they are likely to be erosional features related to the repeated saturation of the sediments as the river levels rise, followed by subsequent collapse and flow as the river level rapidly decreases. Three sediment flows were investigated in this area to assess the likelihood of a karst contribution in their development.

The first sediment flow is located on the river bank in front of Channel ‘Cam’ (refer to previous section), approximately 1.8 m above the river surface on 19/08/00[4]. The survey shows that the base of the small depressions in the backwater channel are 1.5 and 1.6 m above the sediment flow, and approximately 15 m behind it. There is no bedrock present in the immediate vicinity of the feature.

It is possible that the depressions and the channel may contribute to the sediment flow in this instance as the gradient between them is relatively steep (0.1), and at least one of the depressions is located immediately up-slope of the sediment flow. While the sediments in the base of the channel appear to be relatively low permeability being comprised of muds and silts, there was no standing water present approximately 14 hours after station shutdown, suggesting that there may be an efficient hydraulic connection to the main river channel.

A second sediment flow was identified further downstream (approximately Gird ref. 409500 5266600) where the river banks are comprised principally of sands and silts. The feature is of a similar size and height above the water level, and is also adjacent to a creek. A water sample from the creek (KW012) showed very low concentrations of calcium and magnesium suggesting that it is not a karst groundwater source. Behind the river bank, there appears to be some old backwater channels, which are both perpendicular and parallel to the river. A detailed survey was not conducted but these channels were judged to be higher above the river than at the first site. They are also dry and covered in leaf/twig litter suggesting that they have been dry for some time. There is no evidence of any

[4] The water level was relatively low as the station had been off for the previous 12 hours. Previous operation had been at full gate.

outcropping bedrock in the vicinity of either the channels or the sediment flow. The creek bed is currently too low down and too far away from the feature to be a contributing factor, although it is possible that it may have been in the past.

A third sediment flow, located at Grid ref 410400 5266600 at the high water level mark, was briefly observed for comparison. The sediments were particularly wet at this site on 23/7/00, and water flowed from them when they were penetrated with a stick. A water sample was taken for analysis (sample no. KW001; Attachment 1) and the results show that the water was particularly low in calcium and magnesium and had somewhat higher sodium and chloride than the Gordon River water (sample no. KW002; Attachment 1) taken for comparison at the site. This suggests that the sediment flow water is more likely to have been influenced by meteoric waters percolating through the organosol and vegetation layer, and was almost certainly not derived from karst groundwater.

The following additional available evidence suggests that the sediment flows are not augmented by karst groundwater:

- There was no karst bedrock found in the immediate vicinity of any of the sediment flows which could have provided the recharge area for the features. The features were always found to be present at the interface between the sediments and the overlying organosol and vegetation layer.
- The geomorphology team have observed throughout the Gordon and Denison catchments that there does not appear to be any consistent relationship between the presence of backwater channels and the presence of sediment flows, and both occur in places without the other (Lois Koehnken and Helen Locher, pers. comm.). This is supported by karst team observations in the Gordon–Sprent area (refer to Section 3.3.3 below) where a random site without sediment flows was selected and was found to have similar backwater channels present. The sediment flows were also found by the geomorphology team in quartzite and other non-carbonate rock areas, and are not therefore exclusive to karst areas.
- The piezometer data (Koehnken *et al.*, 2001) show that the alluvium in the banks was saturated and that the changes in water levels in the banks were consistent with the filling and draining of the river (Note however, that there were no flood events recorded in the piezometers which is a limitation in the interpretation). All of the piezometers were collared into a cobble layer which is located approximately at low river level. The dolomite in these areas, if it is present at all, is likely to be at greater depths that the river bed and permanently saturated, thereby unable to contribute to the development of the sediment flows, which in contrast, are at high water levels.

It is unlikely that the saturated karst in these areas is either augmenting the development of, or aiding the dewatering of these features. The geomorphology team have found that the increased frequency of these features occurring after high flow conditions, and their repeated locations at or close to the high level mark beneath the organosol and vegetation layer, suggests that there is a close link between the Gordon River fluctuations and their development. Our findings are in support of this view.

3.2.3.4 Conclusion

Based on the available evidence from all three karst areas (refer also to Sections 3.1.3 and 3.3.3), and from investigations by the geomorphology team, it is concluded that the backwater channels are surface water runoff features which are not a necessary component in the development of the sediment flows. Neither feature appears to be dependent on karst groundwater for its development, and neither is specific to karst areas. Issues related to the stability of the systems are outside the scope of this report and will be discussed in the geomorphology report (Koehnken *et al.*, 2001).

3.2.4 Surface landforms

Karst landforms in this area comprise mainly dolomite cliffs and numerous dolines found inland. The dolomite cliffs occur in limited areas, over a 725 m stretch of the right hand bank of the river around the large bend. They reach heights of the order of 5 m and are undercut in places with evidence of scalloping at several different levels.

The scallops and the undercutting are due to chemical weathering by the river water. This occurs over long periods of time as the dolomite, with its high magnesium (and possibly silica) content, is less susceptible to chemical weathering than other, more soluble carbonate rocks. This is a natural process which occurs over geological time and is not expected to be susceptible to the effects of power station operations.

3.2.5 Other interests

Of note, but not of specific interest to the Basslink issue, are the nature and origin of sand deposits found above the high water level mark.

Two sections of white sand deposits (e.g. Grid ref. 410391, 5266734) were found, 8–10 m above the high water level mark, in 0.5–1 m sections immediately beneath the organosol/vegetation layer. The deposits are devoid of any apparent bedding, are well weathered, and contain predominantly coarse sand with few larger pebble sized quartz clasts. One of the samples was been submitted for XRD analysis and will be described in the geomorphology report.

These sediments are located above both the current, and the expected Basslink zone of impact of the river, and so are not relevant to this report, but their characteristics may provide valuable evidence for reconstructing the palaeoenvironment of the area.

3.3 Gordon–Sprent karst

The Gordon–Sprent karst area was the lowest priority of the three areas investigated due to its distance from the power station, and its location downstream of five major tributaries which diminish the effects of the power station discharge. The area was not specifically highlighted for investigation in the work brief and was primarily considered in terms of a brief reconnaissance to ascertain whether further work might be necessary.

3.3.1 Geology

The Gordon–Sprent karst area is underlain by the Gordon Group limestone which is traditionally known throughout the State for the relatively high degree of dissolution features it supports. The rocks include high and low grade limestones with calcareous and non-calcareous siltstones in places, and are present in this area in a long narrow, north-south band from the lower Franklin River southwards into the Olga River catchment. The beds generally strike in a north-south direction and dip towards the east.

The extent of these rocks is shown on the regional geology maps and is therefore not reproduced here. Outcrops in the river channel are shown in Maps 3–5.

3.3.2 Karstification

Several small caves were discovered in the area by caving expeditions in the late 1970s. The largest of these is a 35 m cave, known as the Rocky Sprent cave, which is located on the right bank of the river at the confluence with the River Sprent (Middleton, 1977). Three hundred metres downstream, a smaller cave was found which extends just 4 m into the limestone outcrop (Middleton, 1979). In general, the rocks in the area are relatively pure limestone which have an abundance of solution features. In particular, the rocks at the Devil's Teapot show evidence of scalloping and well developed karren. There are also several dolines which terminate in sediment choked holes.

No speleothems were observed from the river channel investigations, with the exception of the fairly well known Angel Cliffs where a large calcite formation in the shape of angel's wings is present on the cliff face, high above the river.

3.3.2.1 Rocky Sprent cave

Two initial attempts to reach the Rocky Sprent cave failed due to high flow conditions. The cave was finally briefly investigated on 28/9/00 during a trip dedicated mainly to searching for previously unknown karst features between the Olga and Franklin River confluences. The present condition of the cave was estimated (by observation) to be similar to that during the original survey in 1976 and a second full survey was consequently not carried out. The following discussion is based on the literature and on the team's observations.

The entrance to the cave is approximately 2 m wide and is located between two limestone beds which dip at approximately 60º. The passageway, which is horizontally floored, is typically 0.5–1 m wide and follows the bedding plane for approximately 30 m before turning sharply to the left and continuing for another 5 m. At this point the cave opens out into a deep narrow canyon which continues for a further 55 m. A large daylight hole is present along the length of the cave which almost precludes the system from being a true cave environment.

A stream flows through the cave which was estimated during the 1976 survey to be of the order of 1.5 m^3/s, and approximately 20 l/s on the recent trip on 28/9/00. There are three waterfalls in the first 15 m of the canyon ranging from 0.57 to 1.22 m in height (total 2.5 m). The stream bed in the canyon is composed mainly of gravel and has a much steeper gradient than in the cave where it is controlled by a rock shelf with boulders. No speleothems or sediments were observed during the original survey or during the recent visit.

The cave floor was just above the level of the Gordon River on 28/9/00 while the power station was off and there had been little rain over the previous week. The team was able to boat into the cave entrance and step out although the cave stream was flowing. The cave will experience the full effects of the fluctuations due to power station operations at this point in the river. The canyon however, is unlikely to be inundated due to the change of slope of the floor of the cave and the height of the waterfalls. It is considered that there is little potential for accumulation of suspended sediment in the cave from the Gordon River, as the narrow width of the cave with its steeply dipping walls, combined with the high velocity of the cave stream flow will ensure that there is little opportunity for retention of sediment.

The Rocky Sprent cave is considered to be relatively stable and robust for the following reasons:

- the cave does not appear to have changed in comparison to the original survey;
- there are no speleothems or fine sediments present;
- there is a large daylight hole along the short length of the cave which means that the system is not really a true cave environment; and
- the cave stream is of relatively high energy.

3.3.2.2 Other caves

Two other limestone canyons with streams flowing through them were found on or very close to the Gordon River, upstream of the Rocky Sprent cave. The first (Grid ref 5276450, 0398274) is approximately 30 m long, 4–5 m deep, with an average width of 2 m. The stream was estimated to be flowing at approximately 10 l/s and was tannin stained suggesting that it is of surface water origin. The second limestone canyon (approximate Grid ref 5277400 0398430) has a bridge feature approximately 20 m wide. The stream flows through the bridge (not entered), and a small cave (<10 m long) to reach the Gordon River. There are no speleothems or sediments in these features and they are considered to be relatively robust.

Further brief exploration highlighted the presence of dolines and some small solution holes inland in the vicinity of the creek downstream of Angel Cliffs. These are, however, approximately 10–15 m above the river bed, are dry and are considered to be outside the zone of influence of the river fluctuations and so were not investigated further.

The three trips carried out under the current investigations, and the previous exploration have found no evidence of any other major caves in this area. While the pure nature of the carbonate rock, and the extent of the outcrop in the river channel, suggest that there may well be other, as yet undiscovered caves in the area, it is unlikely that there are other major systems present in the immediate vicinity of the river channel.

3.3.3 Karst hydrology and bank stability

Further investigation into the relationship between the sediment flows, backwater channels and karst groundwater was conducted in the Gordon–Sprent area. Two areas downstream of Angel Cliffs, on the right bank, were investigated.

The first site, immediately downstream of Angel Cliffs, was selected based on the presence of a typical sediment flow feature. Inland, backwater channels are present with the characteristic sandy base. The channels all eventually join together and converge on the Gordon River bank, downstream of the sediment flow. While the gradients of the channels are relatively shallow in general, there is a sharp drop of approximately 1 m in height at the final junction before the river. There is no evidence of any bedrock in the vicinity of either feature.

The second site was randomly selected further downstream at the first available landing site where there was an absence of sediment flow features. Subsequent inland investigation proved the presence of the familiar backwater channels, which contained clear flowing water over a coarse sandy base. The channels seem to be part of a fairly complex stream system which is substantially higher above the river (perhaps as high as 5–10 m) than any others seen to date. There is no evidence of any outcrop. There had been a period of heavy rainfall overnight (2–3/9/00) and it is anticipated that this was the source of the water in the channels.

These sites support the conclusions drawn in Section 3.2.3.4 that the backwater channels and the sediment flows are independent of each other, and also of the karst system. They seem invariably to be present in sandy river banks with an absence of any bedrock. Bank erosion and issues of instability of these features are outside the scope of this report.

3.3.4 Surface landforms

The principle landforms of note in this area are the large limestone cliffs which have also experienced scalloping and undercutting. This a natural phenomenon occurring over geological time which is not considered to be relevant to the effects of power station operations.

4 POTENTIAL BASSLINK CHANGES

The results of the TEMSIM modelling[5] have shown that there would be significant changes to the Gordon Power Station operations if a Basslink cable were in place (Palmer *et al.*, 2001). These include:

- Increased short term variability in station discharge. Basslink flows are expected to incorporate more peak flow to zero flow changes compared to the current situation where typically just the total number of turbines in operation changes.
- Increased frequency of short duration and weekend shut downs. It is predicted that the Gordon power station would be used more for step load, satisfying peak demands, rather than to generate the more consistent base load as at present.

[5] TEMSIM (Tasmanian Electricity Market Simulation Model) is a detailed simulation model of the Tasmanian generating system operating according to market rules within the National Electricity Market. The model incorporates all of the State's significant water storages, power stations and associated infrastructure, and can be used to identify hydrological changes associated with Basslink with reference to historical conditions.

- Much less seasonal variation in flow. There are long periods of low generation (and therefore low flows) in the winter months at present when there are sufficient river flows at other power stations to meet demands, as well as periods of relatively high flows during the summer months. The Basslink demand would be more constant all year round.
- Similar generation patterns in wet and dry years. At present generation in wet years is significantly less due to the generation capacity at other stations.
- Increase in the monthly median flows, particularly during the winter when historically the station has had limited output. In general, flows would be higher more often than at present.
- Increase, on a monthly basis, in the ratio of natural pick up to total flow. In a given month, there would be less power station contribution to the flow than at present.

So while there would be less total power station flow relative to the natural pickup (due to the higher number of shutdown events), when the station did contribute, the flows would be higher more often than at present (hence the higher median flows). The timing of the release events relative to natural flood events would therefore seem to be the most critical factor.

The model suggests that there would be no change in the magnitude of peak flows discharging at the station, as it is still restricted to flow through the three turbines which are currently in place and are often used to their full potential. However, there is a higher probability of higher peak flows occurring further down the system when the station peak discharges in winter occur at the same time as high rainfall in the catchments of the tributaries. In a dry year the Basslink station peaks are predicted to be less than at present, while during a wet year they would remain the same. The flood frequency analysis for the system shows very little change.

In summary, the station is predicted to have more on-off sequences of short duration, with higher flows, more often than at present.

4.1 Nicholl's Range karst

The primary Basslink issue in the Nicholl's Range karst area is the potential increase in cave sediment disturbance, in both Bill Neilson Cave and Kayak Kavern. It would appear from the cave surveys carried out in 1976, that there has been significant sediment deposition in both caves in the last 25 years[6]. It is not known whether this is due to current power station operations or whether it was also occurring in pre-dam times.

Basslink operations would facilitate a systematic, repetitive cycle of saturation and dewatering of the sediments due to the increased frequency of on-off sequences. This is expected to encourage further deposition of fine sediment in both caves, and additional slumping and collapse of sediment in the Bill Neilson Cave.

The increased probability of full gate power station operations occurring simultaneously with high rainfall in the catchments of the tributaries, brings an increased probability of higher inundation levels occurring in the Bill Neilson Cave. Significantly higher inundation levels (say to RL 3 or 4) could potentially bring the dry sediment bank into the fluctuation zone. The extent of the potential increase is not known.

The heights of the speleothems and the glow worm colonies above the cave floor in the Bill Neilson cave suggest that they are likely to remain out of reach of Basslink flows. There are no speleothems in Kayak Kavern.

[6] Note that caution must be exercised in using the Kayak Kavern surveys as a baseline assessment as they are not directly comparable being completed to different survey grades.

4.2 Gordon–Albert karst

The primary Basslink issue in the Gordon–Albert karst area, although in our view not a karst related issue (refer to Section 3.2.3.3), is the possible acceleration of the rate of destabilisation of the river banks, via the sediment flows, which an increased frequency in the number of on-off sequences (and therefore drawdown events) may bring.

The dolomite rock itself is unlikely to be significantly affected as it has stood the test of time over many millions of years, and there were no speleothems, karst features, or cave sediments found of particular note. The three small stalactites are protected in an air pocket which is unlikely to change significantly within the life span of the power station.

4.3 Gordon–Sprent karst

The Rocky Sprent Cave was found to be relatively stable and robust under current power station operations and as there were no susceptible karst features found, it is not expected that this status would change under Basslink. Sediments are not currently being deposited in the cave and are not likely to be under Basslink operations due to the steep cave walls and the high velocity of the cave stream.

Current and past investigations have not found any other caves of significance in this area although there is no conclusive evidence that there are none present. Potential Basslink changes to as yet undiscovered caves might include an influx of sediment from the Gordon River and a possible increase in destabilisation of cave sediments if there are any present.

No delicate speleothems have been found in the known caves within the zone of fluctuation of the river in any of the three areas investigated so far. This may be a consequence of the high energy environment of this zone which is continually being inundated by the river during current power station operations and natural flooding. This is also likely to be the case for as yet undiscovered caves in the Gordon–Sprent area.

Sediment flows and bank erosion processes, which may be affected by the increased frequency of drawdowns under the new Basslink regime, are also likely to be an issue in this area, but these are not considered to be related to karst (refer to Section 3.2.3) and are not discussed further.

5 MANAGEMENT ISSUES

5.1 Nicholl's Range karst

The primary management issue in both the Bill Neilson Cave and Kayak Kavern is fine sediment deposition and transfer, which is occurring under present power station operations and is likely to increase under Basslink. The increase in frequency of drawdown events may cause additional slumping and collapse of sediment in the Bill Neilson cave. The slight increase in duration of peak flow events, which will mean that the caves will be inundated for longer periods, may also facilitate additional deposition in both caves.

Limited pre-dam baseline data suggest that the deposition may well be a post-dam phenomenon and therefore cumulative sedimentation, rather than erosion or general disturbance, is likely to be the most relevant issue. Significant accumulation is unlikely in the Bill Neilson cave as the scouring action of the cave stream will remove sediment and maintain a natural balance in the system. Sediment transfer processes in Kayak Kavern are not well understood although it would appear that there is net accumulation occurring which could extend the silt bank further out of the cave towards the Gordon River. The bank will ultimately be controlled by the levels in the river and is currently close to the present high water level mark.

The higher level, dry sediments, which are at present outside the reach of the power station flows, may become a management issue if higher inundation levels were to occur due to the higher probability of full gate discharge events occurring coincidentally with high rainfall conditions. These sediments are potentially considerably older than the wet sediments close to the entrance of the cave and further investigation may prove them to be significant (Section 6). The cave floor is controlled by bedrock in the vicinity of these sediments and so regulation induced degradation of the cave stream is not likely to be a contributing factor.

5.2 Gordon–Albert karst

Current and Basslink management issues identified in the Gordon–Albert karst area relate primarily to the stability of the river bank sediments, bank erosion, and sediment transfer in the backwater channels. These are not considered to be karst issues for the reasons detailed above, and are therefore not further discussed.

Destabilisation of the area around dolines close to the river at, or below the high water level mark may become a management issue with the increase in frequency and average range of drawdown events. Sediments in the karst conduits at the bases of the features could become mobilised into the main river channel with the change in drawdown events. This could lead to consequent further collapse and possible destabilisation of the surrounding area inland. Dolines provide a natural focal point for localised flow and are the most likely place for water movement from the surface to groundwater in a karst system. There is no evidence of this occurring under the present power station operations but the repeated drawdowns expected with Basslink operations may trigger sediment movement.

5.3 Gordon–Sprent karst

The Rocky Sprent cave is relatively stable and robust and no specific management issues have been identified. While this large karst area is still relatively unexplored, the three investigative trips for this project did not find any significant karst features in the zone of fluctuation of the Gordon River.

The primary management issues for any undiscovered caves in the area are likely to be a possible increase in deposition of sediment from the Gordon River, and the potential for a decrease in stability of sediment banks close to river level, if present. The significance of any deposits which may be affected would need to be assessed.

6 MITIGATION OPTIONS

6.1 Importance of cave sediments

The primary potential karst issue for concern is the cave sediments. Cave sediments can provide potentially valuable information about past environmental conditions (Kiernan, 1983). They are often emplaced in caves during deglaciation periods when there is an abundance of water and sediment available, where they are then preserved from the elements in the relative shelter of the underground environment. Cave sediments are important as they can record evidence of climatic events as far back as when they were emplaced. A major problem often encountered with their interpretation however, is the ability to assign ages to particular events, for example emplacement and cessation of deposition. The presence of organic material (wood, leaves, etc), charcoal, and speleothems provide very useful material for dating techniques.

Three potentially suitable dating sites were found in the Bill Neilson Cave. The first, which is the wood located in the entrance cavern, is not considered to be significant because the sediments (and the wood) have been greatly disturbed by naturally fluctuating water levels and current power station operations. It is also probable that the sediments are relatively young having been deposited since the Gordon Power Station came into operation.

The second site, relates to the well preserved dry sediments located in the upper level passageway, where the jaw bone and the speleothem may constrain the ages of the sediments. While none of these features are themselves within the zone of inundating waters from the Gordon River, under either current or Basslink operations, the base of the dry sediment bank is not far above the estimated maximum inundation level. A significant increase in current inundation levels may destabilise the base of the sediment bank which may have implications for the features and the integrity of the sediments.

The leaf litter and other flood debris located on the roof of the upper level passage, may also provide useful information for understanding the flood history of the Gordon River. It is, however, located approximately 6–8 m above the current cave floor level and is considered to be well out of reach of likely flood levels.

Further investigations at these three sites would be primarily for gaining additional background information on the area (e.g. previous flood levels and palaeoenvironmental conditions) rather than for addressing specific Basslink issues. All are currently outside the range of current power station operations, and modelled Basslink conditions.

6.2 Significance of cave sediments in study area

The relative significance of the karst features which will be affected by Basslink needs to be considered before mitigation options can be addressed. A preliminary attempt to assess the general geoconservation significance of the karst features identified in the three study areas, using the National Estate Criteria, is provided in Attachment 2. In summary, all the available information suggests that the Nicholl’s Range and the Gordon–Sprent karst areas are ‘Representative at a Local level’ with almost all the significance ratings against the criteria described as ‘low’. There is insufficient information to assign an appropriate level to the Gordon–Albert karst.

An assessment on the consequential impacts on the Tasmanian Wilderness World Heritage Values is described in Appendix 14 of this report series – Gordon River World Heritage Area Values Assessment (Kriwoken, 2001).

6.3 Conclusion

Based on all the available evidence, the primary karst features which are likely to be affected by Basslink are the cave sediments at the entrance of the Bill Neilson Cave. As these are likely to be relatively recent and are already highly disturbed, they are not considered to be significant and therefore do not merit any special considerations. No mitigation options are recommended.

7 MONITORING CONSIDERATIONS

Any further monitoring of Gordon River karst issues should consider the following.

Monitoring of sediment movement in Bill Neilson Cave and Kayak Kavern, both pre- and post-Basslink, would be beneficial to further the understanding of the sediment transfer processes occurring in the caves, and to see how they may relate to sediment flux in the Gordon River. There is one erosion pin installed in each cave at present which have not yet been in for long enough to provide defensible results. It is also preferable that more than one is maintained in each cave to allow for potential isolated disturbances from floating debris, and for reasonable statistical analysis. It is recommended that a sedimentologist or geomorphologist assess the sediment banks to further determine transfer processes at work and to suggest appropriate monitoring strategies.

Monitoring the dolines close to the river bank in the Gordon–Albert karst area would be useful to provide evidence for whether they may be affected by repeated drawdown in the river channel under Basslink operations. There is no evidence of this occurring under the present power station operations, however, the repeated drawdowns expected with Basslink operations may trigger sediment movement at the bases of the features in sediment choked conduits. Suggested monitoring would include inserting erosion pins into the sides of features close to the banks and photographing them on a regular basis (perhaps at the end of each season) to see whether, over time, there was any subsidence or collapse. Both pre- and post-Basslink monitoring is recommended.

It is strongly recommended that water level monitoring is continued in the Bill Neilson Cave, including both the cave stream and the extent of inundation of the cave by Gordon River water. The present investigations have given crude estimates of the extent of the inundation in the cave but water level monitoring inside the cave is required to provide more accurate results. The cave stream responds rapidly to rainfall and gives a good, relevant indication of natural water level conditions in the immediate area. It would be useful to be able to predict when extended peak power station discharges might coincide with natural high flow conditions, to give abnormally high water level conditions which may affect the dry sediment bank. Water levels approaching 3–4 m RL in the cave, for example, are significantly higher than normal inundation levels and may bring the dry sediment banks, other features, or perhaps faunal colonies into the active zone. The estimated inundation levels are based on extrapolation of data from crude investigation techniques which should be confirmed with appropriate onsite data.

All of the above recommendations are long term investments in understanding the system. Meaningful results could not have been obtained during the short period of investigation.

8 CONCLUSION

Field investigations into the potential effects of changes in power station operations due to Basslink on the karst systems of three areas in the middle Gordon River have been carried out. Work has focussed on karst which is influenced by the dynamics of the river, and was specific to identifying the effects of potential changes between current and Basslink operations.

The Nicholl’s Range karst area, located downstream of the Denison River confluence in the Gordon Limestone Group, has a well developed cave system known as Bill Neilson Cave, and a much smaller cave adjacent to it called Kayak Kavern. The primary current and Basslink management issue in both these caves is the deposition and transfer of cave sediments. Increased saturation and dewatering of the sediments, with increased duration of peak flows and frequency of drawdown events, are expected to accelerate deposition of fine sediments, and slumping and collapse of sediment banks. A dry sediment bank is currently located above the maximum inundation level but may fall into the zone of fluctuation if the river levels increase significantly with the higher probabilities of full gate discharge occurring simultaneously with high rainfall conditions. With the exception of the sediment banks, the caves are considered to be relatively robust. It is unlikely that any speleothems will be affected as they are located high above the estimated inundation levels.

The Gordon–Albert karst area, located between the Albert River confluence and the Second Split, is developed in dolomite which had not previously been described. No noteworthy caves or karst features were identified although there is evidence to show that dissolution has occurred. The primary management issue in this area is the instability and erosion of the river banks due to current power station operations, which is likely to increase with Basslink. Limited investigations into sediment flow features and backwater channels suggests that karst groundwater does not play a major role in their development, and hence is unlikely to be significantly contributing to bank erosion processes. This issue is also further addressed in the Gordon River geomorphology report (Koehnken *et al.*, 2001).

Three investigative trips were carried out in the Gordon–Sprent karst area, including one brief reconnaissance visit into the previously documented Rocky Sprent cave. No cave sediments or delicate speleothems were found in the cave which contains a large daylight hole and a relatively large cave stream. The cave does not appear to have changed significantly since the previous survey and is considered to be relatively robust. Some previously undescribed karst features (holes, dolines, canyons) were found in the area but none were located within the zone of fluctuation of the Gordon River. The primary management issues for any, as yet, undiscovered caves in the area are likely to be a possible increase in deposition of sediment from the Gordon River, and the potential for a decrease in stability of sediment banks close to the river level, if present. The significance of any deposits which may be affected would need to be assessed. River bank instability issues are also prevalent in this area but where inspected were found to be independent of karst groundwater.

There are no recommendations for specific mitigation options to protect karst features in the three study areas as none were found to be highly significant using the geoconservation assessment methods described by Sharples (e.g. 1997). There may be opportunity for further work on cave sediments not expected to be affected by normal Basslink operations, which may provide useful evidence for palaeo-environmental analysis.

Pre-and post-Basslink monitoring of (a) water levels and cave stream flow in the Bill Neilson Cave; (b) sediment transfer processes in the caves in the Nicholl's Range area; and (c) sediment transfer in dolines close to the river bank in the Gordon–Albert area is recommended.

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10 ATTACHMENTS

10.1 Attachment 1: Water chemistry analyses

Sample[1]	Site description	Date	Power station activity and weather conditions	Alk (CaCO3)[2]	Cl	NO3 (N)	SO4	Ca	K	Mg	Na	pH	Cond
KW001	Sediment flow (410400 5266600).	23/07/00	Weather dry on 23/7/00. 26mm rain at Strathgordon in previous 24h. Station off, full gate flow previous day	<1	7.2	<0.03	0.61	0.28	0.75	0.69	6.39		
KW002	River water (410394 5266617).	23/07/00		<1	6.8	<0.03	1.3	1.06	0.39	0.81	5.34		
KW003	Small karst spring (close to 410394 5266570)	23/07/00		<1	11	<0.03	1.1	10.9	0.29	6.76	8.26		
KW004	Small (0.5 l/s) karst spring (410103 5266756)	23/07/00		<1	11	0.05	1.5	25.1	0.44	13.5	7.99		
KW005	Bill Neilson creek water; mouth of cave	30/07/00	Rain on 30/7/00. 20mm rain at Strathgordon in previous 24h. Station off, full gate flow previous day	<1	9.8	<0.03	14	4.25	0.66	1.37	7.87		
KW006	Intermittent tributary in Bill Neilson cave	30/07/00		<1	9.5	0.16	1.4	22.6	0.7	1.33	7.09		
KW007	Ben's channel (0410254 5266449)	19/08/00	Weather dry on 19/8/00 and over previous 3 days. Station off, full gate flow previous day.	<1	8.8	<0.03	0.4	0.41	0.38	0.81	4.53		
KW008	Karst stream by arch (0410424 5266528)	19/08/00		<1	11	<0.03	<0.2	7.64	0.3	5.24	5.78		
KW010	Jeff's resurgence creek (0410206 5266794)	19/08/00		<1	10	<0.03	0.37	5.81	0.24	4.11	5.05		
KW011	Creek resurgence, pile logs (0410123 5266848)	19/08/00		<1	9.2	<0.03	1.4	2.02	0.41	2.02	4.85		
KW012	Creek at 2nd sediment flow site (409500 5266600)	19/08/00		<1	8.7	<0.03	0.55	0.77	0.46	0.84	4.39		
KW013	Artesian groundwater bore (392794 5285957)	21/08/00	Weather dry on 21/8/00 and over previous few days. Station on/off for Basslink simulation	<1	13	<0.03	<0.2	64.5	0.49	6.42	7.23		
Lois's sample	Bill Neilson creek water at mouth of cave	11/06/00	Weather dry on 11/6/00. 16mm rain over previous 24h. Station off/on with reduced flow	30 (total)	15	0.34	1.6	11.9	0.61	4.02	9.43	7.3	120

[1]All samples analysed by Analytical Services Tasmania, Sandy Bay, Tas
[2]Carbonate alkalinity except 'Lois's sample' which is total alkalinity

10.2 Attachment 2: Significance of the karst areas

An attempt was made to preliminarily assess the scale of significance of the study areas in relation to other karst areas using the National Estate Criteria and the principles of geoconservation as described by Sharples (1997, 1998). A full conservation assessment requires exhaustive investigation of the karst system and given the brief and scope of the project this was not an achievable objective.

The relevant categories of the National Estate Criteria against which each of the three karst areas are assessed are summarised below, and are described in full elsewhere (refer to Sharples 1997 for further discussion).

10.2.1 National Estate Criteria

Each criterion A.1, E.1, etc, is rated high, moderate or low for each of the karst areas. Criteria which were not relevant in this instance have not consequently been included. The question marks in the rankings highlight the fact that the assessments are tentative and are based on the available information which is not considered to be definitive.

Criterion A: Its importance in the course or pattern of Australia's natural or cultural history.
A.1 Importance in the evolution of Australia's flora, fauna, landscapes or climate.
A.2 Importance in maintaining existing processes or natural systems at the regional or national scale.
A.3 Importance in exhibiting unusual richness or diversity of flora, fauna, landscapes or cultural features.
A.4 Importance for their association with events, developments or cultural phases which have had a significant role in the human occupation and evolution of the nation, state, region or community.

Criterion B: Its possession of uncommon, rare or endangered aspects of Australia's natural or cultural history
B.1 Importance for rare, endangered or uncommon flora, fauna, communities, ecosystems, natural landscapes or phenomena, or as a wilderness.

Criterion C: Its potential to yield information that will contribute to an understanding of Australia's natural or cultural history
C.1 Importance for information contributing to a wider understanding of Australia's natural history, by virtue of their use as research sites, teaching sites, type localities, reference or benchmark sites.
C.2 Importance for information contributing to a wider understanding of the history of human occupation of Australia.

Criterion D: Its importance in demonstrating the principle characteristics of:
A class of Australia's natural or cultural places; or
A class of Australia's natural or cultural environments.
D.1 Importance in demonstrating the principle characteristics of the range of landscapes, environments or ecosystems, the attributes of which identify them as being characteristic of their class.

Criterion E: Its importance in exhibiting particular aesthetic characteristics valued by a community or cultural group
E.1 Importance for a community for aesthetic characteristics held in high esteem or otherwise valued by the community.

10.2.2 Geoconservation significance

Each of the three karst areas is given an overall category of geoconservation significance, based on the National Estate values, which is appropriate to a particular level. There are three categories of geoconservation significance which include "Outstanding" (O), "Representative" (R), and "Unknown" (U). Each category is qualified by one of five levels of significance which include:

1. International level (I),
2. National level (N),
3. State level (S),
4. Regional level (R), and
5. Local level (L).

10.2.3 Application to study areas

The following table summarises the ratings against each criterion for the three study areas and gives a preliminary geoconservation significance category, followed by a brief description of the reasons behind the designation.

Table 1. Preliminary assessment of karst landform values of three karst areas adjacent to the Gordon River

Area	**National Estate Criteria**									**Geoconservation Significance**	**Reason (s) for significance**
	A.1	**A.2**	**A.3**	**A.4**	**B.1**	**C.1**	**C.2**	**D.1**	**E.1**		
Nicholls Range Karst	L	L	L (?)	M (?)	L (?)	L (?)	L (?)	L (?)	L	R (L)?	some documented caves; dolines; limestone cliffs with solution features; karst potential is still not fully explored; some archaeological finds;
Gordon-Albert Karst	L (?)	L (?)	U	U	U	U	U	U	U	U (?)	insufficient data; dolomite area cursorily explored; full extent of dolomite not known;
Gordon-Sprent Karst	L	L	L (?)	L	L (?)	L (?)	L (?)	L	L	R (L)?	some small documented caves; limestone cliffs with solution features; dolines; karst potential is still not fully explored;

Note that only the relevant criteria have been included.

The Nicholl's Range karst is considered to be 'Representative at a Local scale' on the basis of the available information. Almost all of the National Estate Criteria are ranked 'low', with the exception of A.4 which is assigned a 'medium' rank in light of the potential importance of the dry cave sediments in the Bill Neilson cave.

The Gordon–Albert karst is largely still unknown as investigations to date have mainly focussed on the river channel, and the dolomite karst is not as well known as the limestone karst. The geoconservation significance is 'Unknown' and there is insufficient information to rank many of the National Estate criteria.

The Gordon–Sprent karst is also considered to be Representative at the local scale on the basis of the available information. All the National Estate Criteria rankings were designated low.

FIGURES

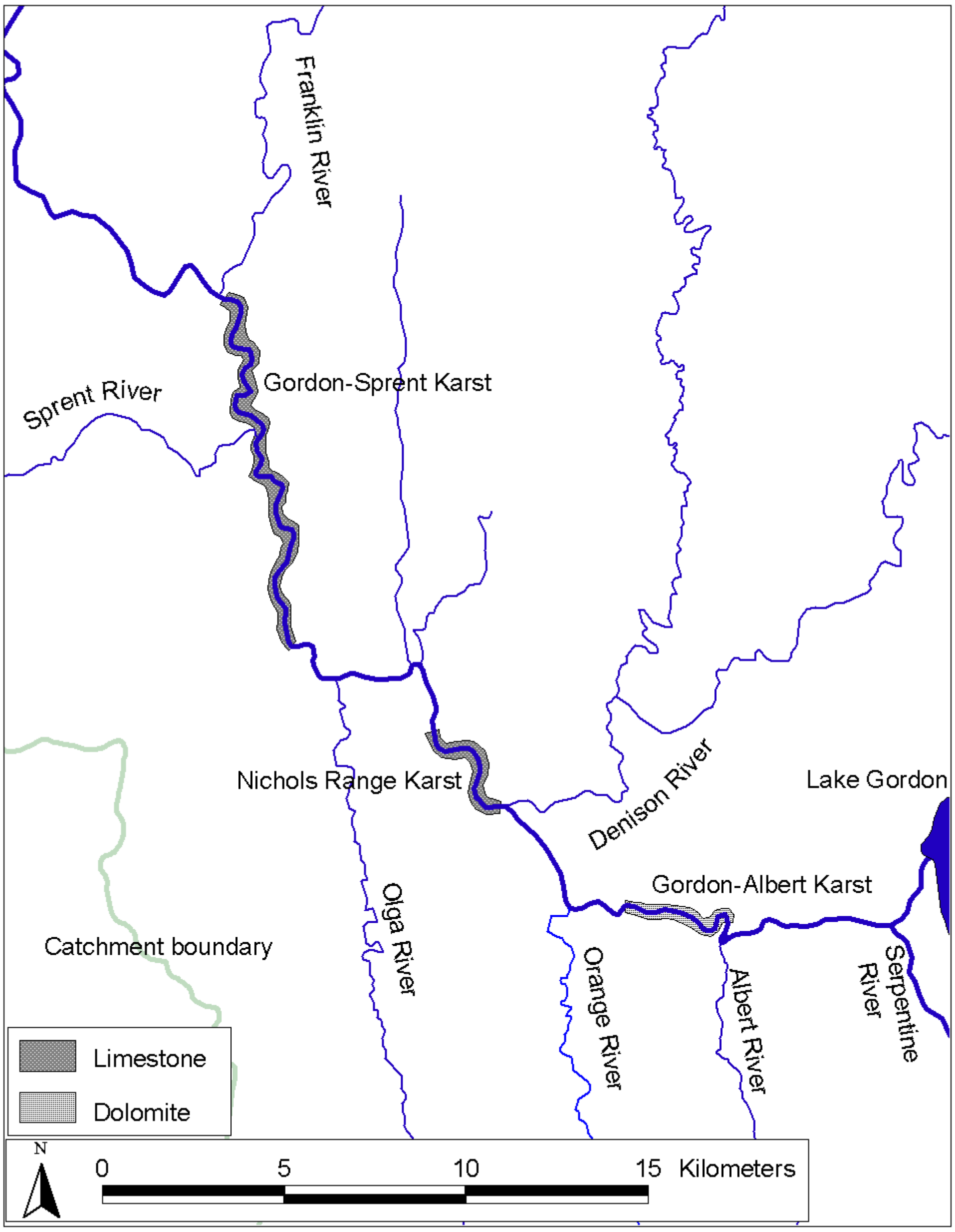


Figure 1. Location of the study areas

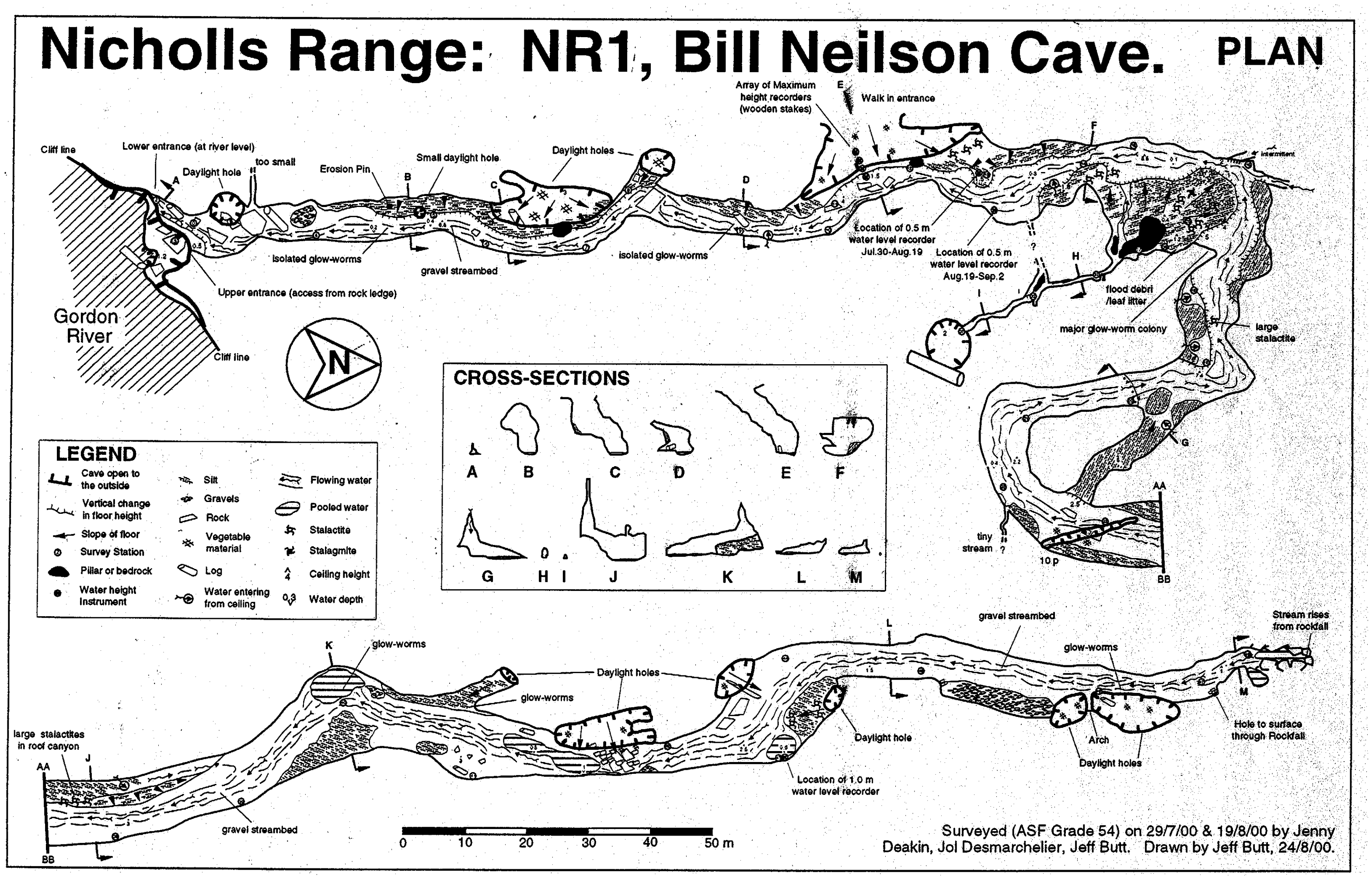


Figure 2a. Bill Neilson Cave survey 2000, plan view

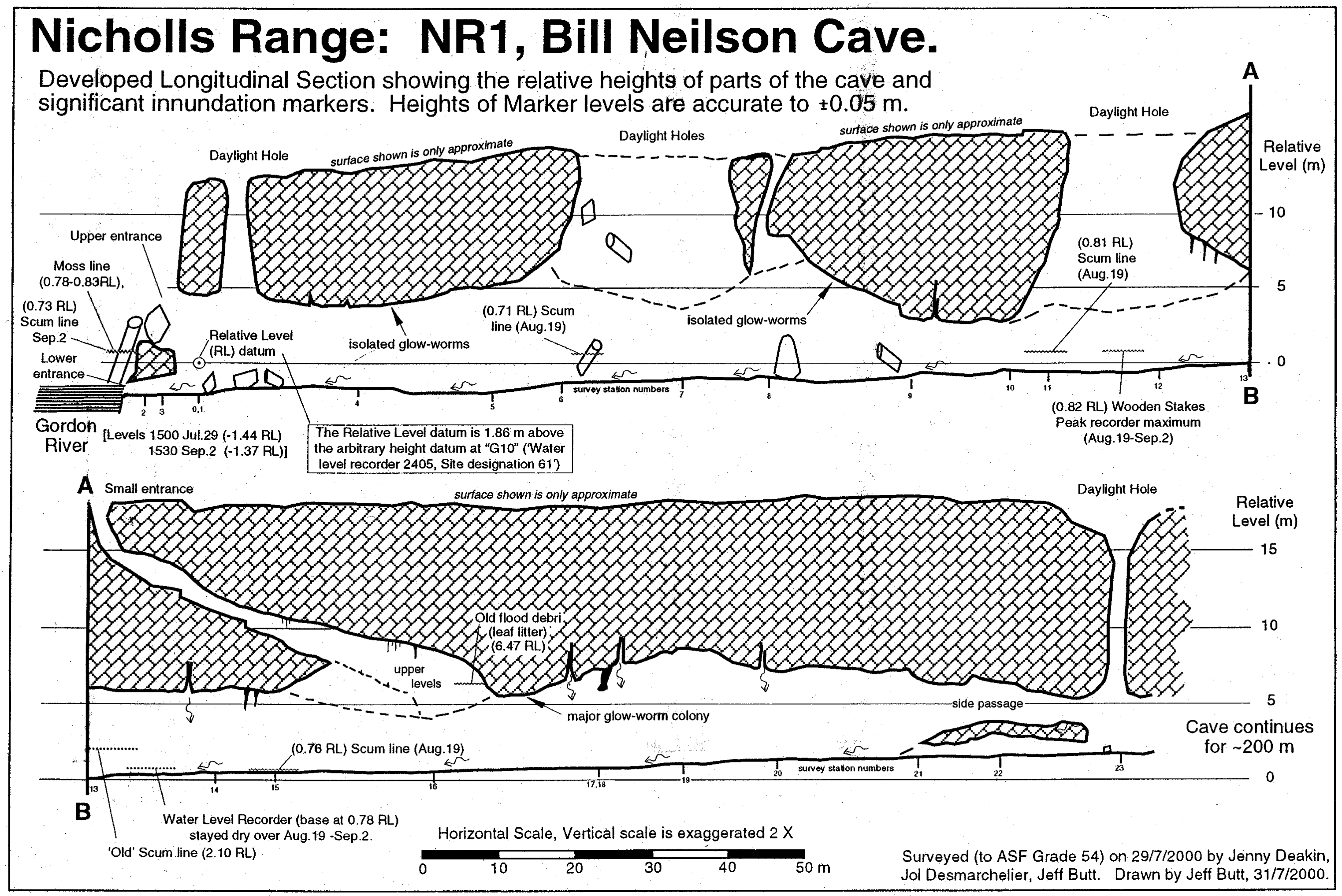


Figure 2b. Bill Neilson Cave survey 2000, developed longitudinal section

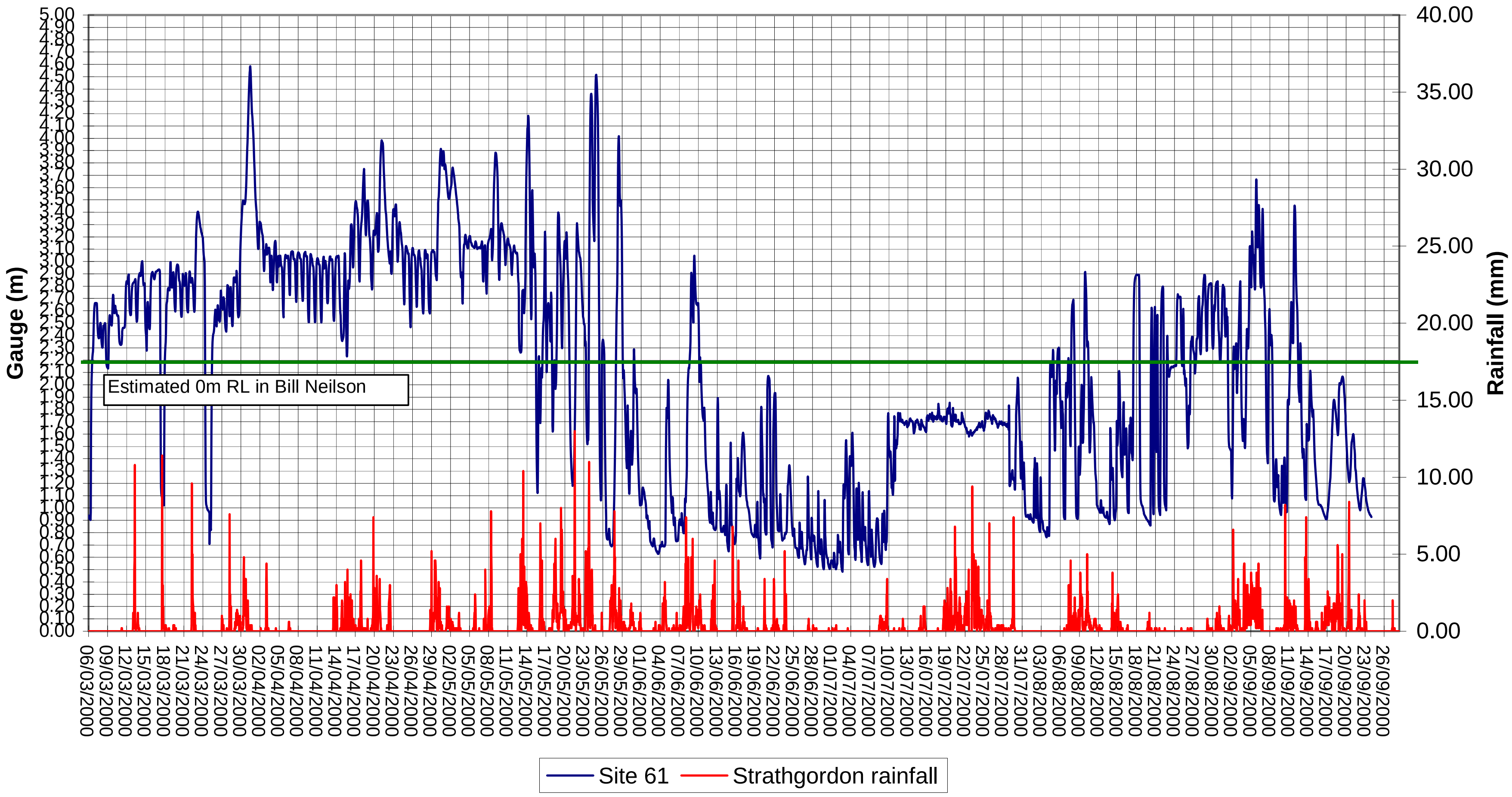


Figure 2c. Water level fluctuations at Site 61.

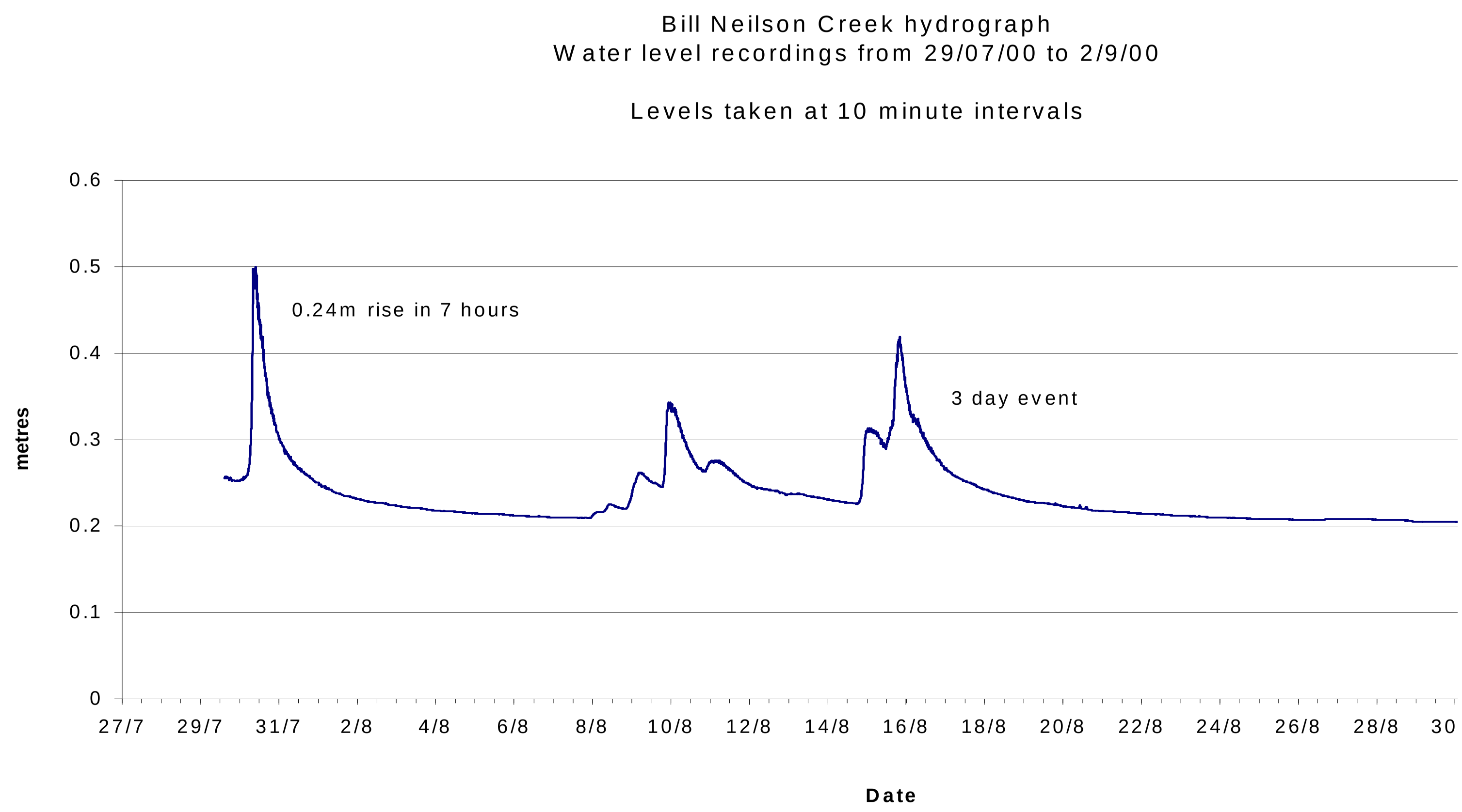


Figure 3. Bill Neilson cave stream water levels

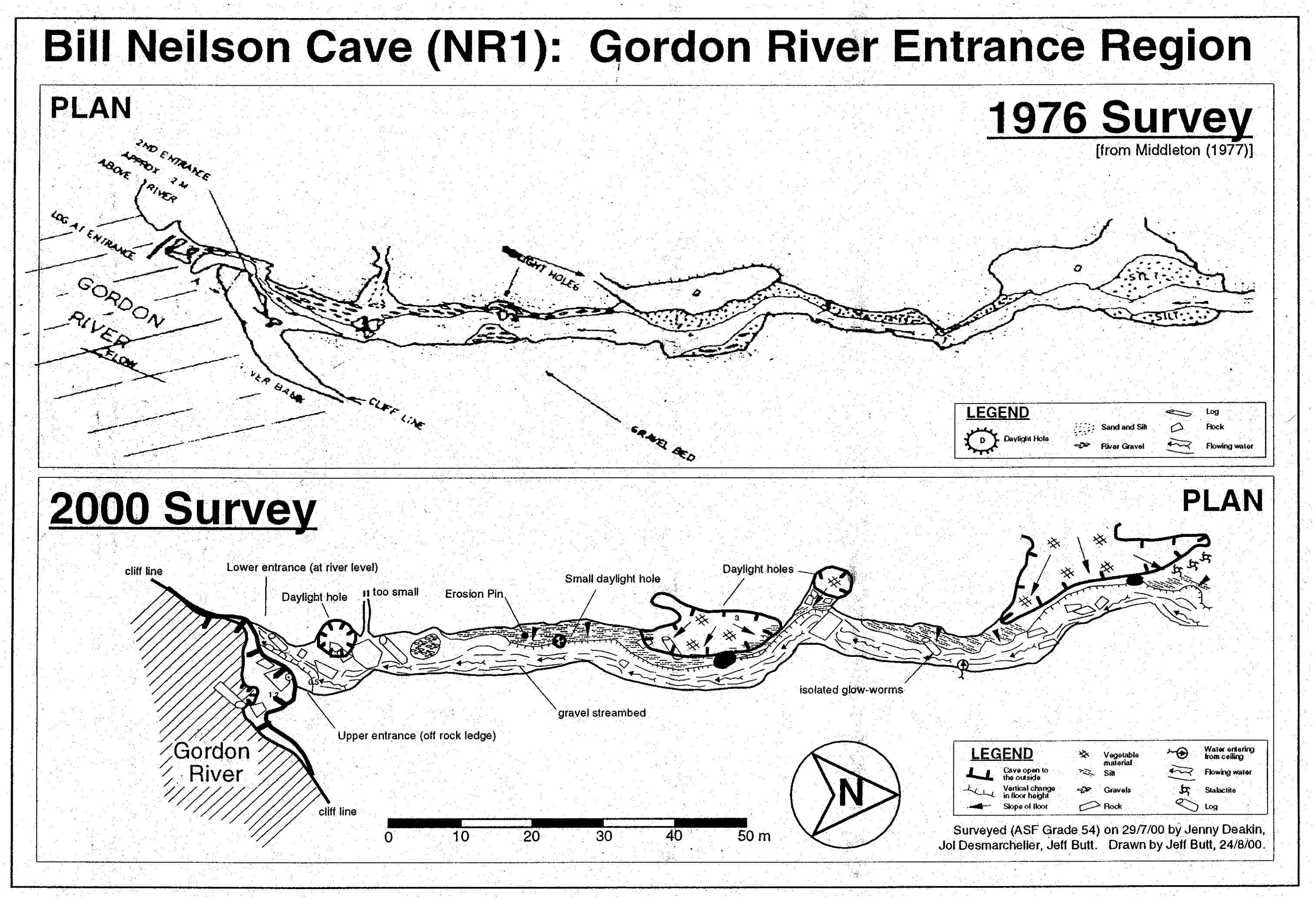


Figure 4. Comparison of 1976 and 2000 surveys of Bill Neilson cave (entrance region)

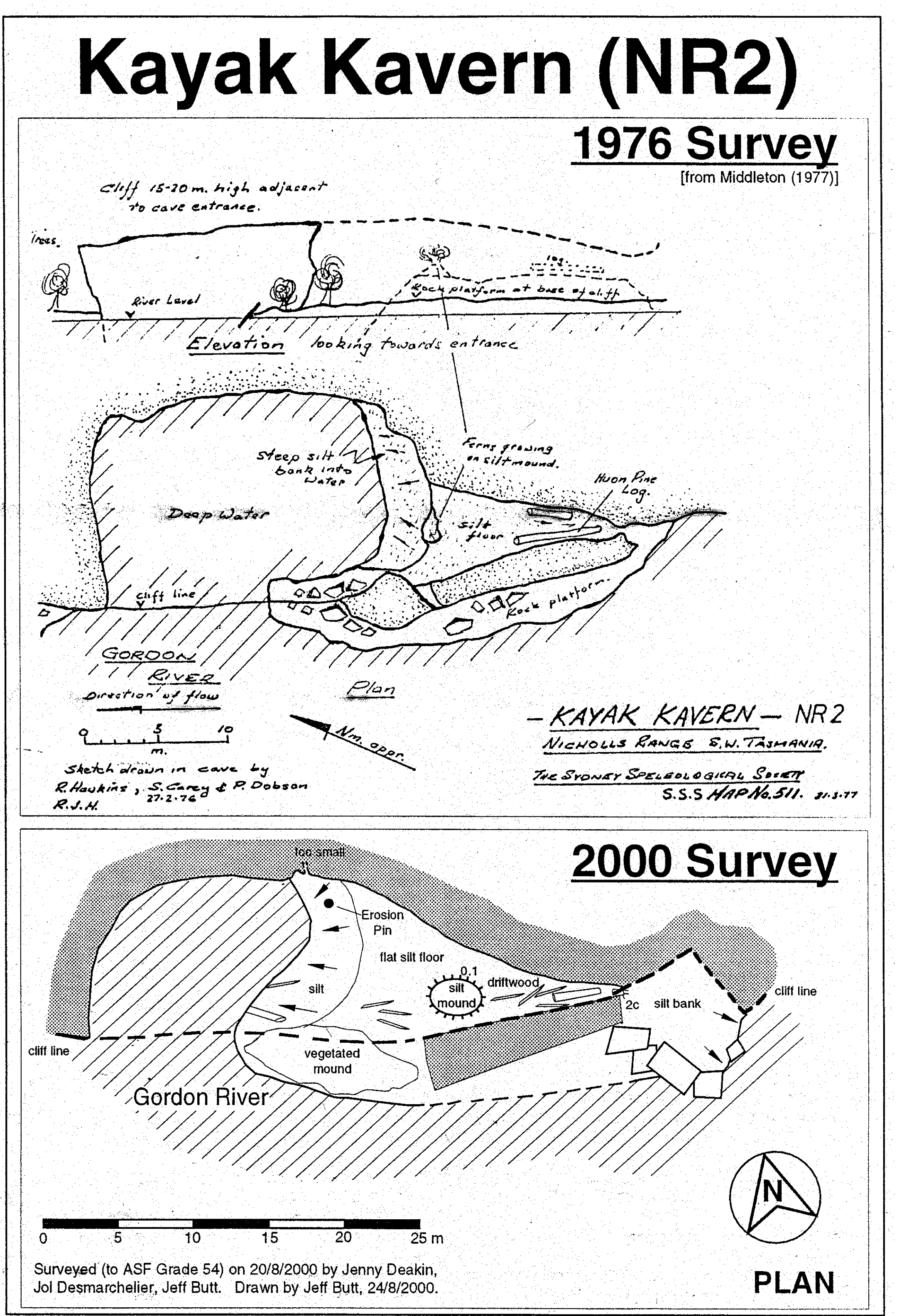


Figure 5. Comparison of 1976 and 2000 surveys of Kayak Kavern

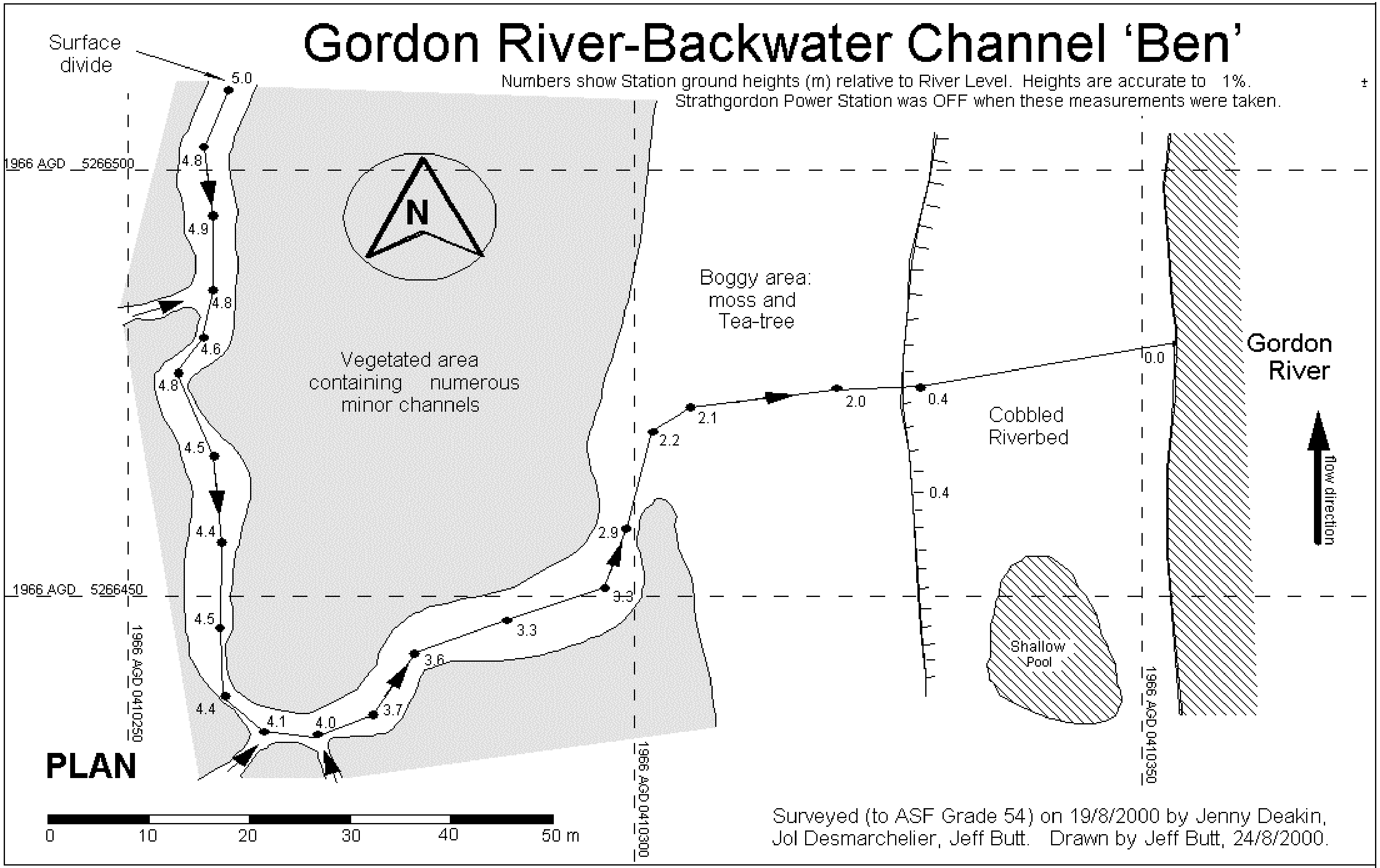


Figure 6. Survey of backwater channel 'Ben'

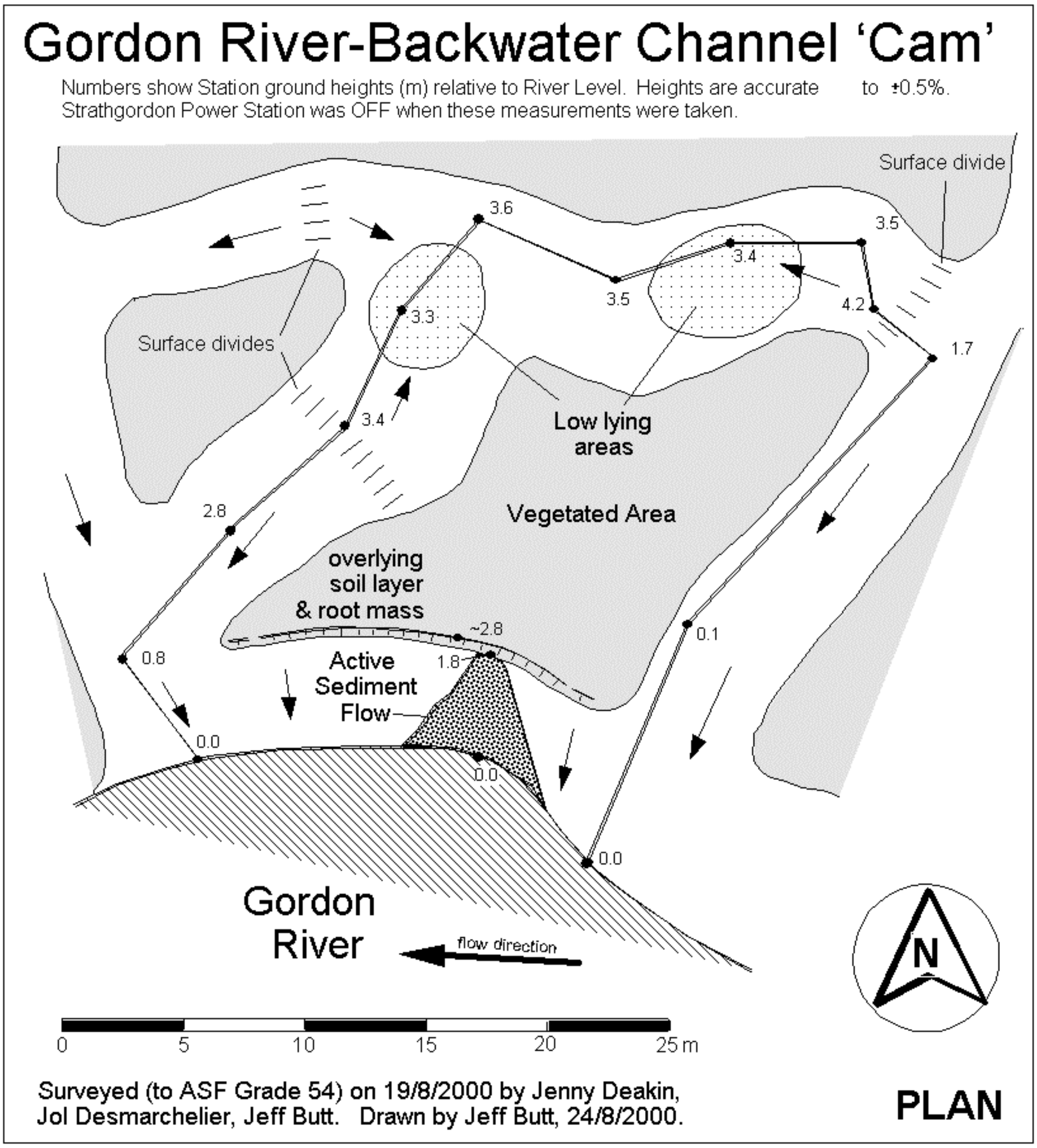


Figure 7a. Survey of backwater channel 'Cam'

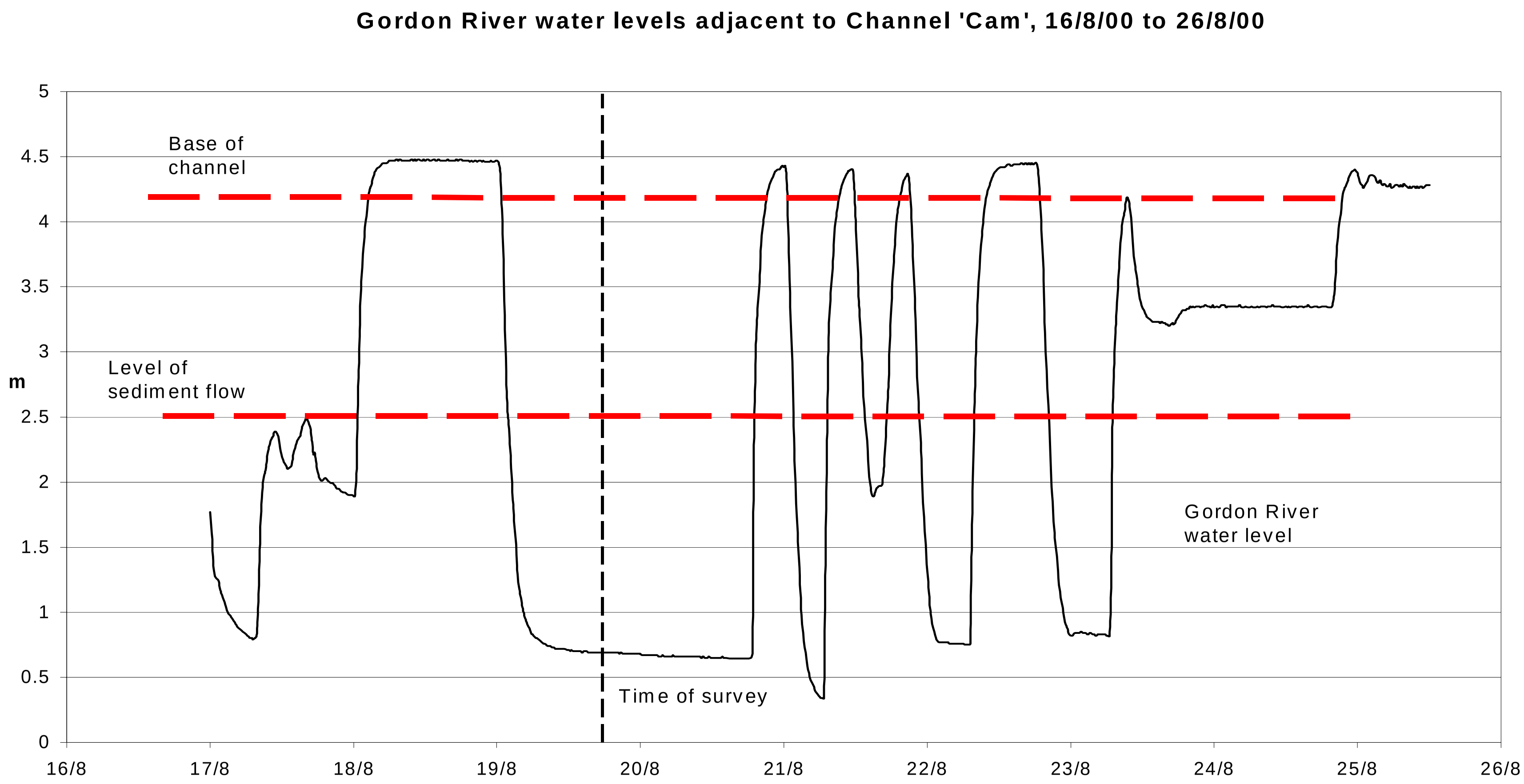


Figure 7b. Gordon River water in relation to channel 'Cam' and sediment flow

PLATES

Plate 1. Scum lines on the walls of Bill Neilson Cave

Plate 2. Sediments in the entrance chamber of Bill Neilson Cave.

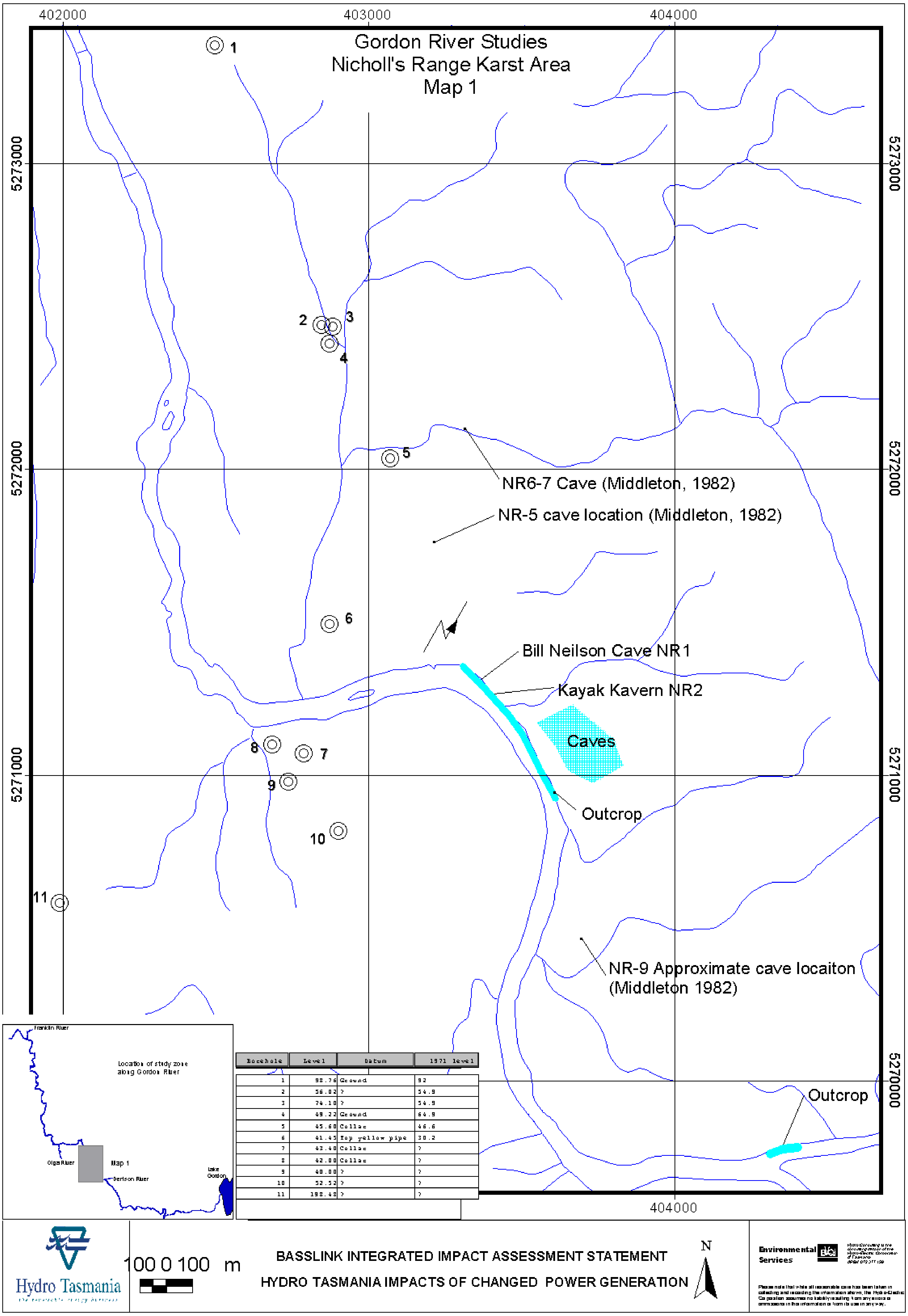
Plate 3. Sediment collapse in Bill Neilson Cave.

Plate 4. Sediment cracking in the entrance chamber of Bill Neilson Cave.

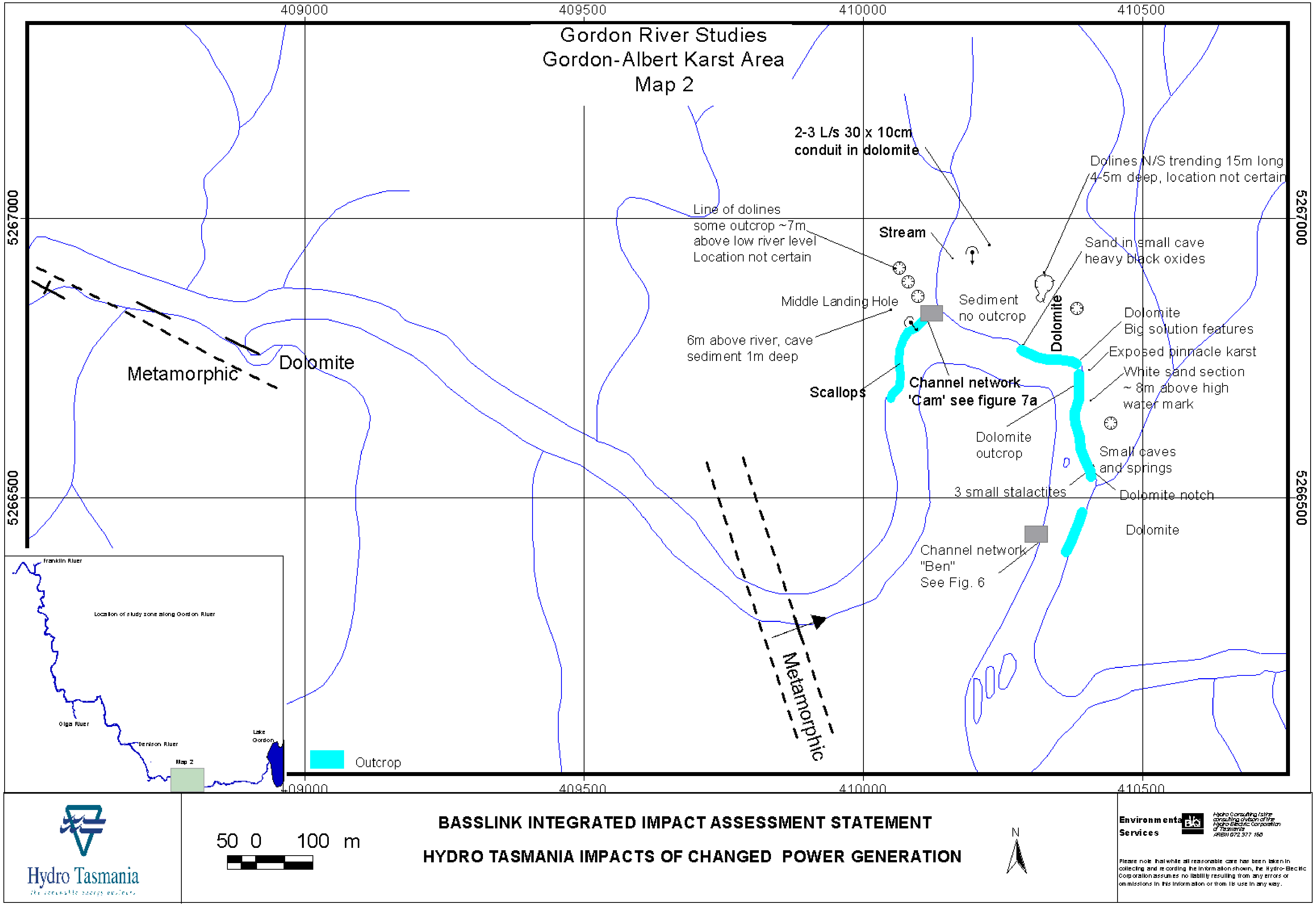
Plate 5. Solution feature in the dolomite of the Gordon–Albert karst area.

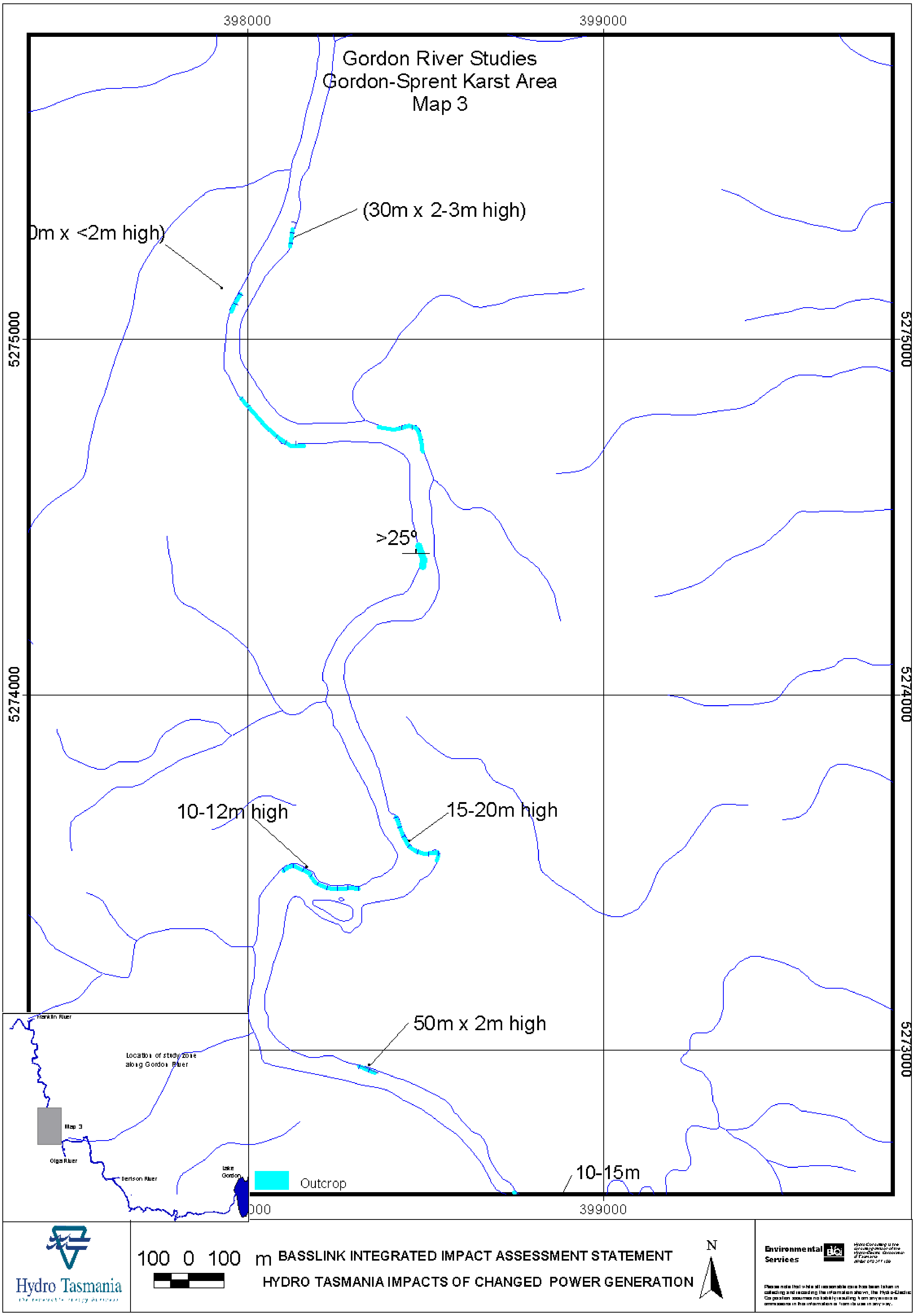
Plate 6. Backwater channel 'Ben'.

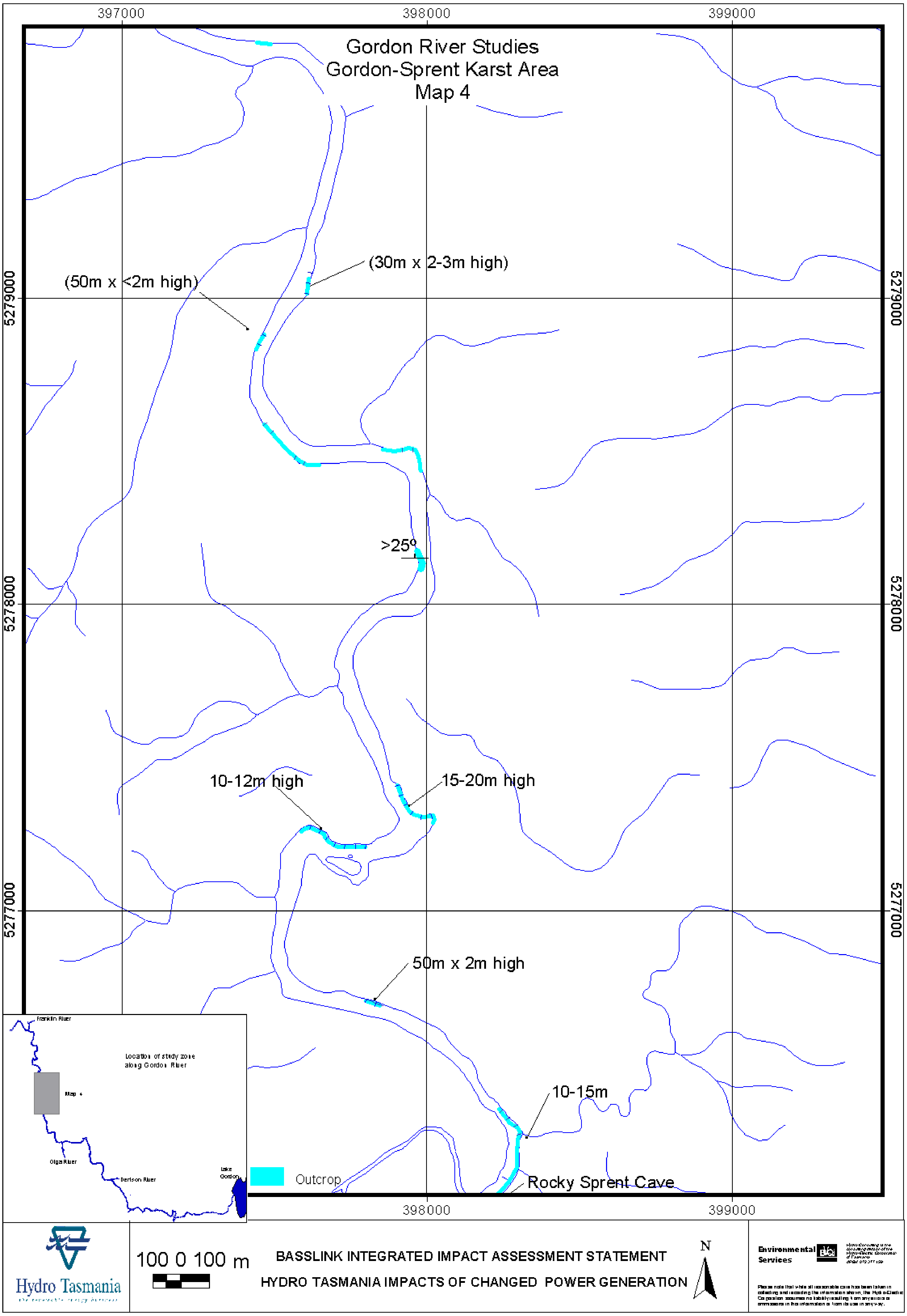
Plate 7. Sediment flow at channel 'Cam'.

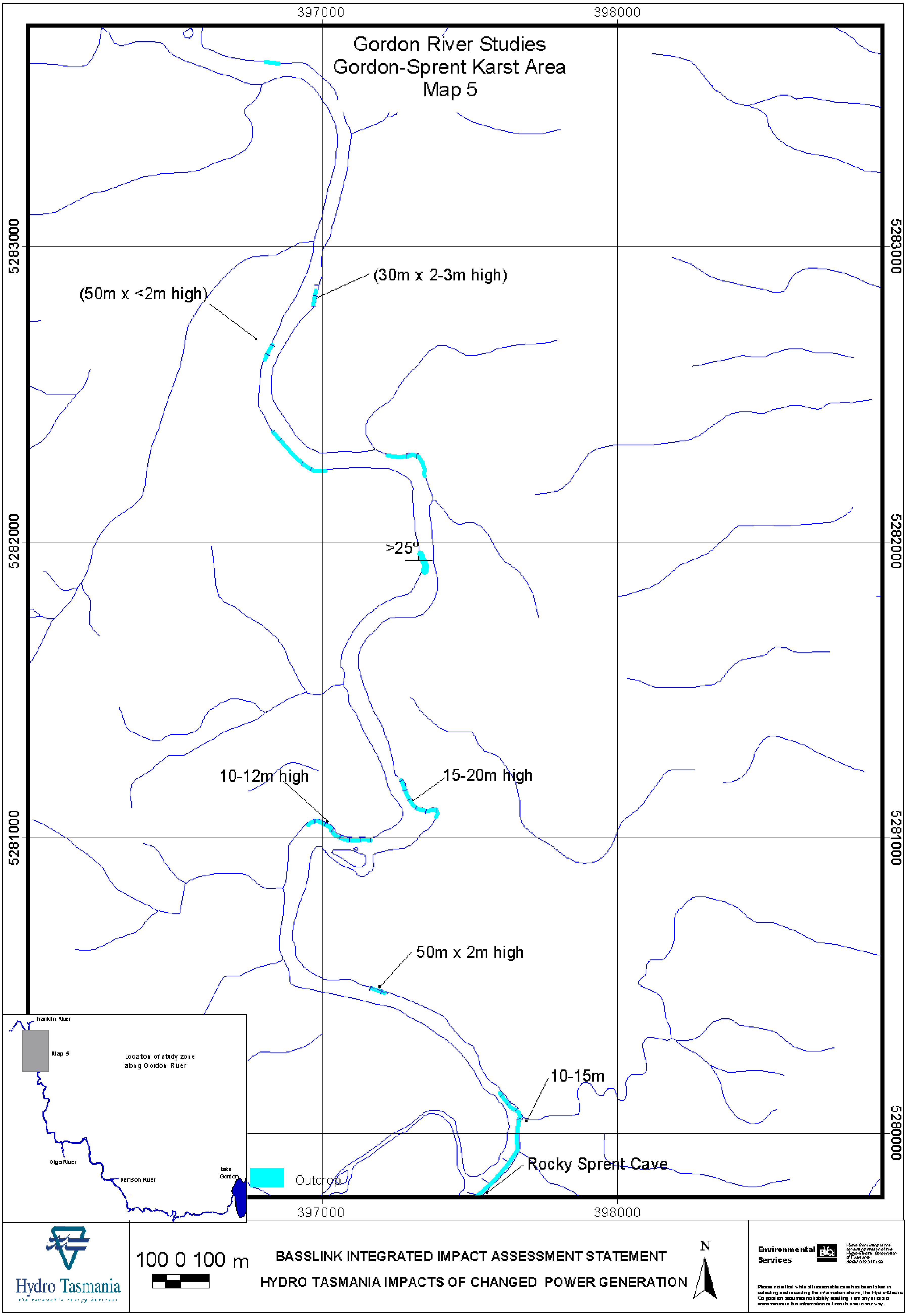


Borehole	Level	Datum	1971 level
1	98.76	Ground	92
2	56.02	?	54.9
3	74.10	?	54.9
4	49.22	Ground	64.9
5	45.60	Collar	46.6
6	41.45	Top yellow pipe	30.2
7	43.40	Collar	?
8	42.00	Collar	?
9	40.00	?	?
10	52.52	?	?
11	198.48	?	?


Gordon River Studies
Gordon-Albert Karst Area
Map 2
409000
409500
410000
410500
5267000
5266500
2-3 L/s 30 x 10cm conduit in dolomite
Dolines N/S trending 15m long 4-5m deep, location not certain
Line of dolines some outcrop ~7m above low river level Location not certain
Stream
Sand in small cave heavy black oxides
Middle Landing Hole
Sediment no outcrop
Dolomite
Dolomite Big solution features
Exposed pinnacle karst
6m above river, cave sediment 1m deep
White sand section ~ 8m above high water mark
Scallops
Channel network 'Cam' see figure 7a
Dolomite outcrop
Small caves and springs
3 small stalactites
Dolomite notch
Dolomite
Channel network "Ben" See Fig. 6
Metamorphic
Dolomite
Metamorphic
Outcrop
Franklin River
Location of study zone along Gordon River
Olga River
Denison River
Map 2
Lake Gordon
50 0 100 m
BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT
HYDRO TASMANIA IMPACTS OF CHANGED POWER GENERATION
N
Hydro Tasmania
Environmental Services


398000
399000
5275000
5274000
5273000
Gordon River Studies
Gordon-Sprent Karst Area
Map 3
(30m x 2-3m high)
0m x <2m high)
>25°
10-12m high
15-20m high
50m x 2m high
10-15m
Outcrop
Franklin River
Location of study zone along Gordon River
Map 3
Olga River
Denison River
Lake Gordon
000
399000
Hydro Tasmania
100 0 100 m
BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT
HYDRO TASMANIA IMPACTS OF CHANGED POWER GENERATION
N
Environmental Services


Gordon River Studies
Gordon-Sprent Karst Area
Map 4
397000
398000
399000
5279000
5278000
5277000
(50m x <2m high)
(30m x 2-3m high)
>25°
10-12m high
15-20m high
50m x 2m high
10-15m
Rocky Sprent Cave
Outcrop
Franklin River
Location of study zone along Gordon River
Map 4
Olga River
Denison River
Lake Gordon
100 0 100 m
BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT
HYDRO TASMANIA IMPACTS OF CHANGED POWER GENERATION
N
Hydro Tasmania
Environmental Services


Gordon River Studies
Gordon-Sprent Karst Area
Map 5
397000
398000
5283000
5282000
5281000
5280000
(50m x <2m high)
(30m x 2-3m high)
>25°
10-12m high
15-20m high
50m x 2m high
10-15m
Rocky Sprent Cave
Outcrop
Franklin River
Map 5
Location of study zone along Gordon River
Olga River
Denison River
Lake Gordon
Hydro Tasmania
100 0 100 m
BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT
HYDRO TASMANIA IMPACTS OF CHANGED POWER GENERATION
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Environmental Services