P T T & S H E R R Y

Geomorphological Assessment - Proposed Pulp Mill Effluent Pipeline Shoreline Crossing Area

Prepared for

Gunns Pty Ltd

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Prepared by: Dr Michael Pollington

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- CONSULTING ENGINEERS
- PROJECT MANAGERS
- BUILDING SURVEYORS
- ENVIRONMENTAL SCIENTISTS

Email: info@pittsh.com.au
Internet: www.pittsh.com.au

HOBART

Lower Ground Floor
Surrey House
199 Macquarie Street
DX 193
PO Box 94
Hobart Tas 7001
Australia
Ph: +61 (0) 3 6223 1800
Fax: +61 (0) 3 6223 1299

Other offices at:

- **Launceston**
- **Devonport**
- **Victoria**

INCORPORATED AS
PITT & SHERRY HOLDINGS PTY LTD
REGISTERED OFFICE:
33 GEORGE STREET
LAUNCESTON TAS 7250
AUSTRALIA

ABN 77 009 586 083

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	Name	**Signature**	**Date**
Authorised by:	**Dr Ian Woodward**		**24 March 2006**

1. Introduction

This report, prepared for Gunns Pty Ltd, provides a geomorphological assessment of the proposed effluent pipeline crossing area between Four Mile Bluff and Five Mile Bluff, east of the Tamar estuary.

The effluent pipeline will be of the order of 1 m in diameter. It is likely to be of steel construction, with a concrete outer coating in the offshore and coastal areas.

The report also provides an assessment of the likely impacts of sea level rise and increased storminess on the effluent pipeline route in the vicinity of the proposed shoreline crossing area during the anticipated 50 year life of the project.

The report is based on an inspection of aerial photographs, a literature review and two brief site visits in August 2005.

2. Geology

The geology of the area is summarised on the Beaconsfield 1:63360[1] geological map and in the associated explanatory report[2].

The area to the west is dominated by the Tamar estuary, which occupies a NW trending graben structure formed by large-scale normal faulting in the Tertiary.

The Tippogoree Hills, on the eastern side of the graben, consist of Jurassic dolerite that has been intruded into Permian and Triassic rocks.

Tertiary basalts are associated with the graben structure and also outcrop extensively along the coastline to the east.

Lower Palaeozoic sandstones and siltstones outcrop to the south east of the area.

2.1 Site Geology

Tertiary basalt forms cliffs and headlands, including Four and Five Mile Bluffs, and offshore reefs along some 15 km of the coastline from the Tamar estuary to east of Beechford.

[1] Gee, RD and Legge, PJ. 1971. Geological Atlas 1:63 360 series, Sheet 30 (8215N). **Beaconsfield**. Department of Mines, Tasmania.
[2] Gee, RD and Legge, PJ. 1979. Geological Survey Explanatory Report. Sheet 30 (8215N). **Beaconsfield**. Department of Mines, Tasmania.

The area is backed by Cimitiere Plain, a flat landform ranging from 15 – 30 m in altitude, which is essentially an erosional surface overlain by a Pleistocene aeolian deposit.

Cimitiere Plain has an extensive cover of windblown sands, which tend to be arranged in east-west ridges. The ridges strongly resemble longitudinal dunes and may reflect considerable transport, possibly from a glacial phase Bassian Plain.

2.2 Basalt

A sequence including at least two basaltic flows occurs in several places in the Tamar graben of the Beaconsfield quadrangle[3]. These basalt flows, which occur mainly as confined lava flows, dip gently to the north.

The basalt in this area is generally massive but has some scoriaceous layers. However, the relative extent of scoriaceous as opposed to massive basalt in this area is unknown.

In this area marine action on the basalt of the coastline has resulted in the production of coastal cliffs and an offshore wave-cut platform. The gentle seaward dip of the basalt flows in the area has resulted in the formation of a wave-cut platform that merges into an offshore reef. There is an extensive offshore "platform" that extends out to about the 40m water depth in the area.

The irregular surface of the platform and reef acts as a trap for cobbles, gravel and sand.

3. Geomorphology

3.1 Features

The coastline along this part of the north coastline of Tasmania is characterised by a series of beaches separated by rocky promontories. The proposed location of the effluent outfall is on the unnamed beach between two of these promontories, Four Mile Bluff on the west and Five Mile Bluff on the east.

The nearshore approaches to the beach in the area are characterised by a mix of permanent and transient areas of exposed reef, interspersed with a mobile sand bed. In some areas the reef has a surficial cover of pebbles and cobbles.

3.1.1 Wave Regime

The wave climate in the Four Mile Bluff area is a mix of diffracted oceanic swell and locally wind-generated waves.

[3] Gee and Legge, 1979.

The dominant south-westerly swells entering Bass Strait become north-westerly as they approach the north-east coast and have produced a series of beaches that run south-west to north-east on the north coast of Tasmania[4].

3.1.2 Wave Cut Platform

In this area marine action on the basalt of the coastline, including the exhumation of underlying rock structure by intertidal weathering, has resulted in the production of coastal cliffs and a shore platform (Figure 1). The gentle seaward dip of the basalt flows in the area has resulted in the formation of a wave-cut platform that merges into an extensive offshore “platform” that extends out to about the 40 m water depth.

The surface of this platform in the vicinity of the creek entrance to the beach is extremely weathered, where observed. Further west, towards Four Mile Bluff, the platform material is less deeply weathered.

Figure 1. Wave cut platform east of Four Mile Bluff

3.1.3 Beach

The beaches along this coastline have longitudinal sand ridges at the back of the beach, which feed easterly trending blow-out dunes. These beaches do not usually represent old persistent features, so that the sand dunes encroach upon older Tertiary deposits rather than on stranded beach ridges. The beaches are predominantly composed of quartz grains and a small amount of heavy minerals[5].

[4] Tasmania Natural Gas Project, DPEMP 2001
[5] Gee, RD and Legge, PJ. 1979. *Geological atlas 1 mile series. Sheet 30 (8215), Beaconsfield. Explanatory Report.* Department of Mines Tasmania.

The current beach in the proposed crossing area consists of a relatively thin sand cover over a wave-cut platform of highly to extremely weathered basalt. This cover was of the order of 0.4 m near the western end of the beach in August 2005. An accumulation of shingle occurs at the back of the beach (Figure 2) along most of the area to the east of the site, with larger accumulations to the west of the site, near the cliffs of Four Mile Bluff. The sand between the low and high tide levels is scattered with small pebbles along most of the beach (Figure 3).

Figure 2. Shingle at back of beach

Figure 3. Beach looking west

3.1.4 Dunes

An extensive area of beach and active dune sand occurs between Four and Five Mile Bluffs. Holocene beach and dune deposits occur in this area and are backed in the embayments either side of Five Mile Bluff by coastal dunes of interglacial age (120,000 years old) (Colhoun, 1989).

Extensive Holocene swell wave-aligned beach and dune complexes occur intermittently around Tasmania and the Bass Strait islands (Davies, 1960[6]). They were formed mainly after 6 ka when the Holocene transgression had attained present sea level (±1 m) (Colhoun, 1983[7]).

The beach is backed by a foredune that is currently being eroded (Figure 4). This foredune is highest on the western end (in the vicinity of the proposed crossing it is 6 – 8 m high) and lowest on the eastern end near Five Mile Bluff (1 – 2 m high).

Figure 4. Foredune, western end of beach

The foredunes in the area have been stabilised by marram grass. The hind dunes have been stabilised by a closed-scrub of coast wattle, prickly mimosa and marram grass. In some areas blowouts have developed in the foredunes, resulting in extensive inland movement of sand. Many of the older dunes have been sown to improved pasture[8].

Early aerial photos (1946) indicate that sand may be exported downdrift to the south of Four Mile Bluff. More recent aerial photos suggest that movement of

[6] Davies, JL, 1960. Beach alignment in southern Australia. *Australian Geographer* 8:42 – 44.
[7] Colhoun EA, 1983. Tasmanian sea level in the last 15,000 years. *In* Hopley D. ed. *Australian Sea Levels in the Last 15,000 Years*. James Cook University, Geography Department Occasional Paper 3:54 – 58.
[8] Pinkard, GJ. 1980. *Land Systems of Tasmania Region 4*, Tasmanian Department of Agriculture.

sand through this aeolian headland bypass system has been considerably reduced since 1946, probably as a result of the establishment of marram grass and the development of improved pastures.

3.1.5 Swales

Swales are long narrow or broad depressions that occur between two linear dunes (Figure 5). They may be shallow or deep and are frequently close to the watertable level. Where they are close to watertable swales often have a damp sandy, marshy or peaty floor. In the wider area they are very long and broad depressions, often with marshy or peaty floors, and drainage lines.

Figure 5. Swale behind foredune, looking west

3.1.6 Fluvial (Catchment)

Drainage to the coastline is restricted to a relatively small intermittent creek that enters the beach east of Four Mile Bluff and a much smaller drainage line close to Five Mile Bluff. The majority of the drainage from the wider hinterland reaches the coastline either west of Four Mile Bluff or east of Five Mile Bluff.

The creek east of Four Mile Bluff may have drained a wider area prior to the extensive drainage measures undertaken on the grazing land to the south and may have connected with the offshore channel in the area. This would appear to be supported by the deeply weathered nature of the shore platform in the vicinity of the creek entrance to the coast, compared with the areas to either side.

The creek catchment is very small (approx 2 km^2) and is restricted to an area of dunes and swales. The infiltration capacity of the dune sands is likely to be generally high but that of the swales much lower because of their organic content. The base flow in the catchment is relatively low, as evidenced by the intermittent nature of flow of the creek.

The Rational Method was used to estimate flows in the creek under a number of storm scenarios. The assumptions used were: critical storm duration of one hour, runoff coefficients of 0.3 – 0.65, ground surface cover of marram grass and swampy marshland. The results are shown in Table 1.

Recurrence Interval (years)	Flow (cumecs)	Velocity (m/sec)
1:1	2.3	1.85
1:2	2.95	2.0
1:5	3.59	2.12
1:10	4.03	2.19
1:20	4.66	2.28
1:50	5.56	2.39
1:100	6.31	2.45

Table 1. Estimated flow and velocity for a variety of storm events in the catchment

3.2 Processes

Marine and aeolian processes are the dominant forces shaping the coast in this area. Fluvial processes are much less important because most drainage from the wider hinterland reaches the coastline either west of Four Mile Bluff or east of Five Mile Bluff.

3.2.1 Waves

Under conditions normally prevailing in the area[9], maximum wave height ranges up to 1.9 m with waves beginning to break in water of about 3 m depth.

Wave height increases to about 3.8 m for a 10 year return period storm, with waves breaking at a depth of about 5 m. During a 100 year return period storm wave height is estimated to be 4.9 m, with waves breaking in water depth considerably greater than 5 m. Such extreme wave conditions would be most likely produced by north-westerly storms[10].

[9] Basslink, 2003. *Horizontal Directional Drilling: Briefing Paper*
[10] Tasmania Natural Gas Project, DPEMP 2001

A depth of 10 m can reasonably be taken to be the limit of significant wave influence on the seabed during a 100 year return period storm.

3.2.2 Longshore Drift

Where waves arrive obliquely on a coast the wave front carries sediment up the beach at the angle of wave approach but the backwash moves it back down at right angles to the beach front. As a result there is a net movement of sediment along the beach, away from the swell direction.

Because of the dominant north-westerly wave regime in the area there is a long term direction of movement of beach materials to the northeast, towards Five Mile Bluff. This long term movement, however, is commonly interrupted in the area by storm events[11]. Furthermore, studies have shown that sand is not transported alongshore in significant amounts in the area and little dispersion occurs from fluvial point sources[12].

3.2.3 Dune Erosion

The coastline between Four and Five Mile Bluffs is currently actively eroding (Figure 6).

Figure 6. Coastal erosion near western end of beach

Dune erosion includes any process that removes sand from the dune form or redistributes it on the dune form. Furthermore, the addition of considerable sand to the dune from the beach can also be considered a type of dune instability.

[11] Tasmania Natural Gas Project, DPEMP 2001
[12] Davies, JL and Hudson, JP. 1987. Differential supply and longshore transport as determinants of sediment distribution on the north coast of Tasmania. *Marine Geology*, **77**, 233 –245

In this area the dunes have been cut back by marine erosion to reveal a profile of younger dunes, older dunes, coffee rock, black clay and weathered Tertiary sediments. In many areas the surfaces of these dunes are also being actively modified by wind erosion.

The unconsolidated sands of the upper part of the dunes are being undermined as the front of the dunes are being cut back by marine erosion (Figure 7). As a result this loosely consolidated sand is falling down on to the beach, from where it is being redistributed by beach processes, either offshore or alongshore. Sand that is falling down on to the beach from the top of the existing dunes is being lost to the existing dunes in most areas as the onshore winds cannot lift these sediments back up on to the dune surface.

Figure 7. Collapsing unconsolidated dune sand

As the dunes are undermined the vegetation cover of the dunes is being destabilised, allowing the dune to become more prone to wind erosion. In some areas, particularly along the eastern end of the beach, this sand has become quite mobile, resulting in the development of blowouts of variable size.

3.2.4 Fluvial Erosion

Where the drainage line enters the beach zone east of Four Mile Bluff there is some periodic fluvial erosion. However, water flow is generally low and intermittent, with any effects on the beach zone soon modified by marine action.

4. Climate Change

Sea level rise and increased storminess are the expected outcomes of the observed variations in the patterns of climate throughout the world, known collectively as "climate change".

4.1 Sea Level Rise

A widely acknowledged outcome of the "greenhouse" effect is that sea levels in many, but not all, parts of the world have risen and will continue to rise. The main causes of this rise are the steric effect (expansion of the water column due to warming) and melting of global ice.

The amount of sea level rise at any particular locality is also affected by land uplift/subsidence in that area. Minor sea level changes can be cyclic, and may be enhanced in effect by changes in climatic variability but are rarely precisely known for a locality that does not have accurate tide gauge records.

Prediction of the potential rise in sea level over the next 100 years is based on computer modelling, but estimation of the likely amount, particularly in the longer term, is difficult.

4.1.1 Projected Sea Level Rise

The most widely accepted estimates of potential sea level rise are those of the United Nations Intergovernmental Panel on Climate Change (IPCC).

The IPCC[13] has estimated that sea level will rise by 20 cm (error band 7-39 cm) by 2050 and 49 cm (error band 20-86 cm) by 2100, ie. 4 mm/yr until 2050 increasing to 5.8 mm/yr until 2100.

Any estimate of future sea level rise in a particular area will be complicated by past and ongoing local uplift in that area.

Port Arthur Study

A recent study at Port Arthur[14], that might apply to much of eastern Tasmania, indicated a rise in relative sea level of 0.8 +/-0.2 mm per year between 1841 and 2002. The study also suggested that the land may have risen during this period by 0.2 mm +/-0.02 mm per year, implying an absolute sea level rise of ~1.0 mm/year for the period, which is a little more than half the 1.8 mm/year estimated from global records.

[13] IPCC, 2001. *Climate Change 2001; The Scientific Basis*. Eds Houghton *et al*. Intergovernmental Panel on Climate Change, Cambridge University Press, 881 pp.
[14] Pugh, D *et al*, 2002. A comparison of Historical and Recent Sea Level Measurements at Port Arthur, Tasmania. *International Hydrographic Review*, 3 (3) (New Series) November 2002.

An extrapolation of this data, using IPCC sea level rise estimates adjusted for local land uplift (ie. a net sea level rise of 3.8 mm/year until 2050), would suggest a maximum sea level rise of ~19 cm by 2050.

The applicability of the Port Arthur study to potential sea level rise in the Four Mile Bluff area is uncertain as the rate of uplift in this area is not known. Nevertheless, the figure of 19 cm has been adopted for the purposes of this study.

4.1.2 Effects of Sea Level Rise

The most significant effect of a rise in sea level is to raise the level of wave attack on the existing coastline. A raised level of wave attack on a coastline will result in existing areas being exposed to more consistent wave attack over time and new areas becoming exposed to wave attack. In addition, on a sandy coastline a rise in sea level may lead to recession of the coast.

The potential response of sandy coastlines to a rise in sea level has frequently been assessed by application of the Bruun Rule.

Bruun Rule

The Bruun Rule has been widely used to predict beach response to sea level rise. This "rule" proposed that with a sea level rise the beach profile would re-equilibrate in form due to the redistribution of a constant amount of energy. The result would be erosion of sand from the upper beach and seaward part of the dunes and deposition on the beach profile down to a closure depth close to wave base.

Equilibration of the average profile would cause the system to migrate landward, thereby causing erosion of the upper beach and dunes. That is, the existing coastline would "migrate" inland. A rule of thumb approximation of the potential impact is that recession of the coastline would be 100 times that of the sea level rise. That is, a rise of 10 cm in sea level would result in a recession of the coastline of the order of 10 m.

Application of this "rule" to the IPCC sea level rise estimate of ~19 cm by 2050 (adjusted for local land uplift) would suggest that recession of approximately 19 m might occur in a sandy coastline over this period.

However, it should be noted that although it has been widely used in planning to suggest safe setbacks for development, the validity and hence application of this "rule" for planning purposes has been seriously questioned, for example by Cooper and Pilkey[15], who concluded that the "rule" had no predictive value. They argued that it cannot, therefore, be used to hindcast what progradation, stability or retrogression has occurred on a beach and dune coast, nor can it forecast these factors under conditions of rising sea level.

[15] Cooper, JAG and Pilkey, OH. 2004. Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global and Planetary Change*. 43 (2004) 157 – 171.

The reasons why it is considered invalid by some workers are:

- The model only considered a simplistic 2-dimensional profile in the shallow water and beach zone and is based on some false assumptions (eg that erosion is a necessary outcome of sea level rise and that sediment is not removed beyond the closure depth).
- It confines itself to the effects of orbital waves operating directly onshore and does not consider longshore effects of oblique waves and sediment movement.
- It ignores the fact that with sea level rises of the order of magnitude envisaged by greenhouse effects, stability of position of shoreline or progradation are possible outcomes.

An understanding of the sediment budget of the coastline is necessary to predict whether progradation, stability or recession will occur in that particular area following sea level rise.

A modification of the Bruun Rule attempts to include sediment budget processes by predicting the loss of sediments from the system due to "winnowing" of fine material. This is often expressed in terms of an "overfill" factor, which represents the factor by which sediment would need to be added to the system to achieve stable volumes of native material. An overfill factor of 1 means that the system would be stable. An overfill factor of 1.5 means that one and a half times the unit volume of material would need to be added to achieve stability.

Based on published estimates for different types of materials[16], the aeolian sands at the site can be assumed to have an overfill factor of approximately 1. The sediment created by weathering of the underlying basalt platform could have an overfill factor in the order of 5. The net overfill factor will be a combination of the two depending on the relative proportions of the materials exposed in the system at a given time. For the purposes of this study, a net factor of 2 has been assumed.

4.2 Increased Storminess

It is anticipated that the intensity of storm events will increase with the projected changes in climatic patterns. In addition, such events are expected to become more frequent, that is, the recurrence interval of major storm events will decrease.

[16] USACE (1984) Shoreline Protection Manual Volume 1, Chapter 5.

5. Potential Impacts of Climate Change on the Area between Four and Five Mile Bluffs

5.1 Sea Level Rise

As a result of sea level rise the level of wave attack on the existing coastline will be raised, resulting in existing areas being exposed to more consistent wave attack over time and new areas becoming exposed to wave attack.

This will result in some change in the location and form of the beach and cutting back of the existing foredune. Undercutting and destabilisation of these dunes will result in the loss of vegetation cover, increased mobility of the dunes and an increase in the incidence of blowouts.

The existing foredune may be overtopped by storm waves at the eastern end of the beach, near Five Mile Bluff. Prolonged overtopping of this foredune may eventually lead to the existing swale behind this foredune becoming a lagoon. If sea level rises sufficiently and the overtopped area is kept open by marine action, this lagoon will eventually become an arm of the sea.

The amount and spatial variation of sediments on the existing wave cut platform may be significantly altered over time but there is unlikely to be any significant alteration of the platform surface. Coastal recession is only likely to strip the overlying dunes and some of the Tertiary sediments off this platform.

Continued sea level rise may lead to significant recession of the coastline, an increase in the current rate of erosion on this section of the coastline, and an increased rate of recession in this area.

The underlying Tertiary sediments are more resistant to erosion than the semi and unconsolidated overlying dune sediments. The rate of recession on this part of the coastline is therefore likely to be less than it would be if the foredune extended down to the existing beach level.

5.2 Increased Storminess

5.2.1 Coastal Impact

Increased storminess would result in larger, more energetic waves reaching the back of the beach more frequently, leading to greater impact on the back of the beach and the dunes. Compounding this, an increase in the intensity of barometric depression results in an effective sea level rise of approximately 1 cm for each 1 hPa reduction in pressure[17].

[17] NSW Government (1990) NSW Coastline Management Manual.

The CSIRO has predicted an increase in average intensity of up to 1 hPa for the most intense lows (defined as the top 1% of events) in the Bass Strait region under an enhanced Greenhouse effect (doubling of CO_2 concentrations)[18]. This could result in a sea level rise of 1 cm.

With greater frequency of storm events, the beach may not have time to replenish and rebuild between storms. As a result, subsequent storms would have greater impact on the coastline, leading to increased rate of coastal recession.

A severe storm event could result in the removal of most or all of the sand on the existing beach, with the area being stripped back to the wave-cut platform surface on the highly to extremely weathered basalt. The wave cut platform is unlikely to be significantly eroded during any one particular storm event.

The size and shape of the beach maintained in the area will be dependent on the availability of sediments to the beach and the ultimate dispersal of these materials by wave and wind action. Wave activity due to increased storminess may be sufficiently strong to move some or all of these sediments offshore, over the edge of the reef, or alongshore. These sediments would then become lost to the beach replenishment budget. Reduced beach replenishment would leave the foredune more exposed to wave attack.

5.2.2 Impact on Fluvial Processes

The creek draining onto the beach at the western end, near Four Mile Bluff, has a very small catchment area. The time of concentration for any storm event will be small because of the small size of the catchment and flow will drop off rapidly following cessation of the rainfall event.

Infiltration capacity of the dunes may be relatively high initially, depending on vegetation cover and previous rainfall events but if the rainfall intensity is greater than the infiltration capacity, runoff will occur. Runoff will drop off rapidly once a rainfall event ceases, but flow in the creek will be temporarily augmented by the increased outflow from the raised watertable.

Potential increased creek flow associated with storm events will probably not be sufficiently high to cause erosion where areas are well vegetated. However, as the estimated velocities within the creek channel for all storm events exceed the minimum velocity required for the erosion of fine sand, unvegetated or sparsely vegetated areas will be prone to significant fluvial erosion during storm events.

[18] CSIRO Division of Atmospheric Research (March 2003) Climate Change in South Australia – Assessment of Possible Climate Change, Impacts and Possible Adaptation Strategies Relevant to South Australia.

6. Consequences

6.1 Potential Pipeline Impacts on Coastal Processes

An exposed pipeline across the coastal areas would have significant impact on coastal geomorphological processes. It would alter the prevailing wave approach patterns in the vicinity of the pipeline, thereby impacting on beach erosion and deposition and longshore drift. An exposed pipeline would also have significant localised hydrodynamic effects and be subject to scouring.

In the region of the shoreline crossing, the pipe is likely to be approximately 1 m in diameter, and be of steel construction with a concrete outer coating in the offshore and onshore areas. It will have low flexibility and therefore limited ability to self bury. Burial in a constructed trench will be necessary.

Emplacement of the pipeline within a trench through the nearshore area to the nominal limit (10 m water depth) of significant wave influence on the seabed during a 100 year return period storm would reduce the potential risk of initiation of hydrodynamic and scouring impacts to an acceptable level. We note that the conceptual engineering study has made a more conservative estimate and has recommended trenching to the 15 m water depth[19].

6.2 Areas at Risk

The existing beach, coastline and drainage lines are all potentially at risk as a result of sea level rise and climate change.

6.2.1 Beach Erosion

Sea level rise and increased storminess may result in increased beach erosion in the area, including potential loss of the existing thin sand cover in the area.

However, if significant amounts of sand are retained in the local environment as a result of erosion from the larger dunes, more material will become available to maintain and enhance the beach. Such maintenance and enhancement of the beach would provide some protection for the remaining dunes as it would act to reduce impact on the coastline in this area and hence slow up the rate of recession.

6.2.2 Past Coastal Recession

Sea level rise is likely to result in ongoing recession of the coastline in this area. This recession will involve ongoing truncation of the existing foredune

[19] Atteris Pty Ltd, March 2006. Bell Bay Pulp Mill Ocean Outfall Conceptual Engineering Study. Section 4.3.6 Pipeline Stability Design.

and continued erosion of the underlying Tertiary sediments. The underlying basalt platform may be exposed as the foredune and sediments are removed but it is unlikely to be significantly eroded. The potential rate of erosion of the unconsolidated dune sands is likely to be reduced in this area by the presence of the underlying consolidated and semi-consolidated sediments. As a result ongoing coastal recession in this area may be less than might be expected.

The foredune on the eastern end of the beach, where the underlying Tertiary sediments are less prominent or absent and the dune is much lower, may be cut back more rapidly than on the western end near Four Mile Bluff.

Recession of the coastline may be altered by significant erosion of the foredune on the western end. The significance of the release of large quantities of sand to the beach would depend on whether this material was moved alongshore away from the site, moved offshore and lost over the edge of the reef or whether it largely remained to be recycled as beach sediment. Retention of a large sand supply in the area may result in the development of an incipient dune at the back of the beach and an overall slowing of the rate of recession, at least in the short term.

Air Photo Interpretation:

Examination of air photo coverage of the area over the period from 1946 to 2005, shown in Appendix A, suggests that along the section of the coastline between Four and Five Mile Bluffs:

- Between 1946 and 1961 the coastline was prograding (ie. moving seaward); progradation appears to have been of the order of 30 m to 45 m.

- Between 1961 and 1985 the coastline receded, and the recession was of the order of 20 m over much of the coastline; it is not known whether recession was relatively constant over this period or whether it occurred largely as a result of one or more large storm events.

- Between 1985 and 2005 there was no apparent recession over much of the coastline, with minor recession on the western and eastern ends.

The apparent variability in the rate of recession on this section of the coastline over the period from 1946 to 2005 may reflect a number of factors including:

- In 1946 an extensive area of unconsolidated dune sands, largely devoid of vegetation, existed to the east of the site, south of Five Mile Bluff. The presence of this extensive area of unconsolidated sands at that point in time may be due to the occurrence of a significant devegetation event shortly before the 1946 photo was taken, but this cannot be confirmed.

- The development of the marram grass cover behind Five Mile Bluff has considerably reduced the impact of wind erosion in the area, stabilising the coastal dunes and thereby reducing the rate of recession.

- There may have been greater storminess over at least part of the period from 1961 to 1985, as compared with the period from 1985 to 2005.

- Impacts on different parts of the coastline over this period of time may reflect changes in the directions of storm wave approach.

- Erosion in the period from 1961 to 1985 may have removed the semi-consolidated and unconsolidated sediments. This would have exposed the underlying more resistant consolidated silts and clays, resulting in a reduction in the rate of recession.

In summary, over the 60 year period from 1946 to 2005, the net movement in the coastline appears to have been relatively small. However, this overall picture clouds the underlying dynamics which show a progradation during the first 20 years, a recession over the next 20 years and an apparent stable period over the last 20 years.

A possible explanation of this is that the progradation and recession over the first 40 years involved unconsolidated and semi-consolidated sediments, which finally were removed to expose underlying consolidated sediments, which are much more stable. Over this period, an additional stabilising factor was introduced through the introduction of marram grass.

6.2.3 Future Coastal Recession

Air Photo Interpretation:

The apparent variability in the rate of coastal recession over the last 60 years makes prediction of likely recession over the next 50 years difficult.

Even in the absence of sea level rise, some recession would be expected on this coastline because the beaches appear generally to be in a recessional state. A recession of 2 m over the next 50 years might reasonably be expected.

Based on the air photo evidence for the 45 years from 1961 to 2005, coastline recession of the order of 20 to 25 m might be anticipated in this area over the next 50 years. Any such estimate, however, can only be considered to be indicative. The actual rate of recession will be affected by factors such as the occurrence and intensity of storm events, changes in the direction of approach of major storm waves and dispersal of eroded sediments along and offshore.

If the above explanation (section 6.2.2) for the apparent changes in the coastline over the last 60 years is correct, the current beach form is likely to be significantly more stable than it was in the period from 60 to 20 years ago. The large coastline movements experienced during that earlier period would then be unlikely to be repeated in the future unless and until fresh unconsolidated sediments are brought back onto the beach. If this did occur, the gross movements would be in those unconsolidated sediments and the underlying consolidated sediments would be less affected.

By their nature, foredunes are likely to be less consolidated than underlying sands, and represent a greater erosion risk.

Based on aerial photo interpretation, the limit of likely beach recession over the next 50 years can reasonably be taken to be a distance of 25 m inland from the back of the existing beach.

Bruun Rule Calculations:

Notwithstanding the questioning of the validity of the Bruun rule discussed in section 4.1.2, an estimation of the predicted extent of coastal recession using this rule is calculated below for comparison with the above estimates from air photo interpretation.

The following assumptions are made:

- A eustatic rise in sea level of 20 cm by 2050 (section 4.1.1)
- Tectonic uplift of 1 cm (see section 4.1.1)
- Bruun rule of thumb factor (F) of 100 (section 4.1.2)
- An overall winnowing (overfill) factor (w) of 2 (section 4.1.2)
- A storm barometric factor of 1 cm (section 4.2)
- A minimum expected retreat in the absence of sea level rise (e) of 2 m (section 6.2.3).

The effective sea level rise is then:

S_e = 0.2 m (eustatic rise) – 0.01 m (uplift) + 0.01 m (storm barometric factor)
= 0.2 m

and the predicted net recession is:

$R = S_eFw + e = 0.2 \times 100 \times 2 + 2 = 42$ m.

Using the Bruun rule, the potential shoreline recession over the next 50 years is 42 m.

6.2.4 Drainage Lines

Erosion along the existing drainage lines is only likely to be an issue where the vegetation cover of the sands is removed or significantly reduced or where it is necessary to excavate across drainage lines.

6.3 Pipeline Exposure Risk

The various zones of the beach system present particular risks of exposure of a buried pipeline.

Nearshore

The risk of pipeline exposure in the nearshore zone will be dependent on where in the vertical profile that the pipeline is located.

If the pipeline is laid in a trench that is completely within the highly to extremely weathered basalt in the existing nearshore zone it is considered unlikely that it will become exposed over the projected lifetime of the project. However, if the trench is of such a depth that the pipeline is partially or completely in the overlying beach sands it will almost certainly become exposed at various times as the sand is periodically moved offshore. This could have detrimental impacts not only on the pipeline itself but also on beach processes.

Foredune

The risk of pipeline exposure in the present fore dune area is high because of potential coastal erosion and recession that would lead to the foredunes moving inland, exposing a pipeline that was not buried to a sufficient depth.

Potentially, the seaward edge of the foredune could move 25 to 42 m inland from its current position (from section 6.2.3). The zone between the current high water mark and 25 to 42 m inland therefore represents the exposure risk zone. The first 25 m can reasonably be taken to be a higher risk zone and the next 17 m a lower risk zone. Inland of the recession limit, burial rather than exposure is the likely outcome of recession, as the foredunes reposition inland from the new high water mark.

Exposure risk will be considerably reduced, and possibly eliminated, if the pipeline is laid within the underlying weathered basalt. To provide an adequate safety margin in the high risk zone, burial to a depth that provides at least 2 m of cover by weathered basalt in the first 25 m inland from the present high water mark is recommended. From this point inland, the pipeline could be allowed to rise gradually, reflecting the progressively lower exposure risk.

The design proposed by Atteris[20] has a maximum pipeline gradient of 9% in the first 100 m inland (reaching the existing ground surface approximately 65 m inland from the back of the current beach). At a 9% gradient, in the 17 m between the 25 m and 42 m marks, the pipeline could therefore rise 1.5 m. Fixing a minimum burial (top of pipe) in the weathered basalt of 2 m at the 25 m mark means that there would still be 0.5 m burial (top of pipe) in weathered basalt at the 42 m mark (in addition to any remaining overlying sands) if the worst case of a horizontal basalt layer is assumed. In fact, the

[20] Atteris Pty Ltd (2005) *Bell Bay Pulp Mill Project Ocean Outfall Conceptual Engineering Study.*

basalt layer almost certainly rises inland (section 2.2), meaning the burial depth at the 42 m mark would be greater than 0.5 m.
The above is considered to provide an adequate safety margin against pipeline exposure for the next 50 years.

Swale
The risk of pipeline exposure across the existing swale at the back of the foredune is currently considered to be very low. This risk, however, will increase substantially if sea level rise results in the current foredune being completely eroded away and the sand moved offshore.

If the existing foredune migrates inland with a rise in sea level a buried pipeline is likely to stay covered but if it is completely removed a pipeline not buried within the underlying weathered basalt may become uncovered.

Old Dune Area
Sea level rise is considered unlikely to have any significant impact on the old dune area, at least in the projected lifetime of the proposal. Exposure of a pipeline laid within the dune is therefore considered extremely unlikely provided that the trench is properly rehabilitated and revegetated.

With appropriate construction methods, careful rehabilitation and maintenance of vegetation cover, the risk in this area is considered to be very low.

Inland
The risk of pipeline exposure as a result of fluvial erosion will be dependent on how close the pipeline is placed to the existing drainage lines and how well vegetation along the drainage lines is maintained. Additional protective measures may be required where the pipeline crosses drainage lines.

With appropriate construction methods, careful rehabilitation and maintenance of vegetation cover, the risk in this area is considered to be very low.

6.4 Remediation of Construction Impacts

Remediation and revegetation of the shoreline crossing area of the ocean outfall have been addressed in a separate report[21]. That report notes that the inland movement of disturbed sand as a result of wind action (ie. dune blow out) is potentially the most significant environmental problem in the coastal zone associated with the works.

As described in the remediation and revegetation report, the pipeline contractor will be required to develop a detailed Construction Environment Management Plan (CEMP) for the dune crossing area prior to commencement

[21] Pitt & Sherry (2005). Gunns Pulp Mill Effluent Pipeline Four Mile Bluff Dune Crossing Remediation and Revegetation.

of trench construction and pipeline installation. That plan will address all environmental management measures to be undertaken prior to construction, during construction and after completion of the work and will also contain details of how the success of the rehabilitation measures will be assessed and how any post-construction problems that may arise will be addressed.

7. Recommendations

In the light of the above discussion and the inherent uncertainties in attempting to predict sea level rise and coastal recession, it is recommended that:

1. For the first 25 m inland from the current high water mark, the pipeline should be laid in a trench excavated into the weathered basalt underlying the beach sediments to achieve a minimum top of the pipe burial in the basalt of 2 m.

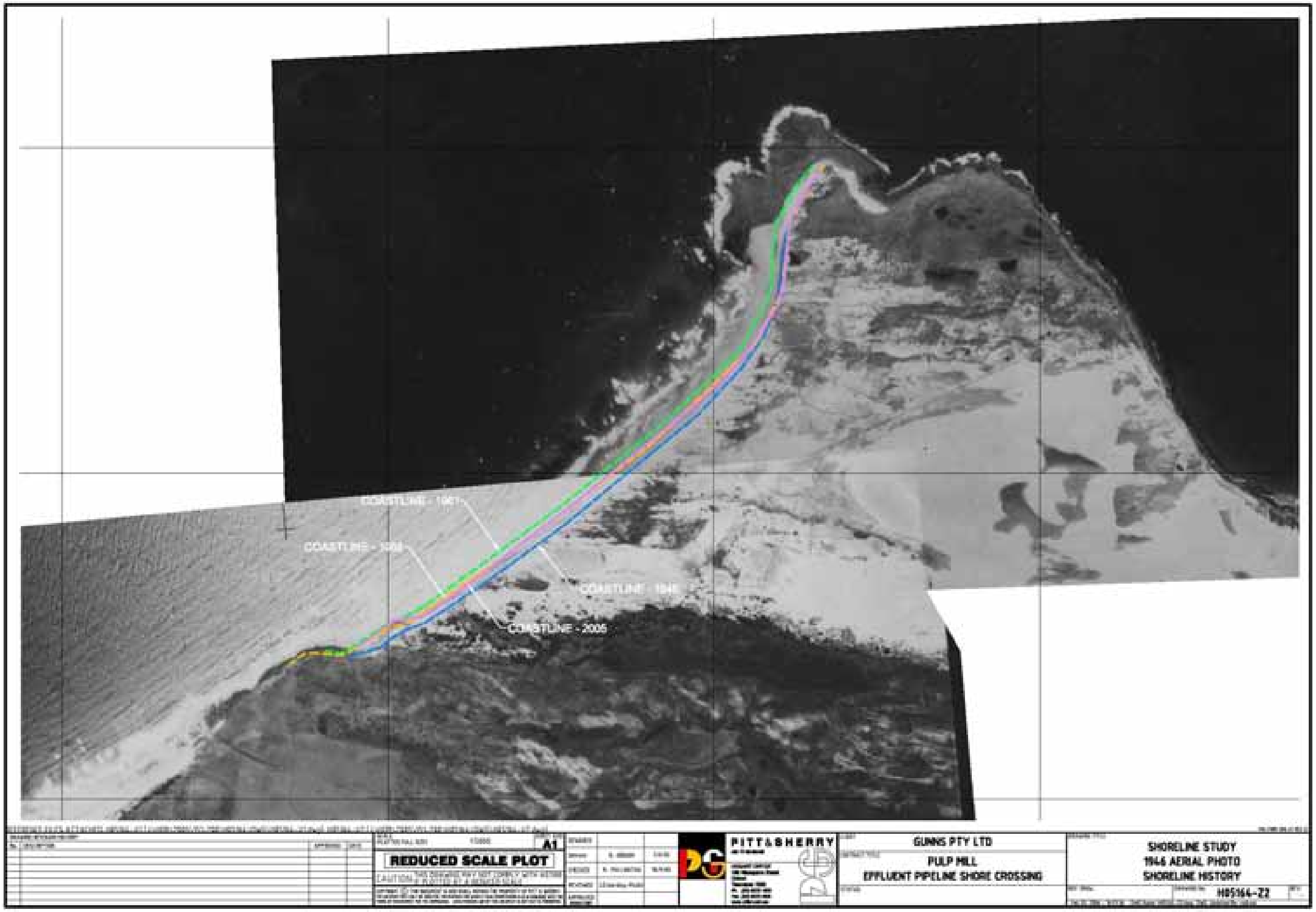
2. Inland from the 25 m mark, the pipeline should rise at no more than 9% gradient until at least the 42 m mark, so as to achieve a minimum top of pipe burial in the basalt at this point of 0.5 m. If detailed geotechnical investigations confirm that the basalt layer rises inland, the pipeline gradient could be increased accordingly provided that at least 0.5 m burial is achieved at the 42 m mark.

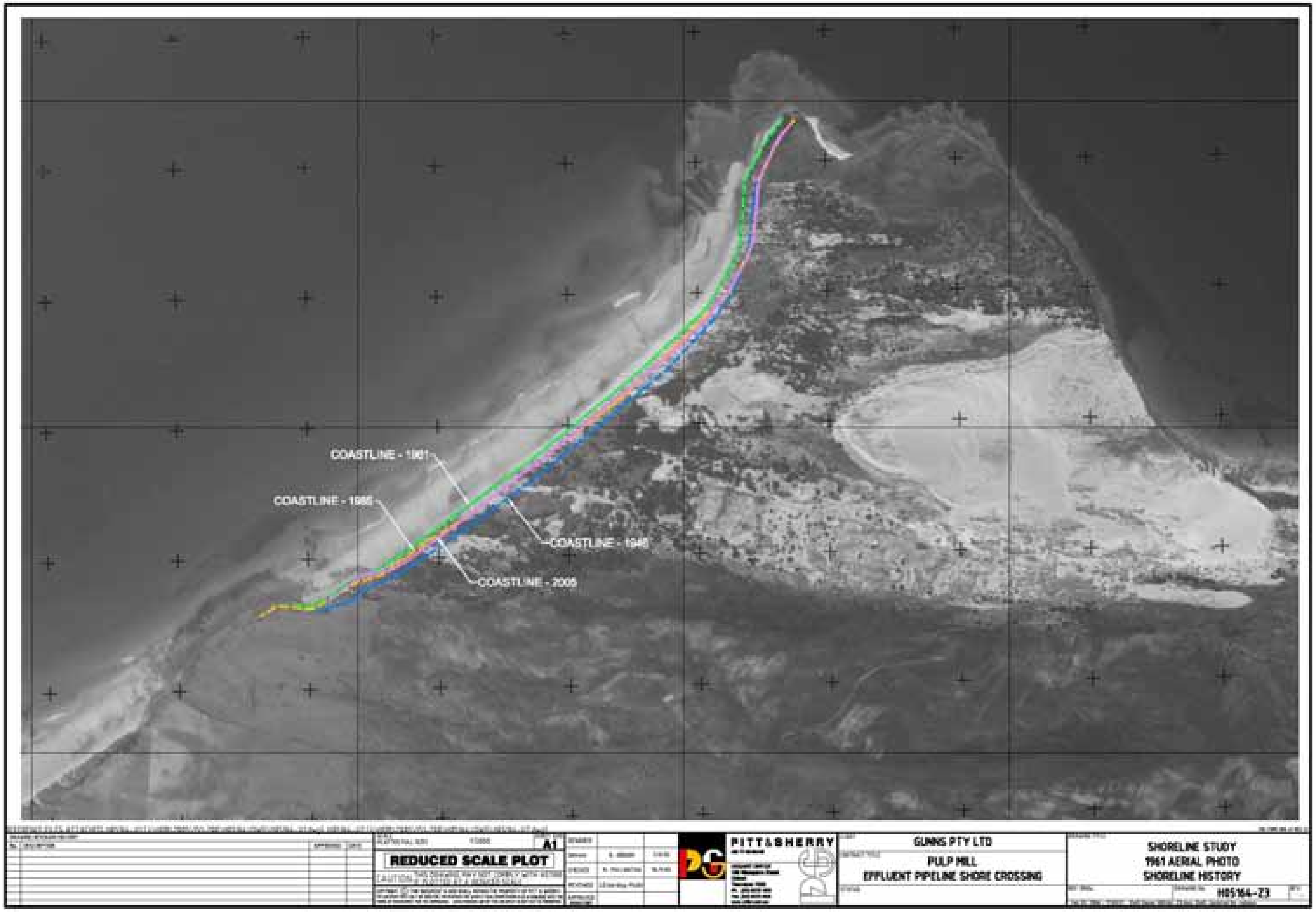
3. The pipeline trench in the weathered basalt should be extended seaward through the nearshore area to at least the nominal limit (10 m water depth) of significant wave influence on the seabed during a 100 year return period storm. It is noted that the conceptual engineering study has proposed trenching to a water depth of 15 m.

Appendix A

AERIAL PHOTO SHORELINE HISTORY


COASTLINE - 1961
COASTLINE - 1985
COASTLINE - 1946
COASTLINE - 2005
REDUCED SCALE PLOT
A1
PITT&SHERRY
GUNNS PTY LTD
PULP MILL
EFFLUENT PIPELINE SHORE CROSSING
SHORELINE STUDY
2005 AERIAL PHOTO
SHORELINE HISTORY
H05164-Z1


COASTLINE - 1946
COASTLINE - 2005
REDUCED SCALE PLOT
A1
PITT&SHERRY
GUNNS PTY LTD
PULP MILL
EFFLUENT PIPELINE SHORE CROSSING
SHORELINE STUDY
1946 AERIAL PHOTO
SHORELINE HISTORY
H05164-Z2


COASTLINE - 1961
COASTLINE - 1986
COASTLINE - 1946
COASTLINE - 2005
REDUCED SCALE PLOT
A1
PITT&SHERRY
GUNNS PTY LTD
PULP MILL
EFFLUENT PIPELINE SHORE CROSSING
SHORELINE STUDY
1961 AERIAL PHOTO
SHORELINE HISTORY
H05164-Z3

REDUCED SCALE PLOT

PITT & SHERRY

GUNNS PTY LTD

PULP MILL

EFFLUENT PIPELINE SHORE CROSSING

SHORELINE STUDY

1985 AERIAL PHOTO

SHORELINE HISTORY

H05164-Z4