

ANGLESEA RIVER WATER QUALITY REVIEW

Independent Review by Professor William Maher

October 2011



Executive Summary

Anglesea River, its tributaries and the estuary experience frequent low pH water quality (pH 3-4) or acid flows. The Anglesea catchment has two natural sources of acid from significant amounts of coal and tea tree marshes (swamps) above the water table. Given the extent of coal and associated pyrites, it is reasonable to consider that the catchment holds significant acid- generating potential. Marshes make up only a small percentage of the total catchment area and may contribute some acid input, but are unlikely to be the major natural source of acid.

Rainfall is the main factor which determines whether or not an acid flush occurs. In other words, rain in the catchment creates, collects and transports acid. The flush of acid from the catchment is made worse when a dry period is followed by soaking rains through autumn to spring. Major fish kills have usually occurred after dry periods followed by rain.

The only potential major anthropogenic (caused by human activity) source of acid is wet and dry sulphur deposition (acid rain) from coal burning at Alcoa's power generation station. Approximately 37 Kilotonnes (Kt) of sulphur is emitted each year, with approximately 1.6 to 3.9Kt deposited in the Marshy Creek catchment. Soil and vegetation surveys show no indication of significant quantities of acid rain, decreased soil pH or change in soil properties that would otherwise indicate soil acidification. Chloride/sulphate ratios do indicate enriched sulphate concentrations across the Anglesea catchment but sulphate concentrations for Marshy Creek (inside the plume area) are significantly less than the sulphate concentrations measured in Salt Creek. If significant sulphur deposition did occur, Marshy Creek and its tributaries would be expected show higher levels of sulphate. At this time there is no evidence to indicate acid rain is a significant source of acid.

There is clear evidence of high concentrations of aluminium, iron, manganese and associated trace elements entering the Anglesea River and estuary after rainfall, as well as evidence of aluminium and iron floccating (building up) on seagrasses. There is little evidence that sediments containing elevated trace metals are being deposited in the estuary, although the data available is nearly 30 years old.

Three sources are likely to be contributing trace metals to the estuary:

- natural sources;
- activities associated with power generation; and
- storm water runoff from the Anglesea township.

No data is available to assess the inputs from township runoff. There is clear evidence of naturally elevated aluminium, iron, manganese and boron concentrations in streams and tributaries which drain into the Anglesea River. This is expected in situations where there are flows from acidic soils with underlying coal deposits, acid sulphate soils and marshes rich in these elements. Aluminium and iron are particularly soluble under oxidizing conditions at low pH.

Alcoa ash pond effluent provided a source of dissolved salts including trace metals and boron, but of the trace metals measured, only aluminium, nickel and zinc marginally exceed ANZECC/ARMCANZ (2000) trigger levels for the protection of freshwater aquatic organisms in moderately disturbed systems. During periods of high flow when fish deaths occur, the contribution

of aluminium is relatively small (less than 0.06%). During low flows the ash pond effluent will be a significant source of base metals; however the relative contribution and impact of the catchment and effluent on the Anglesea River freshwater ecosystems remains unclear.

Boron concentrations in water discharged from the ash pond grossly exceeds the ANZECC/ARMCANZ (2000) guideline for boron and at periods of low flow, when the ash dam constitutes most of the river flow, be possibly detrimental to the Anglesea River freshwater ecosystems downstream of the power plant. In the estuary, however, as boron concentrations are naturally high in seawater, boron should not constitute a problem to marine life.

In his public submission, Frank Parsons provided data on water samples measured in the Anglesea River below Alcoa's discharge point between 30 October 2010 and 6 February 2011. This data shows trace metal and boron concentrations regularly exceeding the ANZECC/ARMCANZ (2000) trigger levels for toxicity to aquatic organisms. Without trace metal load data (flow and trace metal concentration data) taken during this time it is not possible to evaluate the relative contribution of natural and other sources to trace metal loads entering the Anglesea River.

It is likely that floccation of iron, manganese and aluminium occurs where acidic tributary waters meet neutral to alkaline waters discharged by Alcoa. After heavy rain, pH drops and built-up material probably releases associated trace metals. However, the significance of this as a source of trace metals during an acid flush event is unknown.

Estuarine mixing of freshwater and saline water is likely to flocculate most of the dissolved aluminium, iron and manganese and other associated trace metals. In particular, aluminium is removed by the time a salinity level of 8 parts per thousand (ppt) is reached. It is expected that some of this material would be re-solubilised during floods as the pH and salinity drop. Where this occurs will depend on the flow of freshwater into the estuary. During low flow, flocculation will occur at Coal Mine Rd at the head of the estuary. During high flow, if a layer of fresh water exists over the more saline estuarine water, flocculation will occur at the boundary where fresh water and sea water meet, and will continue as far as the layer of freshwater extends into the estuary. It may also occur on the gills of fish in this section of water.

Conclusions

Low pH waters result from natural processes in the catchment in which sulphides in coal and other pyritic materials are oxidised. There is no evidence of any significant input of acid from oxidation of sulphur dioxide emitted from Alcoa's coal-fired power plant. A flush of acid water occurs after prolonged periods of low rainfall, followed by soaking rain. Large amounts of aluminium, iron, boron and probably associated trace metals are generated and transported naturally during acid formation.

Alcoa discharges aluminium, boron and trace metals directly into the Anglesea River from their ash pond, but during high flow periods the contribution of aluminium is relatively small (less than 0.06%). During low flows the ash pond effluent will constitute a major portion of the Anglesea River flow. A more detailed assessment is necessary to determine the relative contributions of trace

metals during high and low flows. This will require the measurement of flow and trace metals concentrations above, below and at the Alcoa discharge.

Given the large amounts of boron being discharged from the ash ponds, particular attention should be given to assessing the risk of boron to Anglesea River freshwater ecosystems downstream of the effluent discharge point.

There is clear evidence flocculation occurs when low pH water encounters higher pH water in the estuary, but where this occurs will depend on the flow of freshwater into the estuary. This process must be better understood to determine whether it is necessary to act to minimize trace metals or flocculation.

Barwon Water's water extraction may alter groundwater levels but current modelling is not sufficient to understand the effects of these activities. More data should be collected to populate the models to better understand the effects in the catchment. Alcoa's pumping is likely to have had little impact on acid drainage from the greater catchment however more information should be collected on the drying out of surrounding marshes and the wider catchment area.

There are a number of options for acidity management but each needs further investigation before any meaningful recommendation can be made. Further investigation would involve assessing the viability, appropriateness and cost effectiveness of each option as well as the potential social, economic and environmental impacts.

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1 Anglesea River Review and terms of reference

In the summer of 2010/11, a series acidification events occurred in the Anglesea River estuary causing a series of substantial fish death events and closure of the estuary for recreational users for several months. The Anglesea community is understandably concerned at the recent ecological damage to the Anglesea River and consequent effects on tourism. Community concerns have focused on the need for a better understanding of the cause(s) of the events and have resulted in suggestions to moderate their effects. A consulting report has already considered the possible remediation options in the estuary itself (Water Technology 2010).

In response to growing community concerns about the health of the Anglesea River, in April 2011 the Minister for Environment and Climate Change, the Hon. Ryan Smith, announced an independent investigation with the following terms of reference:

- Review the history of acid events in the Anglesea estuary.
- Identify sources of acidic water and metals to the estuary.
- Investigate the role of specific factors that are concern to the community, such as, the role of land use in the catchment, licensed discharge into the river and water extraction.
- Review options for remediation of poor quality water originating from the catchment.

This review has been commissioned by the Victorian Department of Sustainability and Environment to report on the current scientific understanding of processes operating in the catchment and to investigate possible ways that actions in the catchment could reduce the incidence or impacts of the events.

The review considered written submissions in line with the above terms of reference. Following this process a number of additional concerns from the public and organisations were added to the investigation. These included:

- Gravel and coal extraction within the catchment.
- Leaching from waste disposal sites.
- The effects of stack emissions on surrounding vegetation and pH levels within the catchment.
- Fuel reduction/asset protection burning and its effect on ground water flows and pH levels.
- Illegal dumping of waste within the catchment, both industrial and domestic.
- Data presented by Frank Parsons.

This report has reviewed existing information and also public submissions on the matter. The details of submissions and information are outlined in Section 2.

2 Information and documentation used in the review

Information available for the review and submissions presented to the review, are listed alphabetically in sub categories below.

Academic

- Holdgate, G., Smith, T., Gallagher, S.J. and Wallace, M.W. (2001). Geology of coal bearing palaeogene sediments, on shore Torquay Basin, Victoria. *Australian Journal of Earth Sciences* **48**, pp. 657-679.
- Hermon, K. (2002). The cause/s of the acidification of the Anglesea River Victoria. BSc Thesis, Deakin University.
- Lithgow, S. (2007). The Source of Acid Run Events in the Anglesea River and its Tributaries. BSc (Hons) Thesis, Deakin University.
- Meyrick, J. (1999). Trace element distribution and speciation in the Anglesea River. BSC (Hons) Thesis, Deakin University.
- Pope, A. (2006). Freshwater influences on the hydrology and seagrass dynamics of intermittent estuaries. PhD Thesis, Deakin University.
- Tutt, T. (2008). Acid Drainage, Limnology and Bioremediation of Western Victorian Coal Mine Lakes. PhD Thesis, Deakin University.

Alcoa

- Anglesea Environmental Improvement Plan 2008.
- Atkins, L. and Bourne, A.R. (1983). Alcoa of Australia Limited Anglesea (Vic) mining lease environmental study Volume 2. Environmental Survey of metals in the Anglesea River (1981-1982). Report Document January 1983.
- Doley, D. (2002). Vegetation Health Survey of the Anglesea mine and power station area Alcoa of Australia Limited 15 January 2002. Department of Botany, University of Queensland (report to Alcoa).
- Gower F. (2000) *Anglesea river report*. Report for Alcoa World Alumina Australia.
- Hancock SJ 1967 'Hydrogeology of the Anglesea Area Victoria' Geological Survey of Victoria
- Hill, J. (2008). Vegetation Health Survey of Anglesea Power Station 18th November. (Report to Alcoa).
- Laidlaw, W.S. Attiwill, P.M., Hill, R.J., Doley, D. and Uren, N. (2005). Natural and industrial sources of acidification in natural ecosystems surrounding a coal-fired power station (Collaborative investigation and report).
- Submission to the review.
- Various email correspondence, including: long term water quality monitoring data, information on stack emissions.

Barwon Water

- Appendix G - Hydrogeological Assessment Anglesea bore field project GHD 2008.
- Audit Panel Audit Report ANGLESEA BOREFIELD ASSESSMENT November 2008.
- Barwon Water Anglesea Borefield Project – Project Impact Assessment February 2008.
- Bulk Entitlement (Anglesea Groundwater) Order 2009.

- Cunningham, A. and Morgan, L. (2010). Anglesea Borefield Project: Groundwater Resource Development for Urban Supply. The assessment of potential impacts associated with extraction and strategies for mitigation of potential impacts while addressing data gaps. Paper at Groundwater 2010 Canberra 31 Oct to 4 Nov sourced online.
- Environmental Flows Technical Audit Panel Review of the Ecological Risks Associated with the Anglesea Borefield Project.
- Various email correspondence including; lithological bore logs from bore field project

Consultant

- CSIRO (2007). Scoping study of coastal and inland acid sulphate soils in the Corangamite CMA. Report to Department of Primary Industries and Corangamite Catchment Management Authority.

Corangamite Catchment Management Authority

- Water Technology (2010). Investigation of Anglesea River Estuary Mouth Dynamics. Report to Corangamite CMA.
- Various correspondence email and phone discussions

Department of Sustainability and Environment

- Background brief.
- Various information as requested including: maps of controlled (fuel reduction) burns in recent years; bushfires map.

Department of Primary Industry

- Correspondences with D Crawford, soil scientist re acid sulphate soils.

Environment Protection Authority

- Anglesea fish death causes and recent investigations. Nov 2010 Dr Adam Pope, Deakin University, Report for EPA Victoria
- Anglesea Fish Death Q&A December 2010.
- Anglesea River Fish Death Community Update December 2010.
- EPA Publication 655.1 July (2009) "Acid Sulphate Soil and Rock".
- Interim report on the Risk-based Assessment of the Anglesea Estuary Identifying the Values and Threats to the Anglesea Estuary to Assist with Targeted Management Actions August 2005. Submitted to Surf Coast Shire as part of the Health Waterways Project by EPA Victoria
- Various correspondence including responses to questions in regards to EPA licenses, landfills, and water quality data.

Other and on-line information

As cited in document and or including those listed:

- ASSAY #55 March 2011 ASSAY is a free, quarterly newsletter about acid sulphate soils around Australia. It is produced by Industry & Investment NSW with funding assistance from the Federal, State and Territory governments.
- Cochrane G.W., Quci G.W., and Spencer J.D. Eds (1995). Introducing Victorian Geology.
- Effects of fire on catchment hydrology etc www.catchment.crc.org.au/bushfire/intro.html

- Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council (2011) National guidance for the management of acid sulphate soils in inland aquatic ecosystems, Canberra, ACT.
- Garvie, A.M. and Taylor, G.F. (2000). Manual of techniques to quantify processes associated with polluted effluent from sulfidic mine wastes. Australian Centre for Mining Environmental Research, Brisbane.
- Geelong Independent 15-7-2011 “Acid soils discovered around housing sites”.
- GeoVic - Explore Victoria Online
- Heritage Victoria (Jack Vines) 2008 – Coal Mining Heritage Study in Victoria.
- Sherwood, J. (2004). unpublished data Deakin University.
- U.S. Environment Protection Agency (1994). Acid Mine Drainage Prediction. Washington
- Victorian National Parks Association Submission on Referral no. 2008-03 Anglesea Borefield Prepared by Jenny Barnett March 2008.
- www.dse.vic.gov.au/about-dse/interactive-maps
- www.epa.vic.gov.au/air/issues/air_sox.asp
- www.ozcoasts.org.au/indicators/acid_sulfate_soils.jsp

Public Submissions

- Parsons F. 2011 Submission to the Anglesea River acid and trace metals review
- 104 other submissions (were made from a range of sources, including local business, school camps, community groups and individuals)

Surf Coast Shire

- Anglesea Estuary Management Plan (2004)
- Hyder Consulting for Surf Coast Shire – Quarterly Groundwater Monitoring at the Anglesea Landfill July 2007
- CAPIM (2010). Anglesea River Water and Sediment Results undertaken on 17 December 2010.

3 Context

3.1 Anglesea

Anglesea is a coastal town located approximately 110km south west of Melbourne (Figure1). The town is a popular holiday destination and a stopover point for travellers along the Great Ocean Road. The Anglesea River is a major feature in the landscape of the town. It arises in the nearby Otway Ranges and enters Bass Strait through the town.

Anglesea

Department of Primary Industries

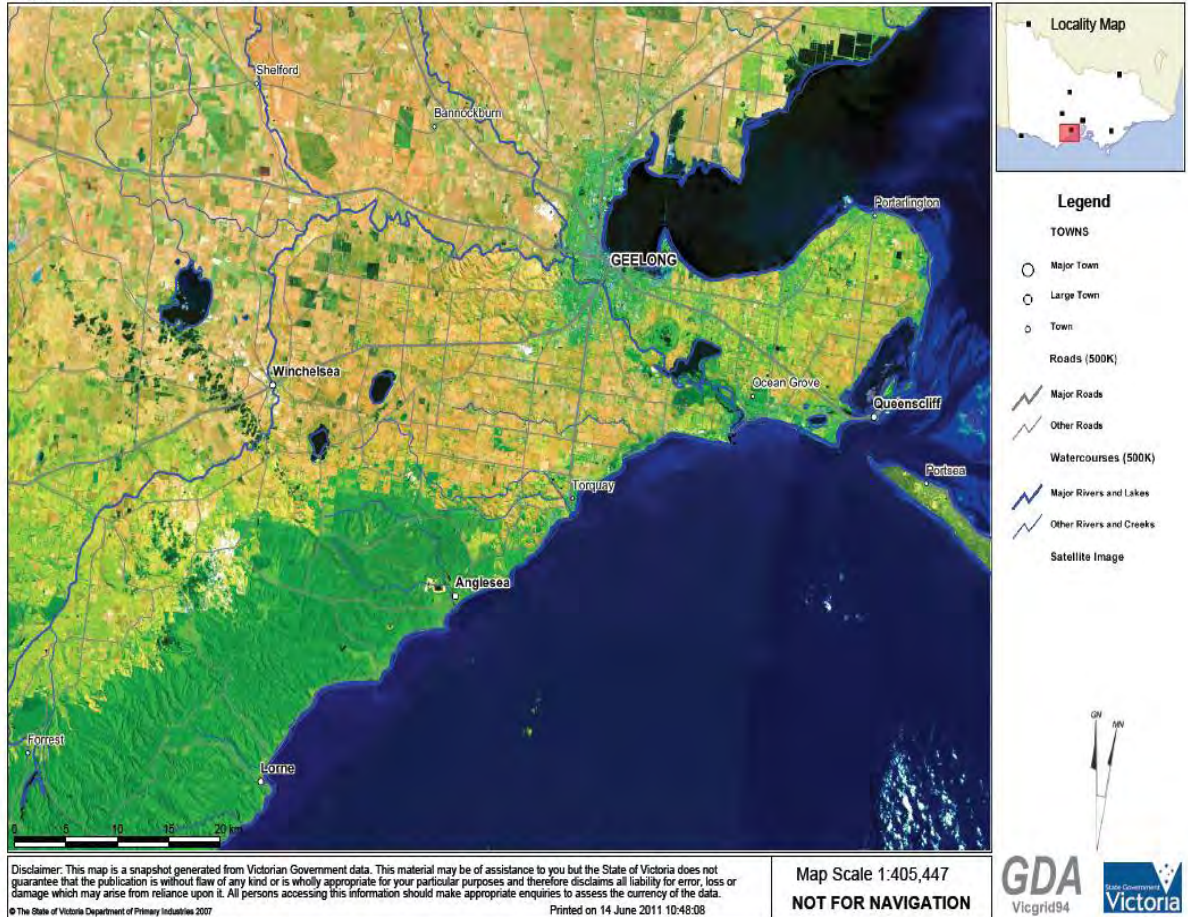


Figure 1. Anglesea location map and satellite image of region (source DPI interactive maps).

An overhead view of the catchment is shown in Figure 2a and an aerial photo of the Anglesea township and power station (Figure 2b) shows the town and estuary located in the top of the image with the Alcoa power station and open cut coal mine across the middle of the image.

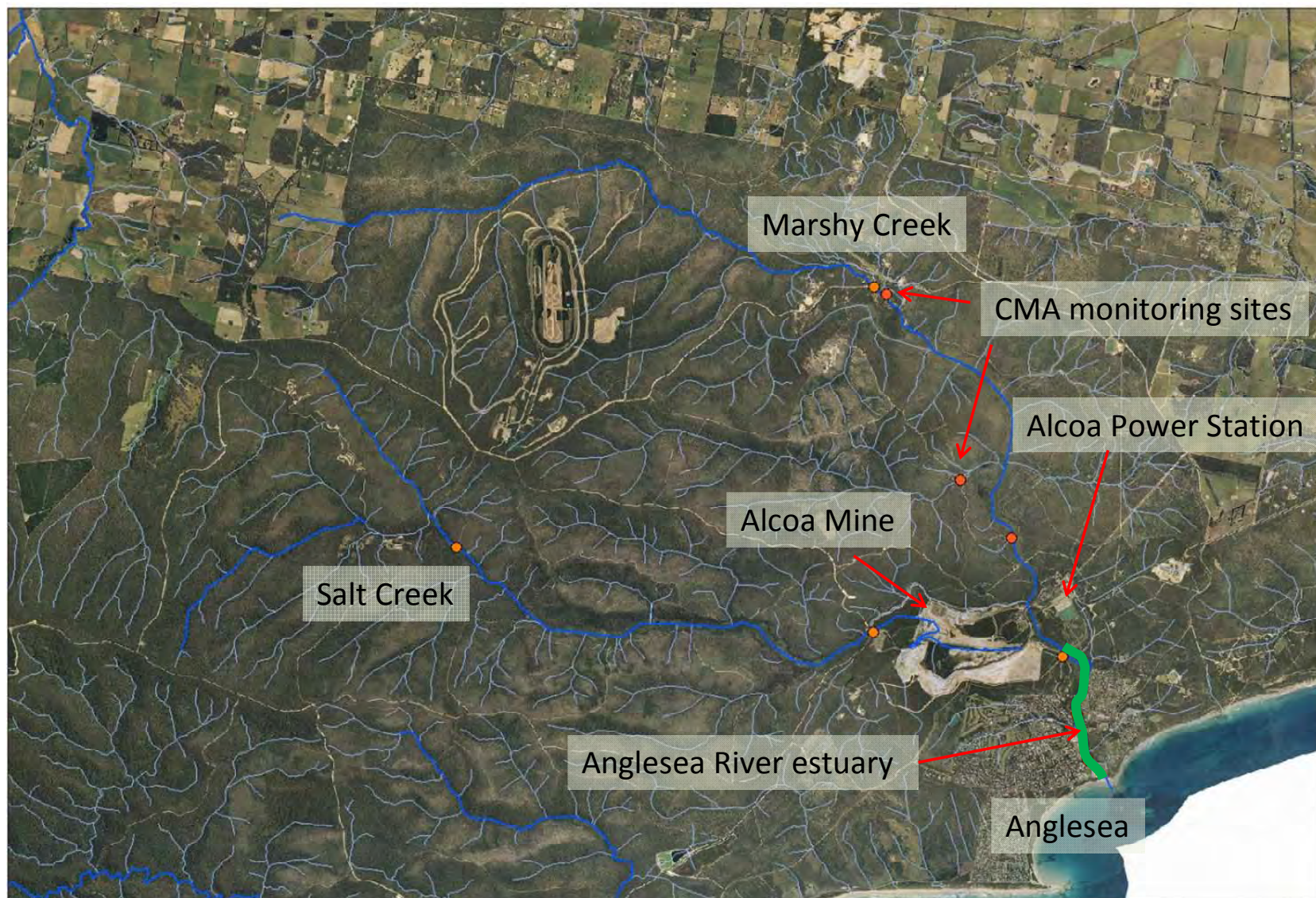


Figure 2a. View of Anglesea catchment highlighting major tributaries, Alcoa's operations and the Anglesea River estuary.



Figure 2. Aerial shot of the Anglesea township and estuary (top left corner) and Alcoa power station and coal mine. Two large water bodies are known as the ash ponds (Source; Wolfgang Seivers 1979 image from State Library Victoria).

3.2 Fish Death Events – Anglesea River

Historically, the water in the Anglesea River, its tributaries and its estuary, frequently becomes acidic (i.e. low pH) for short periods. Some of these acid periods have resulted in fish deaths which have been documented in 2000, 2007 and in spring 2010 to early 2011.

On the 13 September 2010, the Environment Protection Authority (EPA) responded to a fish death event in the Anglesea River estuary. Further investigations by the EPA at this time found that the estuary waters were pH 4 and that similar or lower pH measurements were recorded in the upstream tributaries. At this time, the EPA-licensed discharge into the river from the nearby Alcoa power station and mine site was within required limits, with a pH level just above 7.

A subsequent EPA investigation of the 2010 fish deaths found that the probable cause was a combination of pH stress (acidic water), aluminium toxicity, and suffocation through smothering of the gills by precipitated aluminium compounds (Pope 2010). The investigation concluded that the source of both the acidic water and the elevated concentrations of aluminium were likely generated from acid sulphate soils, coal seams (both generating sulphuric acid) and peats swamps (generating humic acids) within the catchment. A fourth potential source, the licensed discharge from the Alcoa open cut coal mine, was also suggested (Pope 2010).

A wide range of potentially acid-generating soil types, such as acid sulphate soils, have been identified in the Corangamite region and the Anglesea catchment itself (CSIRO 2007; Department of Sustainability and Environment 2010; ASRIS 2011). Acid sulphate soils occur naturally in coastal and inland settings throughout Australia. These soils contain metal sulphide minerals, which, if drained, excavated or exposed to air, can react with oxygen and water to form sulphuric acid. This acid can trigger the release of other contaminants, such as heavy metals. When combined with acid, these heavy metals can cause harm to plants and animals (Department of Sustainability and Environment 2009). This is a problem throughout many coastal areas in Australia.

As mentioned, a similar fish kill event occurred in the Anglesea estuary in October 2000. Investigations into this event by authorities and Alcoa showed acidic flows from the catchment frequently occur (see Section 4.1) Subsequent studies investigating the acidification include Gower 2000 (Alcoa), Hermon 2002 (Deakin University), Pope 2006 (Deakin University) and Tutt 2008 (Deakin University).

The most likely direct factors contributing to the recent fish deaths in the Anglesea River estuary are pH stress, toxic effects and physical effects of metals associated with acidic inflows. Pope (2010) concluded that the probable cause of the fish deaths in the Anglesea River estuary in September 2010 was a combination of pH stress, aluminium toxicity and suffocation through smothering of the gills by precipitated aluminium compounds. Other factors may also have contributed, including salinity stress and toxic effects from other metals. Toxic effects from metals, particularly aluminium, are common in flows from acidic soils.

Aluminium becomes more toxic to fish as pH decreases (low pH indicates high acidity). Flows from the Salt Creek sub-catchment of the Anglesea River had concentrations of soil-derived aluminium many times the national freshwater quality guideline and were also higher than those measured during the 2000 fish kill. High concentrations of aluminium in fish tissues, particularly the gills, is supporting evidence for the likely influence of metal toxicity as a cause of death. The formation of solid aluminium compounds (from previously dissolved aluminium) as the in-flowing waters mix with estuary waters is a possible contributor to fish deaths through clogging of gills of some species and individuals. To some extent, this is supported by gill damage and aluminium concentrations observed in fish post-mortems.

This concludes the contextual outline of the Anglesea River Water Quality Review and a summary of potential sources of acid and metals. Subsequent sections of this document present more information on the subject and highlight existing knowledge gaps.

Key Points

The Anglesea River, its tributaries and the estuary, experience periods where water quality is acidic (i.e. has low pH). Some of these acid periods result in fish deaths. Deaths were documented in 2000, 2007 and spring 2010 to autumn 2011.

After a fish death event in the Anglesea River estuary on 13 September 2010, EPA investigations found estuary waters were pH 4 and similar, or lower, pH measurements were recorded in the rivers and streams upstream in the catchment.

Fish deaths in the Anglesea River estuary were probably caused by a combination of pH stress, aluminium toxicity and suffocation as a result of gills being smothered by precipitated aluminium compounds.

4 Acid: history, sources, generation and transport

4.1 Acidification history – Anglesea River

The Anglesea River frequently undergoes periods of low pH. Figure 3 shows that the pH of the river has regularly reached levels close to pH 4 since 1972 when regular monitoring began.

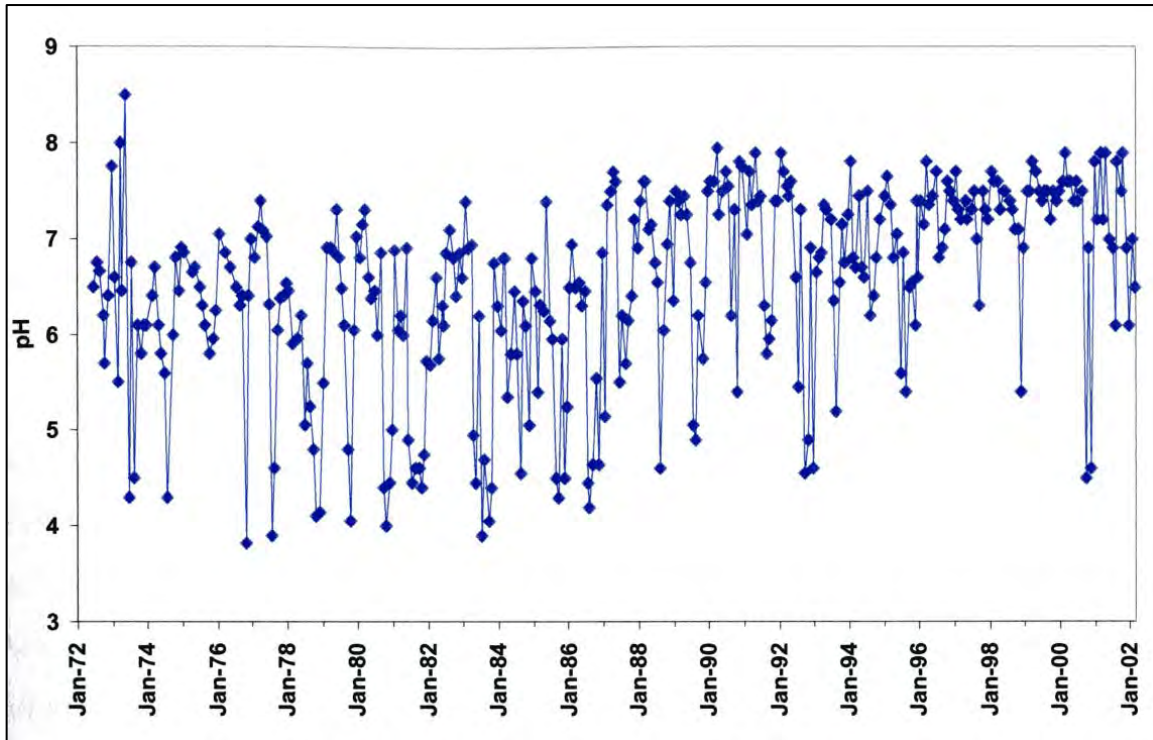


Figure 3. Estuary (mid) surface water pH showing numerous drops to pH 4 (source; Alcoa).

Monitoring from October 2010 to February 2011 undertaken by Parsons (2011) and presented in Figure 4 shows similar results to the historical measurement of pH in Salt and Marshy Creek tributaries and in the Anglesea River at the location of Alcoa's EPA-licensed water discharge point (SP3) (Please refer to section 5.8 for more information on Parsons' submission).

Alcoa's pH monitoring data for a similar period is presented in Figure 5 at the locations of Salt Creek (SP2a) and Marshy Creek (SP2b) upstream of the power station, Alcoa's SP1 discharge, SP3 (downstream of SP1, SP2a & SP2b) and the Anglesea River.

Both Parsons (2011) and Alcoa data shows the consistent low pH of both creeks and the fluctuating pH at SP3, which is a result of different proportional volumes of inputs (i.e; creeks versus Alcoa's discharge).

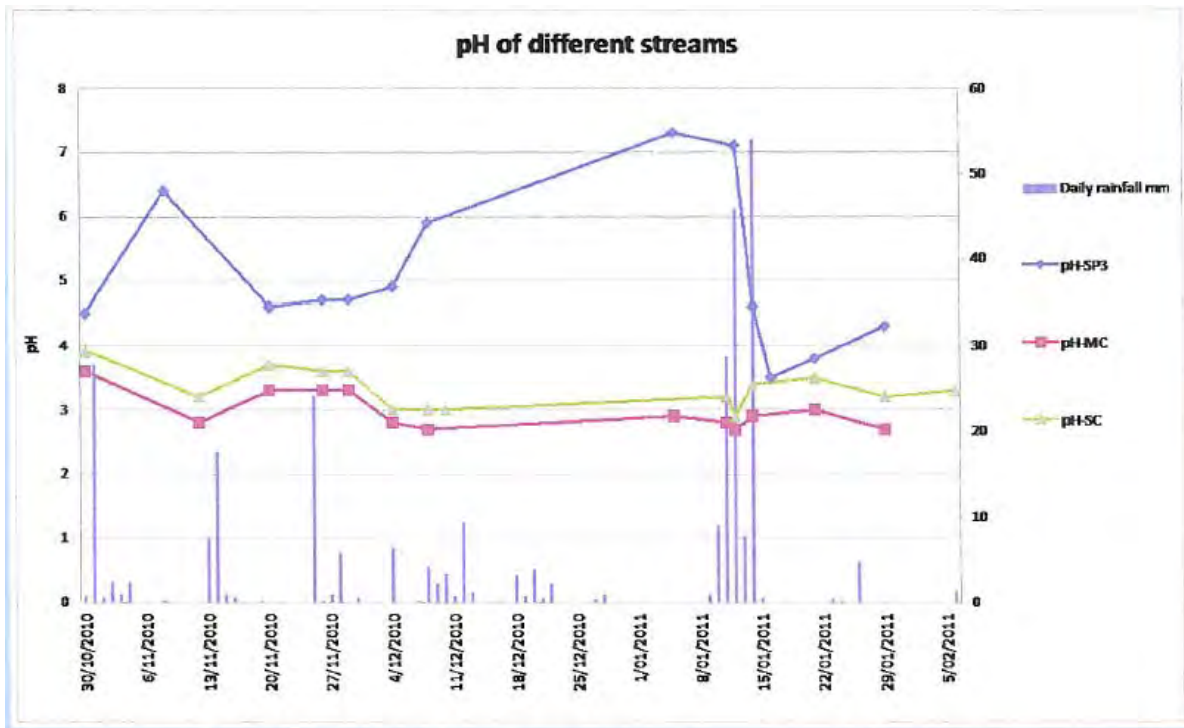


Figure 4. Rainfall and pH measurements for Salt Creek (green line), Marshy Creek (pink line) and the Anglesea River at point SP3 (Alcoa's EPA-licensed discharge point) by Parsons (2011).

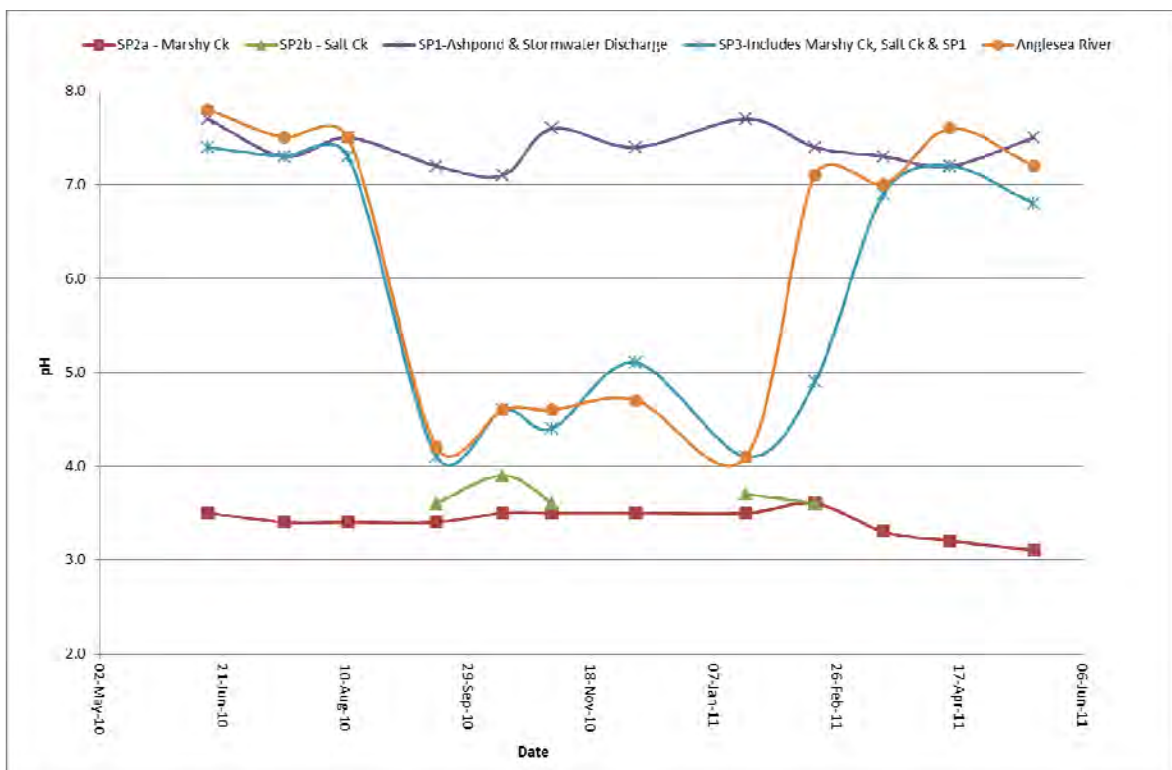


Figure 5. Alcoa pH monitoring data for June 2010 to May 2011 at Salt Creek (SP2a) and Marshy Creek (SP2b) upstream of the power station, Alcoa SP1 discharge, SP3 (downstream of SP1, SP2a & b) and the Anglesea River.

Conclusions

Anglesea River, its tributaries and the estuary experience frequent acidic water quality (pH 3-4) or acid flows which have been documented since 1972 when regular monitoring began.

Key Points

Water quality data dating back to 1972 indicated numerous estuary acidifications to pH 4.

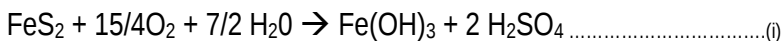
Monitoring from October 2010 to February 2011 by Frank Parsons (2011) shows similar results to the historical measurement of pH in Salt and Marshy Creek tributaries and in the Anglesea River above the Alcoa discharge.

4.2 Acid Sources

Acid generating soils occur naturally in both coastal and inland or upland (freshwater) settings throughout Australia and acid drainage is a well-known phenomenon that can cause environmental impacts. Victorian EPA publication 655.1 "Acid sulphate soil and rock" (EPA July 2009) provides background information on the problem and makes the distinction between the sub categories of acid sulphate soils and acid sulphate rocks. The distinction is made primarily on the basis of the environment where they are found and the publication notes that the two types have different properties, identification and assessment requirements.

The sulphur mineral usually responsible for acid generation is pyrite (FeS_2) or iron disulphide.

Acid generation can be represented by the chemical equation;



(iron disulphide plus oxygen plus water gives iron hydroxide and sulphuric acid)

In the Anglesea catchment, both of the potential sources of acid listed in the EPA publication are present. These are the tea tree marsh (swamps) of the catchment, and mineral coal deposits and pyritic strata including marcasite (a form of iron sulphide) bands. Each is discussed in more detail in the following sections.

Another source of acid at Anglesea is generated from the combustion of coal (i.e. sulphur emissions from the Alcoa power plant). This and other possible sources such as organic 'humic' acids are also discussed in this section.

4.2.1 Geology – coal and pyrites

The geology of the Anglesea region including the Anglesea River catchment is relatively well understood because it is an important mineral resource. Coal, water and to a lesser extent, gravels and sands, are won from the catchment. The geological survey map of 1965 (Figure 6) shows many mines department investigative bores, maps the eastern view formation (EVF) and lists coal as one of lithological units of the EVF. It also shows an open cut brown coal mine, known as the

Roche Bros Mine, which operated in the late 1950s until the early 1960s in the lower reaches of Salt Creek and west of Alcoa's current open cut mine. The mine void is now backfilled.

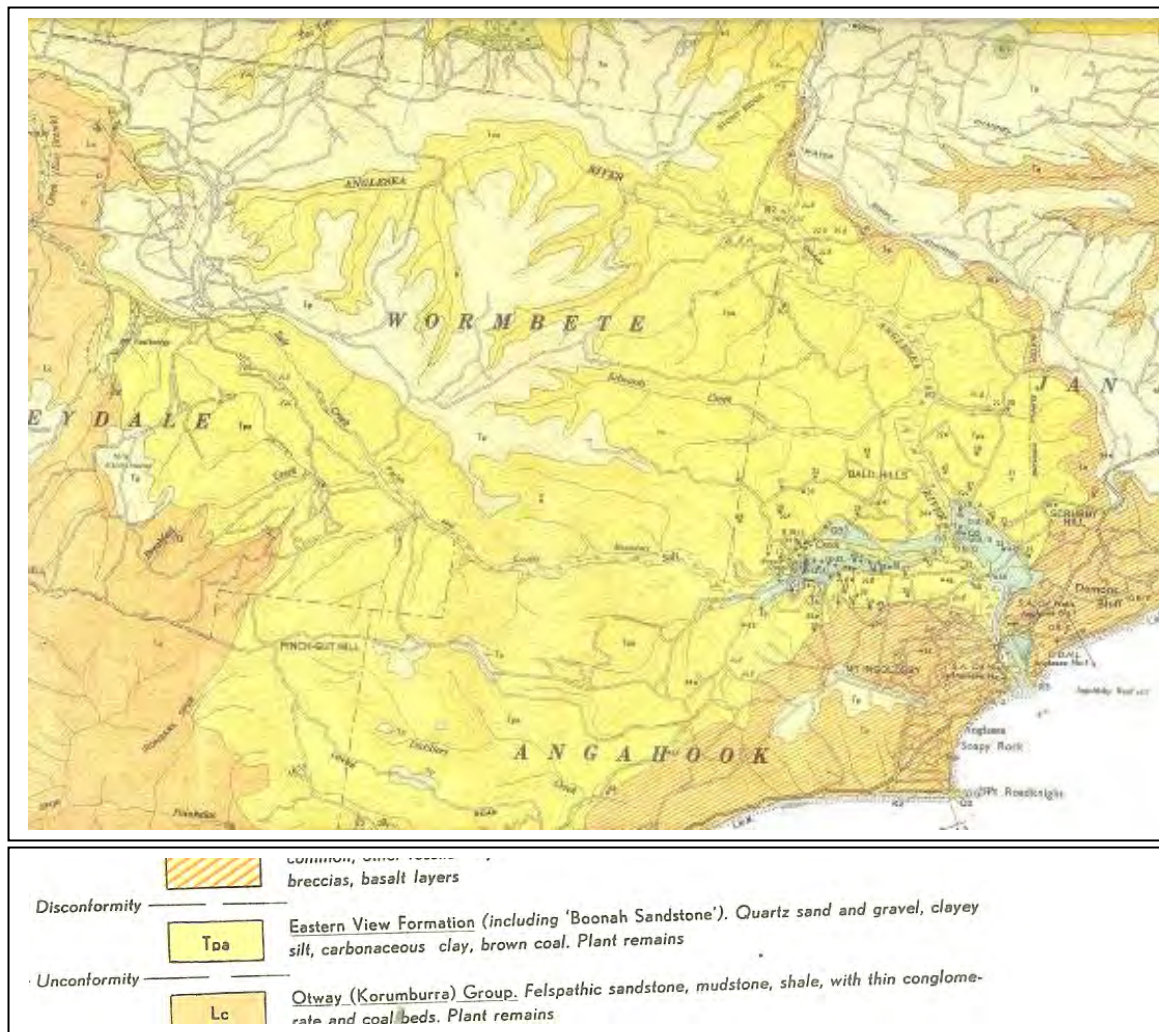


Figure 6. Geological Survey Map circa 1965, showing the extent of the Eastern View Formation (EVF). Note the legend listing brown coal as one of the strata of the EVF.

Reports from the 1960s discuss the complexity of the EVF. *“Eastern View Formation: quartz sands, fine grained to pebble size, silts, coals, carbonaceous clays and silts. The sediments were deposited in a fresh water environment under fluvial conditions. Inland they are intensely variable lensing and changing gradationally both vertically and laterally e.g. sandy clay passing to sand vertically or brown coal passing to ligneous clay laterally”* Hancock (1967) referencing Abele (1966).

In the 1990s, investigations into the EVF groundwater resources for a potable water supply were completed (SKM 1994). Describing the EVF, the report identifies three sub units - the upper, middle and lower units. It also estimates groundwater resources of the upper and lower units, while the middle unit is described as a confining aquitard layer. Holdgate (2001) reported coal sulphur contents in the currently mined coal at 3.8% (w/w dry basis) but notes variations across the seam with peaks over 5% (w/w dry basis) at top and bottom. Holdgate (2001) also noted “pyritic” shale and siltstone strata as units present in the regional geology. Hancock (1967) notes in a review of attempts to retrieve sand cores from the EVF, that hard bands of marcasite (iron disulphide with a different crystal structure to pyrite) often resulted in damage to the coring tool.

The “Manual of techniques to quantify processes associated with contaminated effluent from sulfidic mine waste” (Garvie and Taylor 2000) states that every 1 per cent of sulphur present in a reduced state, (i.e; pyrite) per one tonne (1000kg) of material such as coal, has the potential to generate 30.6 kg of sulphuric acid, based on the stoichiometry of equation (i). For example, based on Garvie et al (2000), if 1 million tonnes of sandy overburden (with some small lenses of coal and marcasite bands) were to be excavated, testing to establish the acid generating potential could be undertaken. Testing results may indicate an average sulphide content of 2% w/w and therefore the 1 million tonnes (1,000,000) of overburden has 61,200 tonnes of sulphuric acid potential.

In recent years, the groundwater resource has been developed by Barwon Water (the bulk entitlement for groundwater extraction was issued in July 2009) which completed further work and modelling of the EVF. The hydrogeological investigations (GHD 2008) describe the upper EVF as “brown coal seams are common in the top of the sequence...in general the major thickness of coals lie within the upper third of the unit and the major thicknesses of sands are located in the lower two thirds of the unit”. The extent of the information on the geology and coal of the region is displayed in more recent maps: DPI Coal Basin Map (Figure 7), and Barwon Water maps (Figures 8, 9 and 10).

Coal basin and boreholes Department of Primary Industries

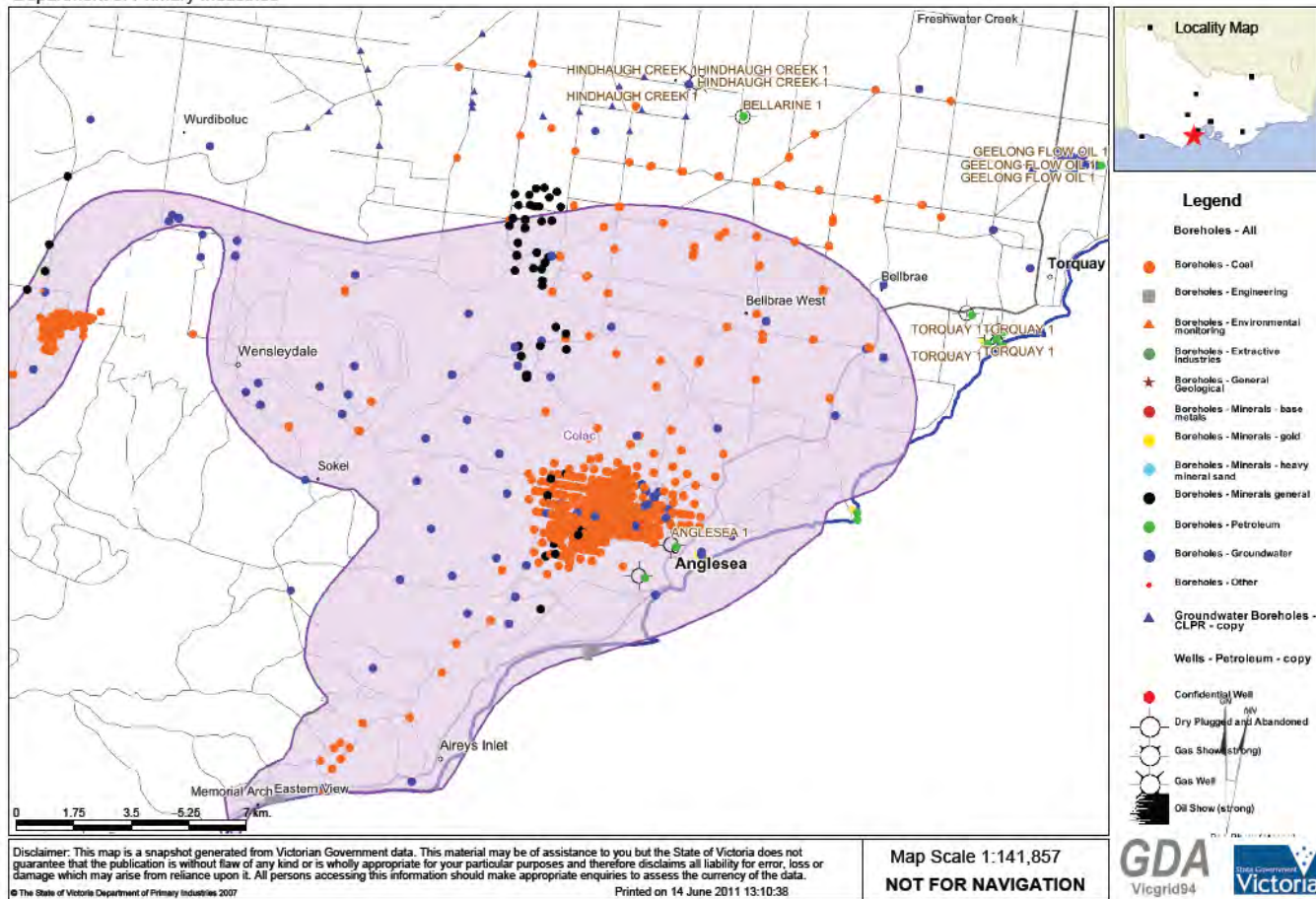


Figure 7. Map showing the coal sub basin (purple) and the numerous bores in the Anglesea region (over 500), primarily drilled for coal purposes (tan dots) pre 1970, but also for groundwater (blue dots).

Barwon Water / Anglesea Borefield Project
Figure 10 - Geological Cross Section B-B'

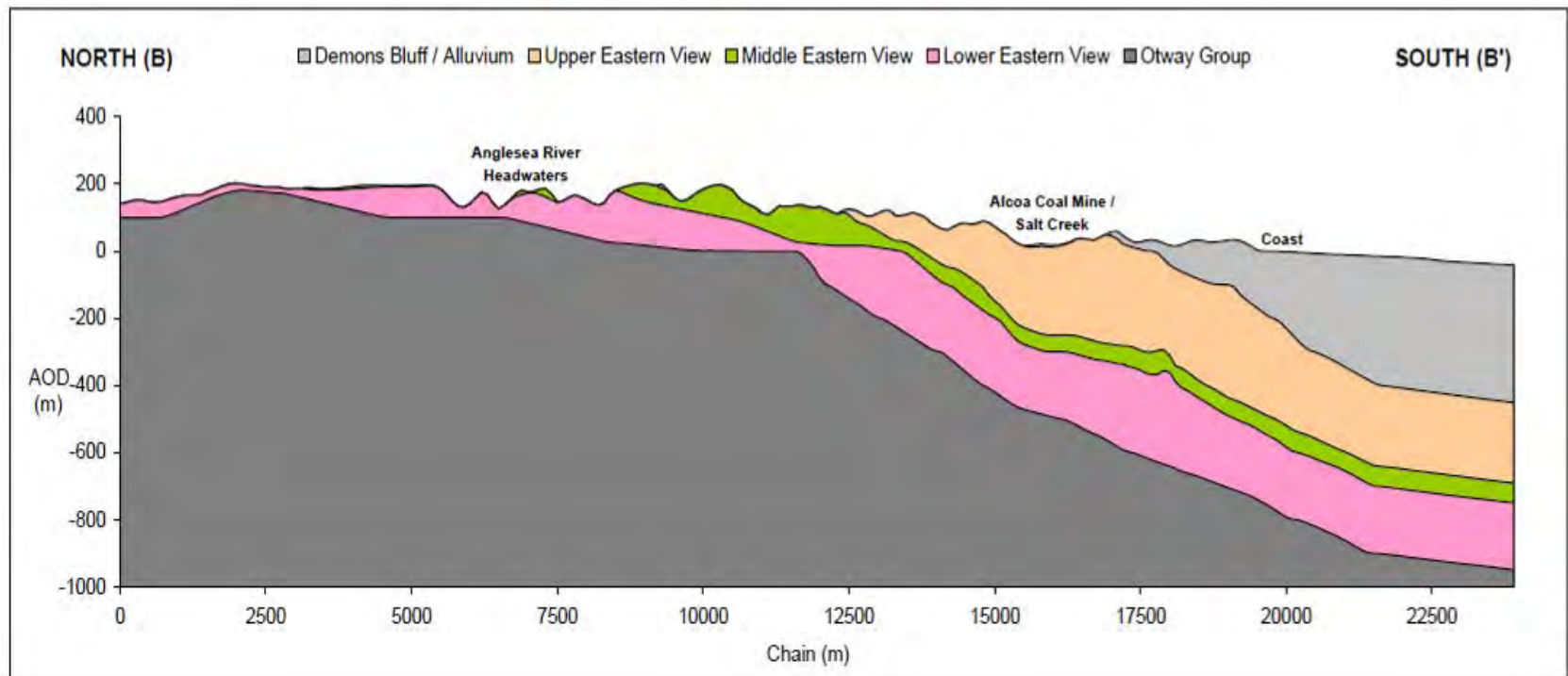


Figure 9. Cross Section of the EVF prepared for Barwon Water showing the different sub units of the EVF, lower (pink), middle (green) and upper (orange).

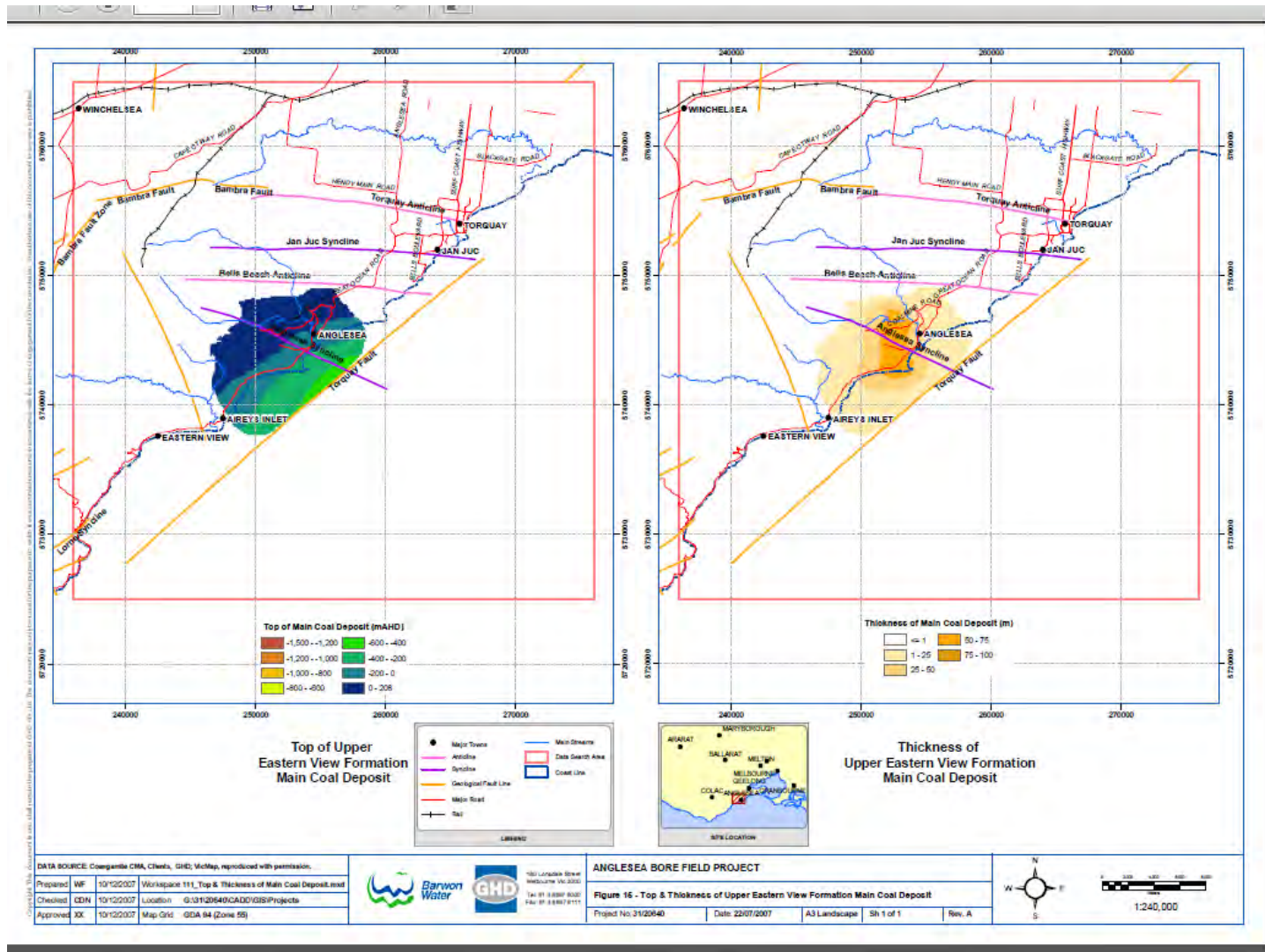


Figure 10. Image prepared for Barwon Water showing coal deposits of the upper EVF in the 0-200m elevation.

Given the known presence of coal and lignitic strata associated with the EVF and outlined by the coal basin (Figure 7), the known sulphur content of coal deposits and possibly other strata (marcasite bands), it is reasonable to deduce that the catchment holds significant acid generating potential.

Tutt (2008) used information from SKM (1994) investigations to broadly estimate the acid generation potential of the catchment. Of 14 bores drilled in the SKM investigations, 11 had lithology logs recorded. Figure 11 shows the location of nine of these bores (red dots) listed on the Victoria Water Resources online website.

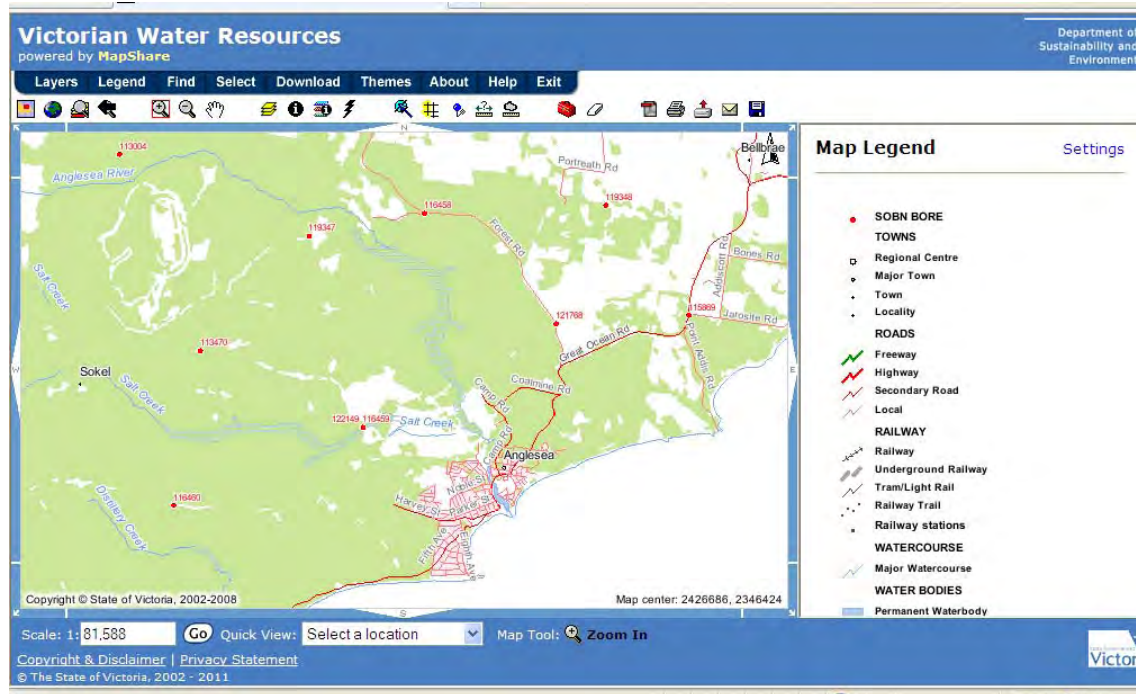


Figure 11. Groundwater bores from investigations into the EVF circa early 1990s (Source: <http://nremap-sc.nre.vic.gov.au/MapShare.v2/imf.jsp?site=water>).

Lithology logs and groundwater levels of the bores were compared. An example of a lithology log for a bore at the corner of Forrest and Gum Flats Rd (Table 1), and the bore's groundwater level graph is shown in Figure 12. The data shows a 42m coal seam between 25 and 67m below surface level, and the water table is at approximately 75m below surface level. When converted to Australian Height Datum (AHD), this data puts the coal seam between 43 and 85m AHD. This is at and above the level of the river and the marshes (lying between the 40-50 m AHD) at this point in the catchment.

A summary table showing the thickness of coal units or units mentioning coal above the water table from Tutt (2008) is shown in Table 2.

Table 1. Lithology Log for bore 116458 at the corner of Forrest and Gum flats Rd showing a 42m coal seam between 25 and 67m (Source: www.vicwaterdata.net.).

Site Name:	BORE 116458
------------	-------------

Bore Lithology Logs

	Depth From	Depth To	Description
1	0	0.5	TOPSOIL
2	0.5	3	ORANGE GRAVEL AND CLAY
3	3	11	RED AND WHITE CLAY
4	11	17.5	YELLOW CLAY
5	17.5	25	BROWN SILTY CLAY
6	25	67	BROWN COAL
7	67	82	CEMENTED SAND CLAY
8	82	95	COAL LARGE GRAVEL
9	95	100	LIGHT YELLOW CLAY
10	100	112	MEDIUM TO LARGE SAND
11	112	116	COAL

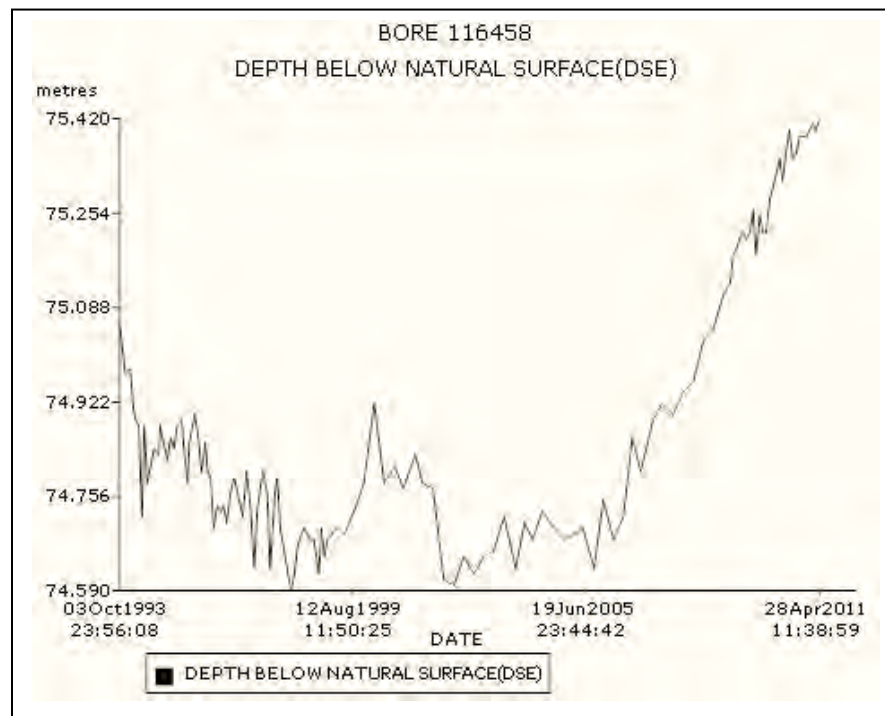


Figure 12. Groundwater level below natural surface for bore 116458 confirming the coal seam is above the water table (Source: www.vicwaterdata.net.).

Table 2. Thickness of lithological units above the water table that are listed as coal or heterogeneous units mentioning coal from Tutt (2008).

Bore Number	Thickness of coal or heterogenous units mentioning coal (m)
B113002	24
B113003	18
B113004	18
B113470	51
B115867	12
B115868	37.4
B116458	42
B116460	40
B119347	3
B119349	0
B121768	70

The significance of coal deposits relative to the water table is discussed in more detail in the next section, but as equation (i) in section 4.2 shows, pyrite undergoes oxidation to form acid. A more detailed investigation into the extent of coal and “pyritic” materials above the water table is needed before a quantitative assessment of acid potential in the catchment can be made. This is beyond the scope of the review, although a general qualitative assessment can be made that the catchment has the necessary geology above the water table and above creek and stream levels to explain the low pH of stream waters. The generation and transportation of acid is discussed in section 4.3, with particular reference to coal which is shown in a model.

More lithological data on the catchment is available at the Geoscience Victoria online mapping website (<http://new.dpi.vic.gov.au/earth-resources/products-services/online/geovic>). Earlier investigations to date, including Tutt (2008), appear not to have discovered or drawn upon the extensive information available at this site. The dates listed on the bore log reports are 22 October 2007, suggesting that information may have only been made available on this website after this time. Some examples are provided to further support the qualitative assessment of geological sources of acid.

Bore AL622 shown in Figure 13 at the left end of the red line is approximately 2.6km upstream from Gum Flats Rd adjacent to the Anglesea River in the upper catchment above the marshes. The bore drilled in 1963 for groundwater investigations has an AHD elevation of 66m. At this point the river is between the 60m and 70m, based on map contours. The lithology log is shown in Table 3.

AL622
Department of Primary Industries

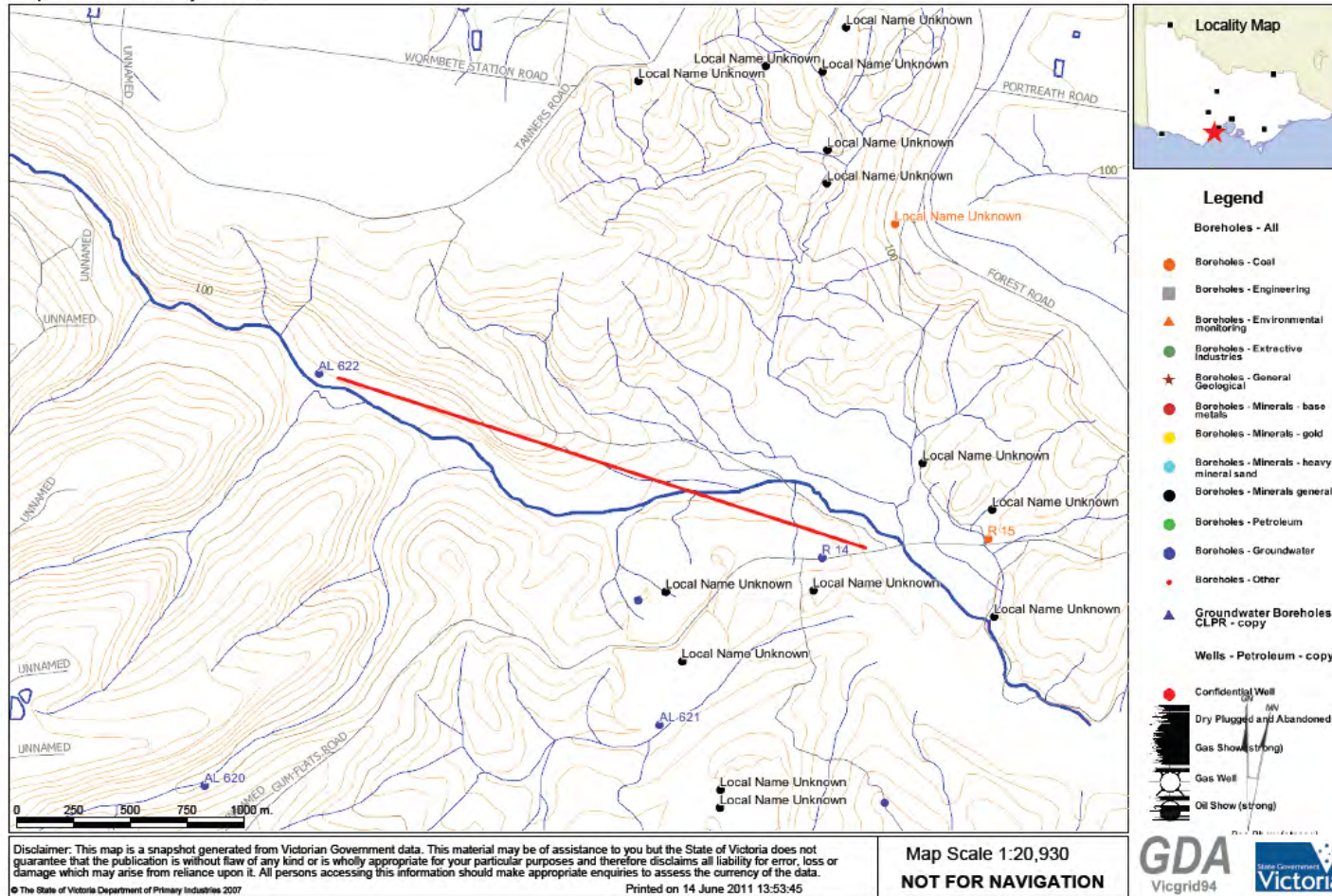


Figure 13. Bore AL622 (left hand end of the red line) approximately 2.6km upstream of Gum Flats Rd in the upper portion of catchment and in the vicinity of the boundary of the upper and middle EVF.

Table 3. Lithology log for bore AL622, coal strata (1m thickness) is within 10m of the ground surface.

Lithological Logs

Geologists Log created by GEO-ENG PTY LTD on October 31, 1963

From	To	Comments
0.0	0.6	*OLD STRATA* : TOPSOIL(8)
0.6	4.3	*OLD STRATA* : CLAY(1)
4.3	9.4	*OLD STRATA* : SAND(2)
9.4	10.4	*OLD STRATA* : COAL BROWN(0 0)
10.4	26.5	*OLD STRATA* : SAND AND GRAVEL(2 5)
26.5	32.0	*OLD STRATA* : COAL BROWN(0 0)
32.0	35.1	*OLD STRATA* : SAND AND GRAVEL(2 5)
35.1	39.3	*OLD STRATA* : LIGNEOUS CLAY(0 8)
39.3	56.7	*OLD STRATA* : SAND WITH COAL BANDS(2 6)
56.7	61.6	*OLD STRATA* : CLAY(1)
61.6	65.5	*OLD STRATA* : SAND WITH COAL BANDS(2 6)
65.5	74.7	*OLD STRATA* : CLAY(1)
74.7	80.2	*OLD STRATA* : SAND(2)
80.2	89.6	*OLD STRATA* : CLAY(1)
89.6	106.7	*OLD STRATA* : SAND(2)

The logs show that at 9.4m below ground surface level is a 1m band of coal. This is overlaid by 5m of sand, almost 3m of clay and 0.6m of topsoil. Importantly, the coal is at a depth that would certainly allow water interaction between the coal and the river, and be a potential source of acid. Furthermore, considering the description provided earlier of the EVF *"Inland they are intensely variable lensing and changing gradationally both vertically and laterally e.g. sandy clay passing to sand vertically or brown coal passing to ligneous clay laterally"* (Hancock 1967 referencing Abele 1966), coal and sulfidic strata could well be within a zone of waterway interaction.

Another lithology log from a bore (id 307444) drilled at the upper end of the catchment in the vicinity of the gravel pits does not list coal but does list "pyrites" in small bands at depths of 40 to 45m (Table 4). This data again confirms that sources of acid are spread throughout the geological setting of the Anglesea River catchment.

Table 4. Lithological log for Bore 307444 on the west side of current gravel pits with bands of pyrite listed at depths of 40 to 45m.

Lithological Logs

Geologists Log created by UNKNOWN on December 31, 1963

From	To	Comments
0.0	0.91	YELLOW CLAY
0.91	2.44	MOTTLED SANDY CLAY
2.44	3.96	YELLOW SANDY CLAY
3.96	5.49	SAND
5.49	10.67	WHITE CLAY
10.67	23.17	WHITE CLAY AND GRAVEL
23.17	26.52	FINE GRAVEL
26.52	35.05	BROWN SANDY CLAY
35.05	35.97	SAND
35.97	41.76	BROWN MOTTLED SANDY CLAY
41.76	41.86	PYRITES
41.86	42.37	GREY SANDY CLAY
42.37	42.52	PYRITES
42.52	45.11	GREY SANDY CLAY
45.11	45.21	PYRITES
45.21	48.16	GREY SANDY CLAY

The recent Barwon Water bore field project also provided more information on the geology of the catchment, in areas not well covered before. A bore known as WTOB5 is located in the upper catchment of Salt Creek on Breakfast Creek Rd near Sokil. This bore recorded trace coal, ligneous clay and coal at approximately 30-50m below surface level. Also at this depth range was a significant portion of sand units.

The bore's natural surface level is reported at 158m, while the levels of Salt Creek and Breakfast Creek nearby are in the 90 to 100m contour range. During drilling, circulation was lost to some degree at approximately 20m depth when it passed through sandy gravels. The point of note is that, similar to the bore AL622 example, coal (and assumed associated pyritic material) is again

found in the catchment geology amid hydraulically conductive strata units at or above local watercourse and stream heights (i.e; there is a likely source of acid to streams).

As mentioned previously, coal was mined in the lower reaches of Salt Creek west of the current Alcoa mine in the late 1950s and early 1960s. Although details of the operation are limited due to its age, two aspects are significant. Firstly, coal reserves are located in the current valley floor at relatively shallow depths, and secondly, disturbance of the swamp and coal has occurred at this site, making acid generation quite likely. Further discussion of the Roche Mine is in section 6.4.2.

Other geological indicators of long term (geological time) weathering (oxidation) of iron sulphide in the region are the jarosite deposits in the Point Addis area. An old jarosite mine (marked as disused in the 1965 geological map – Figure14) and jarosite named features (i.e; Jarosite Headland) are located in the geologically younger Demons Bluff Formation.

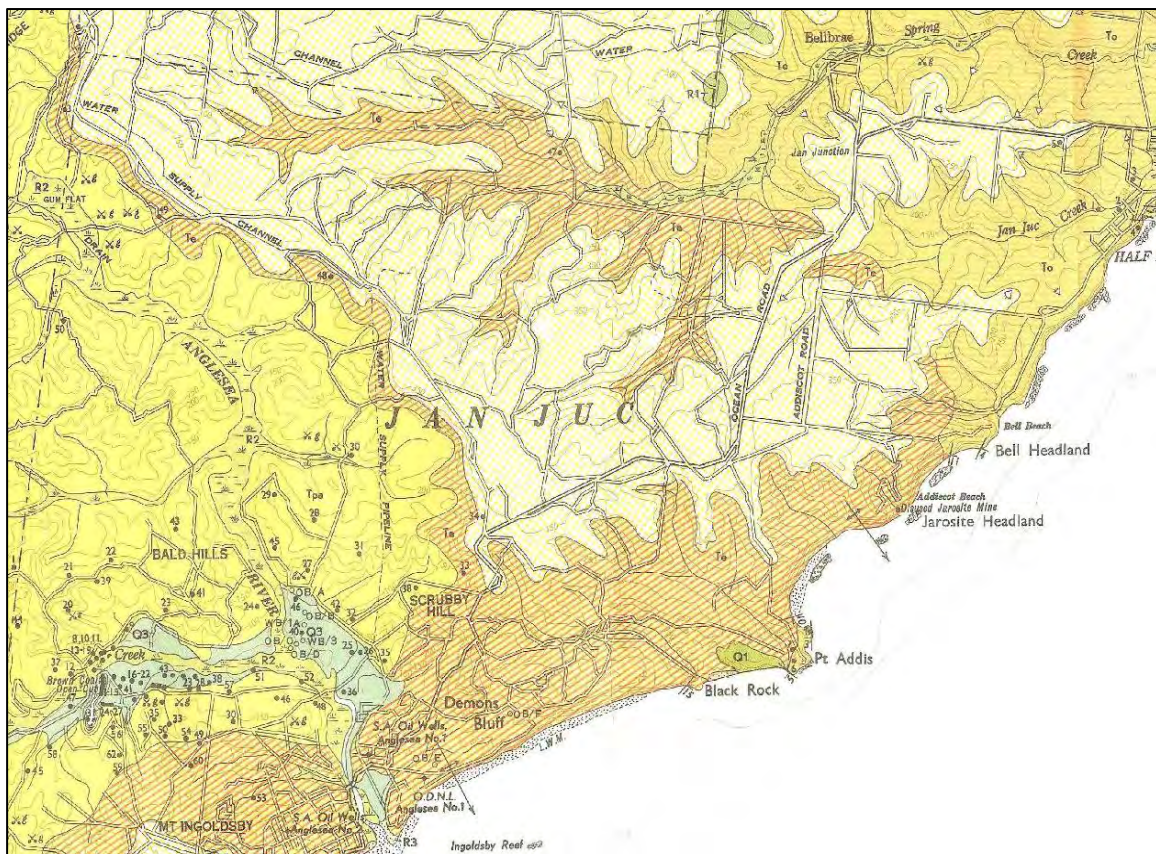


Figure 14. Geological Survey map circa 1965 showing Jarosite Headland and disused jarosite mine in the Demons Bluff Formation.

The jarosite mineral is found in “secondary deposits formed by the prolonged weathering of pyritic rocks and ores” (www.earth.uq.edu.au/sulfates-jarosite). The geological time sequence suggests pyritic deposits of the EVF group have been weathered over time (i.e; naturally, before human influence) and this is shown by the presence of jarosite in the younger Demons Bluff Formation.

Conclusions

The catchment has the necessary geology and acid generating capacity above the water table and above creek and stream levels to explain the low pH of stream waters.

The acid generation potential of coal and pyritic strata within the catchment, and connectivity between potential acid producing strata and waterways, needs investigating to fully understand acid generation within the catchment.

Key Points

In the Anglesea catchment potential natural sources of acid are tea tree marshes (swamps), mineral coal deposits and pyritic strata, including marcasite (a form of iron sulphide) bands.

Substantial coal deposits extend throughout the Marshy and Salt Creek catchments under the valley swamps and in the hills.

Coal was mined in the lower reaches of Salt Creek west of the current mine in the late 1950s early 1960s. This indicates that coal reserves are located in the current valley floor, and that disturbance of the swamp and coal occurred at this site. This makes it highly likely that acid generation occurred in the lower reaches of Salt Creek.

Coal is known to be acid generating and other pyritic strata, including bands of pyrite, have been recorded.

The known presence of coal and lignitic strata associated with the Eastern View Formation, and the known sulphur content of coal deposits and possibly other strata (marcasite bands), means it is likely that the catchment has significant acid generating capacity.

Knowledge gaps

The extent of coal and pyritic strata throughout the Anglesea catchment.

The sulphide content and acid generation potential of coal and pyritic strata (such as that listed at site AL622 in the upper the catchment) are unknown.

The connectivity between potential acid producing strata and waterways.

4.2.2 Tea tree marshes (swamps)

On many occasions the tea tree marshes were cited as a potential source of acid at Anglesea due to the likely presence of acid sulphate soils in the marshes. The Australian Soil Resource Information System shows the marshes in Anglesea have a high probability of occurrence for acid sulphate soils (ASS) (Figure 15).

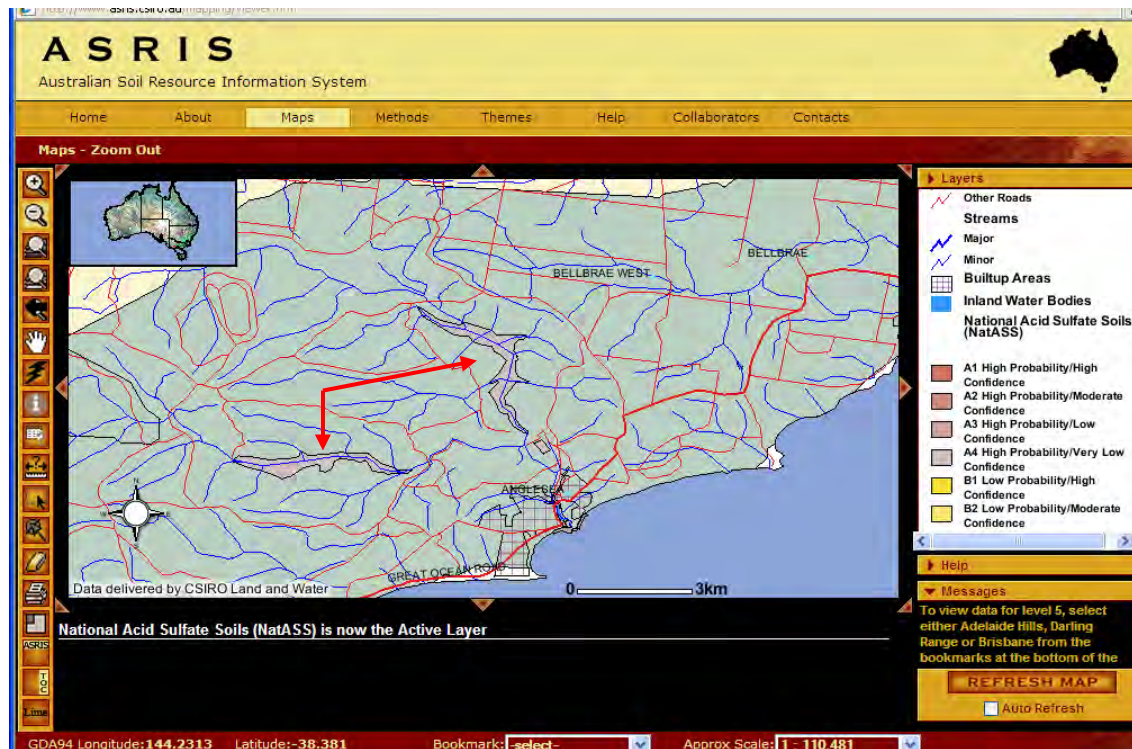


Figure 15. Australian Soil Resource Information System showing marshes in the catchment (mauve colour polygons indicated by red arrows) having a high probability for ASS (source <http://www.asris.csiro.au/about.htm>, maps circa 2008).

The EPA publication “Acid sulphate soil and rock” (EPA July 2009) also indicates that swamps or marshes disturbed by particular actions (including lowering of the water table) can become acid generating, as per the pyrite oxidation process.

The Anglesea catchment was not sampled in the report by CSIRO (2007) which investigated acid sulphate soils in the Corangamite Catchment Management Authority (CCMA) region. Resource limitations seemed to exclude regional sampling, with only 29 sites sampled across the CCMA region. The report acknowledges its limitations but may be useful if further investigations are to be completed at Anglesea, particularly on the marshes. Recent reporting in the Geelong Independent newspaper (“Acid soils discovered around housing sites” 15 July 2011) refers to various department and agency reports on acid sulphate soils in the Corangamite catchment which has 13845 Ha of acid sulphate soil.

An investigation on the marshes by a Deakin University Honours student (Lithgow 2007) reported core samples of marsh sediments with pH in the 3 to 5 range. Lithgow used a standard method for measuring soil /sediment pH (Method 4B1 Rayment and Higginson, 1992) which involves mixing 1

part sediment to 5 parts CaCl_2 solution. This method often gives lower pH results than the same test when water is used. He also measured seasonal water table fluctuations which varied over 1m, although this alone does not indicate long term drying out, and the moisture content of sediment samples was high at 75 to 87% w/w (i.e; not dry). No testing was undertaken for sulphate content, which is a truer indicator of acid potential attributable to acid sulphate soil.

Tutt (2008) noted that the marshes only cover a small percentage of the total catchment area (approximately 2%). Given observed water quality results throughout the catchment, Tutt believed they may contribute some acid input but are unlikely to be a major source of acid.

Barwon Water's recent hydrogeological work concluded that the marshes in the catchment appear to be perched (GHD 2008). In other words, they are above the main upper EVF aquifers water table. It also observed that the significant cone of groundwater depression around the mine and power station appears not to have "drained" the marshes over the last 40 years of Alcoa operation, implying that they are perched. The ecological consultancy used for the flora and fauna survey also noted the general good health of the marshes which might not be the case if current operations were impacting on them (in GHD 2008, referring to Ecology Australia 2007 Anglesea Bore field Project Groundwater Investigations: Terrestrial Flora and Fauna Report).

Investigations into the catchment's acid flows consistently identified the marshes as a possible source of acid due to the good general knowledge in Australia on acid sulphate soils, but no confirmation of this in tests for sulphur content of sediments was located. A Department of Primary Industries (DPI) soil scientist also indicated in correspondence that he had no knowledge of mapping of inland (marshes) sulphate soils (as opposed to coastal) in the Anglesea catchment. Another swamp in the region was found to contain sulphides. Analysis of sediments from Big Swamp (south east of Colac) measured reduced inorganic sulphur levels of 16% w/w (Assay 55 2011). When combined with other observations on site; this data provides more certainty by concluding that acidity is from disturbed acid sulphate soils.

Definitive evidence of current anthropogenic disturbance of the marshes has not been located. Differing water quality results from each sub catchment may indicate some differences in processes occurring. The Salt Creek sub catchment shows stronger signs of typical acid drainage, including drainage from acid sulphate sediments.

Water quality results show higher in general sulphate and metals concentrations, such as aluminium from the Salt Creek sub catchment when it flows, which contrasts with Marshy Creek (EPA and Alcoa water quality monitoring data from the 2000 acid flush event). These measurements and Hermon's (2002) results (which show a larger decrease in chloride/sulphate ratios through Salt Creek marshes versus Marshy Creek marshes [Figure 29] when taken in context with the more intermittent flows from the Salt Creek catchment) may indicate some drying out of acid sulphate marsh sediments.

Accounting for how this drying may have occurred (from climate variation, current mining operations or groundwater extraction) is difficult without data (see Sections 3 and 6.2). Hancock's (1967) description of the Salt Creek catchment describes the swamps as heavily overgrown with tea tree, with little flow except in times of high intensity rainfall and very little flow on the

downstream edge. This comment is consistent with current observations but limited data exists on Salt Creek's flows, water tables or sediment moisture contents.

It is also possible the old Roche Mine may have altered the local hydrology and hydrogeology (further discussion in section 6.4.2), but its small size and extent relative to the greater catchment and marsh areas must be taken into account. The Salt Creek catchment and its marshes are located over the three sub units of EVF (see Figure 8), whereas Marshy Creek is primarily located in the upper EVF unit. The difference in underlying geology of the two catchments gives a plausible explanation for the different characteristics of each creek in terms of their respective flow patterns and water quality.

Better information on the hydrology / water table of the marshes has apparently been gathered recently as part of the Barwon Water bore field project (GHD 2008). Up to 11 bores were installed to measure perched water table levels (bore data supplied by GHD/Barwon Water), although no data on water table measurements are in this review.

Conclusions

The extent of sulphide contents and drying out must be known before the marshes' acid contribution in the catchment can be determined. How any drying may have occurred (ie; climate variation, historical or current mining operations or groundwater extraction) is difficult evaluate without relevant data.

Key Points

Marshes are likely to have acid sulphate (pyritic) materials present in their sediments and are therefore a potential source of acid.

If marshes are disturbed by a lowering of the water table they dry out and can become acid generating.

The marshes only cover a small percentage of the total catchment area (approximately 2%) and are unlikely to be a major source of acid.

The marshes in the catchment appear to be perched, so the significant cone of groundwater depression around the mine and power station appears not to have "drained" the marshes over the last 40 years of Alcoa's operation.

A larger decrease in chloride/sulphate ratios through Salt Creek marshes compared to Marshy Creek's marshes, plus more intermittent flows from the Salt Creek catchment, may indicate some drying out of acid sulphate marsh sediments.

Knowledge Gaps

The sulphur content of the marsh sediments is unknown and this information is key in determining the contributing effect of the marshes to potential acid generation in the Anglesea catchment.

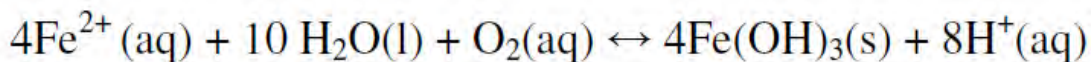
The extent of the 'drying out' of the marshes is unknown.

4.2.3 Other natural sources of acid

Other sources of acid are humic acids and ferrorlysis acids (acid waters resulting from the precipitation of dissolved iron in groundwater).

Limited information was located on humic acids of the Anglesea marshes. Humic acids are formed in the breakdown of organic material. Typically, they give water a brown tea colour and produce pHs in the range of 4 to 5. Some amount of humic acid will be naturally generated in the marshes. This source of acid is acknowledged as part of the review but not considered to be of further concern.

Ferrorlysis acids were observed by Tutt (2008) from springs adjacent to the old Wensleydale Coal Mine (now a lake). The pH of the springs were consistently in the pH range of 3, with the acid being generated from the following equation:



Pope (2006) noted an artesian spring (a suspected uncapped artesian bore, see Aitkens and Bourne (1983) in the Marshy Creek catchment with signs of a ferrorlysis reaction occurring and a small flow rate (90 to 400ML/year estimated by Aitkens and Bourne 1983) may have added to Marshy Creek's flow. A similar example was reported by Tutt (2008) who measured an iron-stained spring flow adjacent to the old Wensleydale coal mine with a pH of 3. This type of acid generation can occur in the catchment, but other observations like more widespread iron staining are not evident. This source also doesn't fit with the seasonal rain-related nature of the significant acid flows of concern.

Key Points

Other sources of acid, such as acid waters resulting from the precipitation of dissolved iron in groundwater (humic acids and ferrorlysis acids), are likely to be minimal

4.2.4 Potential artificial sources of acid: Deposition of sulphur dioxide from smoke stacks

Background information on the fate of sulphur dioxide in the atmosphere

In 1961, Alcoa World Alumina Australia was granted a 7,221 hectare mining lease, known as the Anglesea Heath, on which they operate the Anglesea Power station.

Every year, Alcoa Anglesea uses around 1.1 million tonnes of brown coal to generate electricity that is transmitted to the Point Henry plant via a 45km high-voltage line. As a consequence of burning brown coal, sulphur dioxide (SO₂) is released from the stations stacks.

The atmospheric reactions of SO₂ are complex and depend on many factors including temperature, humidity, light, intensity and types of particulate matter present. Gaseous reactions proceed through three different pathways to the sulphate ion (SO₄²⁻). Sulphur dioxide can react with the hydroxyl radical to form an HSO₃ radical, which can react with another hydroxyl radical to form water and SO₃ or H₂SO₄ (sulphuric acid). Sulphur dioxide also dissolves in water droplets where it can react with oxygen gas to form SO₄²⁻. The third pathway to sulphate is when sulphur dioxide reacts with atmospherically-generated hydrogen peroxide to form sulphuric acid as shown in Figure 16.

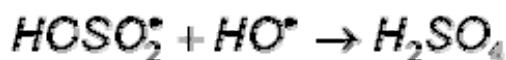


Figure 16. Reactions of sulphur dioxide to form sulphuric acid.

Oxidation of SO₂ to SO₄²⁻ also occurs on solid surfaces catalysed by iron and manganese and is the other primary mechanism by which sulphate is formed in the atmosphere. The ultimate fate of SO₂ in the atmosphere is to be oxidized to the sulphate ion, usually as sulphuric acid (H₂SO₄). The most common base present in the atmosphere is ammonia (NH₃) which reacts with sulphuric acid to form ammonium bisulphate (NH₄HSO₄) and ammonium sulphate ((NH₄)₂SO₄). Sulphuric acid, ammonium bisulphate and ammonium sulphate are all hygroscopic substances, readily dissolving in water.

Sulphates are removed from the atmosphere by dry deposition (deposition of particles or direct uptake by plants and soil) or precipitation (washout and rain) events. Removal rates are not well quantified but are estimated to be between 1 and 7 days, so transport may extend hundreds of kilometres from the original source.

The Alcoa operation (open cut brown coal mine and 160 MW steam turbine power station) commenced power production in 1969. The operation is EPA-licensed for waste discharges to the environment. Specifically, excess process water is discharged to the Anglesea River and emissions from burning coal are discharged to the atmosphere. Emissions to the atmosphere are released via a 110m high stack fitted with an electrostatic precipitator to remove fly ash particulate matter. No sulphur capture or scrubbing technologies are installed.

Limits for emissions are set in the EPA license and monitoring locations to measure sulphate concentrations are located at the emissions source (i.e; the stack and in the nearby area, including Anglesea township). Limits are based on State Environment Protection Policies (SEPP) targets for the protection of human health. Two types of emissions are emitted; particulate matter and gases (including sulphur dioxide). Anglesea coal has relatively high sulphur content (3.5%). Once in the atmosphere, emissions can undergo a number of process and reactions, including gravitational settling, adsorption into larger particles, and reaction with atmospheric water and rain (acid rain). Historically, severe acid rain and deposition cases, such as those experienced in the northern hemisphere, are not widely experienced in Australia.

Data from modelling carried out by Ecoplan for SO₂ deposition 2004/05, 2005/06 and 2006/07 indicates that between 1.7 - 3.9 kilotonnes (Kt) of sulphur dioxide was deposited within the Anglesea River catchment in these years. 2005 was a shutdown year for Alcoa's operation when the plant was offline for about 1 month for maintenance, so emissions for this year are lower due to lower power generation. Major shutdowns occur every 4 years.

2004 Report

"The model predicted that 6.3% (2,550 in 40,399t) of emitted SO₂ was deposited on the grid (4.1% or 1667t within the Anglesea River catchment) the rest was dispersed."

2005 Report

"The model predicted that 7.2% (2,620 in 36,372t) of emitted SO₂ was deposited on the grid (4.6% or 1674t within the Anglesea River catchment) the rest was dispersed."

2006 Report

"The model predicted that 13.1% (5,071 in 38,676 t) of emitted SO₂ was deposited on the grid (10.0% or 3,887 t within the Anglesea River catchment) the rest was dispersed."

This modelling of dispersal within the Anglesea Catchment concurs overall with BOM weather station monitoring at Aireys Inlet. Figures 17 and 18 show long term (approximately 20 years of data) wind roses and indicate prevailing westerly wind patterns with coastal influences of afternoon sea breezes. Expressed as a percentage, the roses display the direction and strength of the wind measured at 9am and 3pm everyday.

For example, in Figure 17 over 20% of observations recorded a wind direction from the north-west and in Figure 18, approximately 20% of observations are from a south west direction (the Anglesea River catchment generally extends north and west from the power station site).

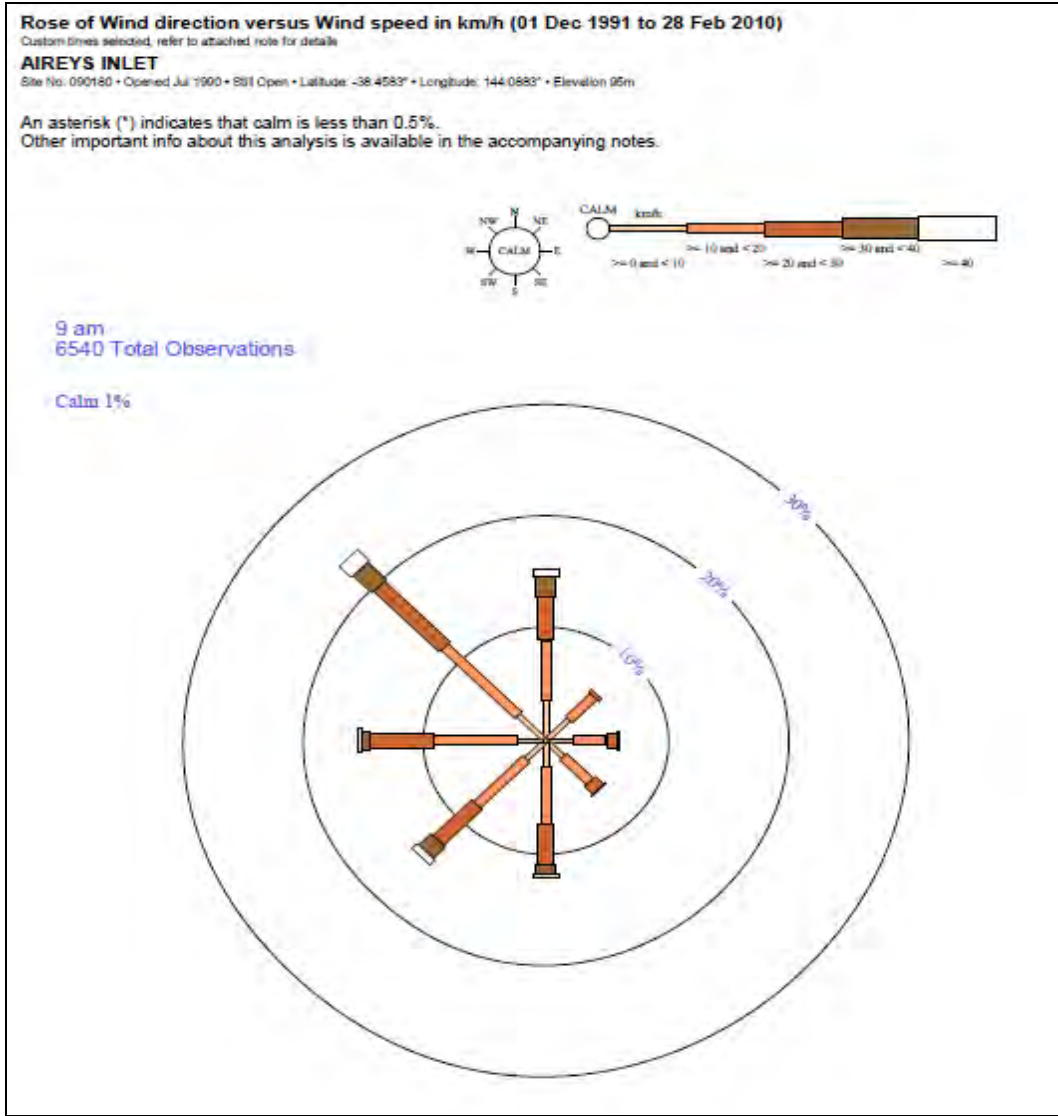


Figure 17. Rose of wind direction for Aireys Inlet at 9am (BOM website).

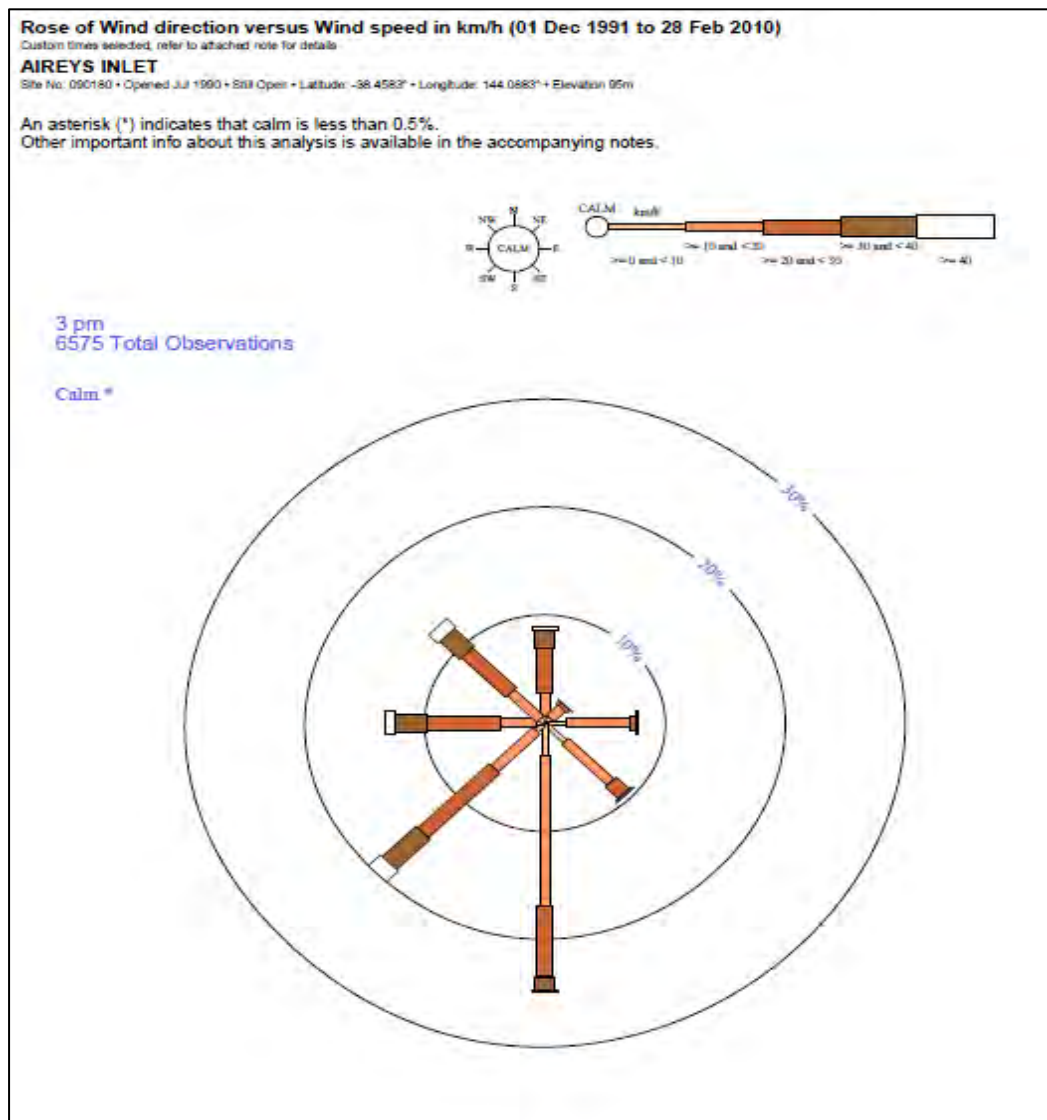


Figure 18. Rose of wind direction for Aireys Inlet at 3pm (BOM website).

The Laidlaw (2005) report, “Natural and industrial sources of acidification in natural ecosystems surrounding a coal-fired power station”, studied atmospheric deposition of sulphur dioxide in the catchment. The report is the most comprehensive body of work located on the effects of stack emissions at Anglesea.

The Laidlaw report summarises results from a two year study conducted between 2000 and 2002 on two field sites (Figure 19) where rain, soil, atmosphere and vegetation were studied and analysed as part of the project. Sites were chosen predominantly on the basis of plume modelling (Figure 20) and matching woodland types.

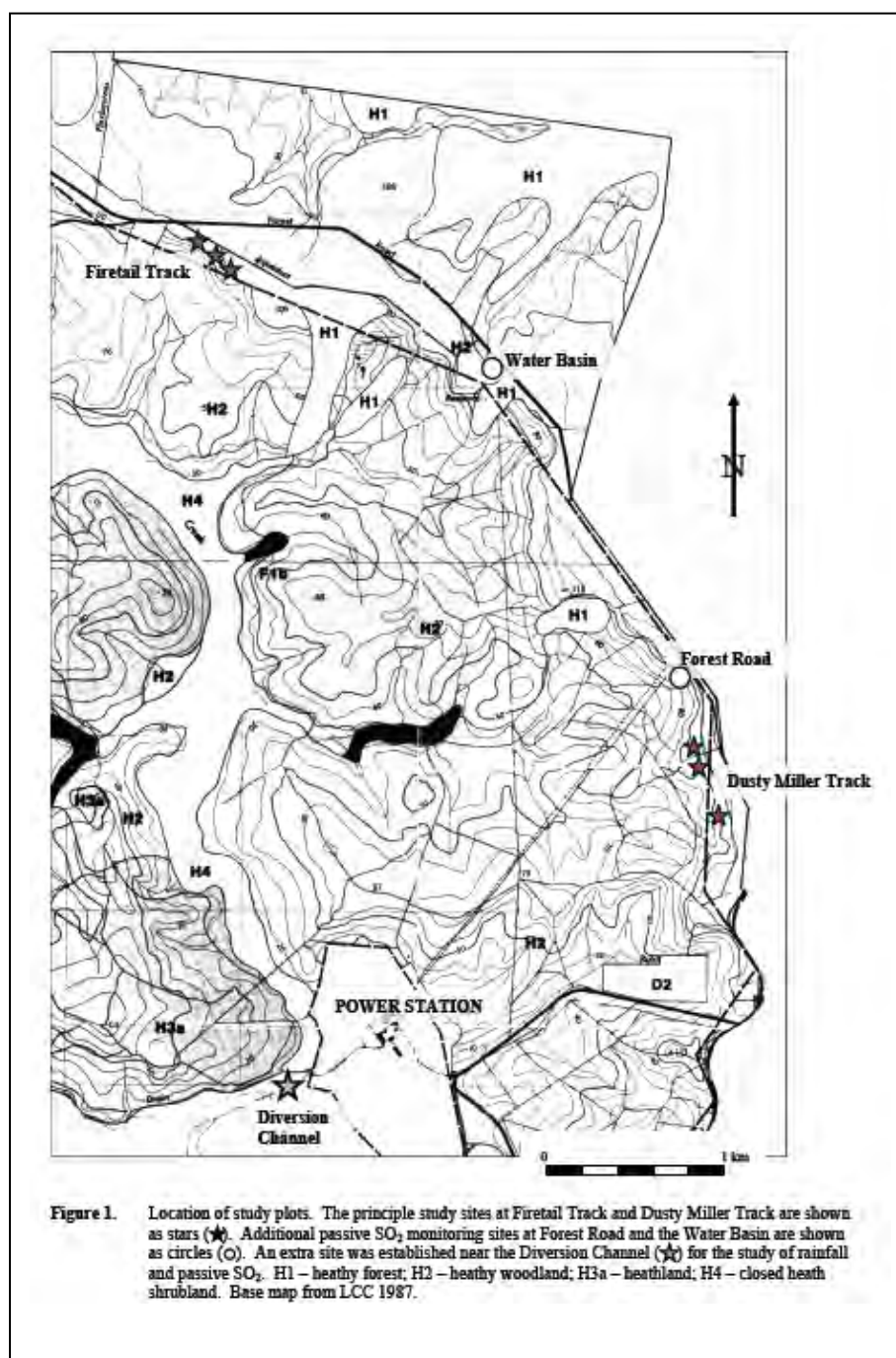


Figure 19. Location map of study sites (indicated by blue and red stars on the map) investigated by Laidlaw (2005).

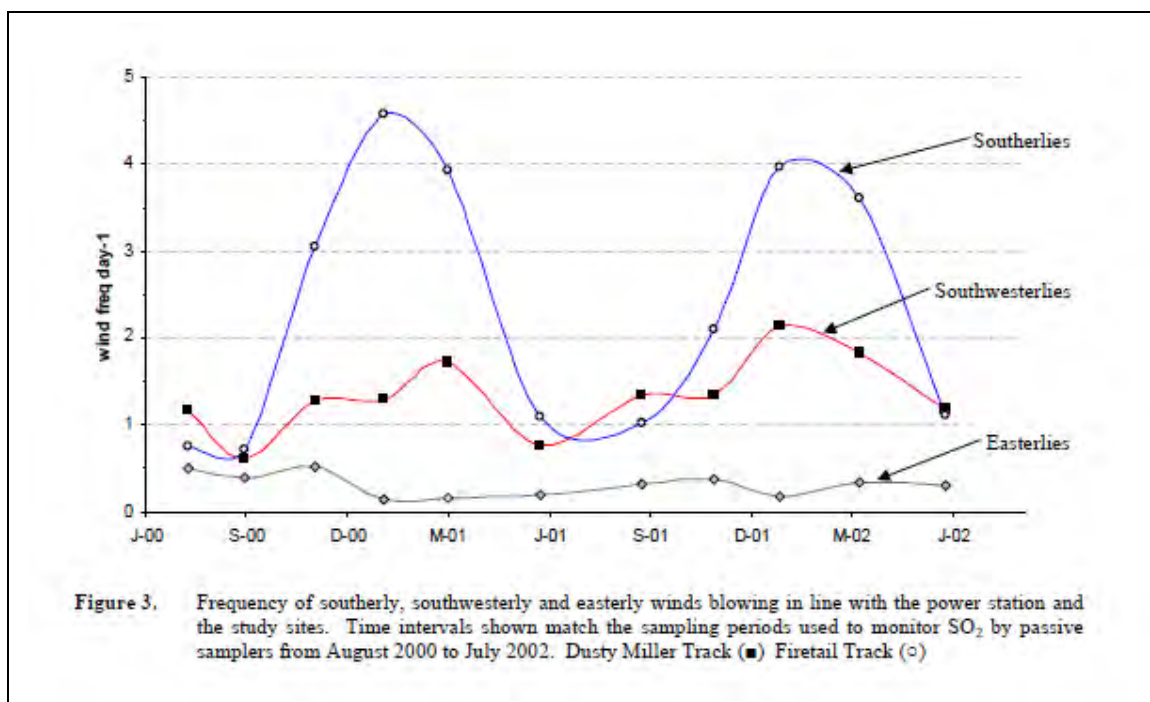


Figure 20. Wind direction measurements presented and used in Laidlaw (2005), the more frequent southerly winds directing the location of monitoring sites.

Passive sampler measurements of SO₂ from both the Laidlaw study and separate Alcoa monitoring (presented in the report) show the relationship of prevailing winds and increased concentrations of sulphur in the atmosphere. As show in Figure 21, the Firetrail Track and the Water Basin sites (downwind southerly direction) recorded higher concentrations than the Forrest Rd and Dusty Miller Track sites (downwind south westerly direction).

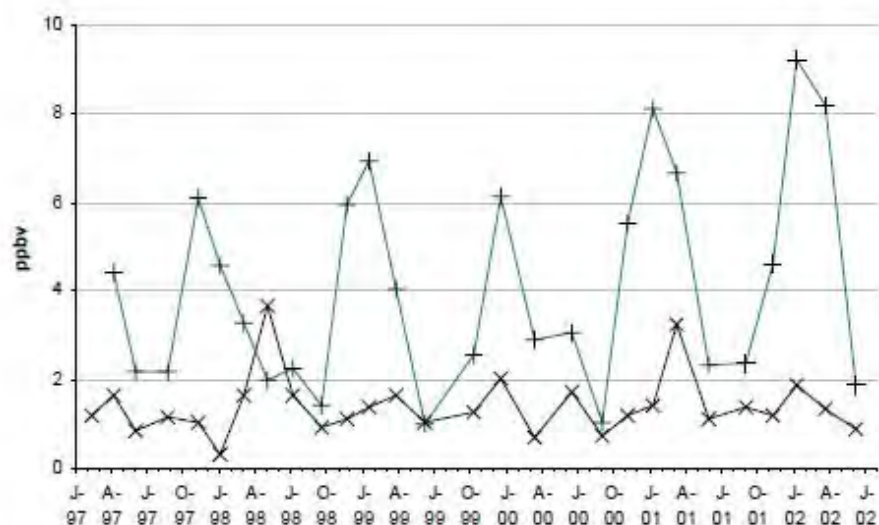


Figure 4. Ground level concentration of SO_2 recorded at Forest Road (x) and the Water Basin (+). Data were collected using passive samplers between January 1997 and June 2002 (Alcoa unpublished).

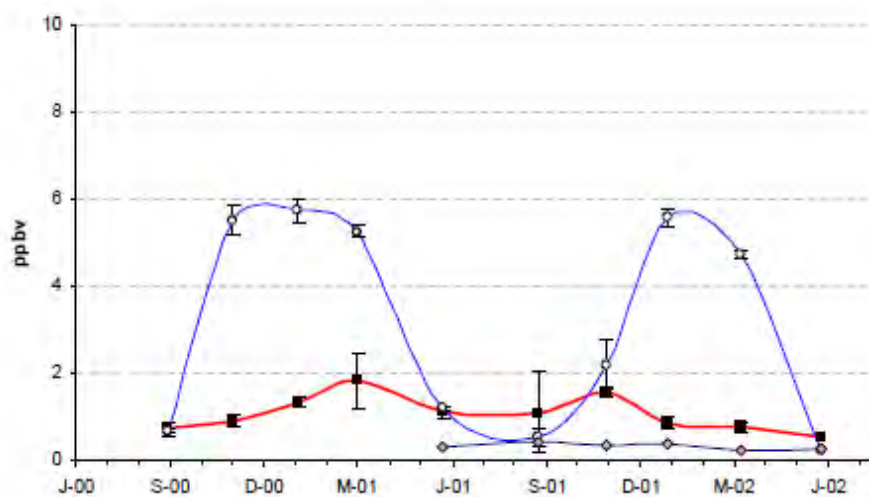


Figure 5. Ground level concentrations of SO_2 recorded by passive button samplers at Dusty Miller Track (■), Firetail Track (◊) and the diversion channel west of Power Station (○). Points are plotted at the middle of each sampling time period between Sept 2000 and June 2002.

Figure 21. Concentrations of SO_2 measured at Water Basin (predominant downwind site = higher concentrations), Forrest Rd and Firetrail Track (predominant downwind site = higher concentrations), Dusty Miller Track (Laidlaw 2005).

Key statements and information from the report include:

- Plume modelling is being developed to more accurately identify land based locations for highest SO₂ deposition.
- Passive samplers recorded measureable concentration of SO₂ at each site, with measurable difference between sites relative to prevailing winds.
- Wet deposition of plume SO₂ is likely to be low as the conversion rate of SO₂ is low at 0.2-4%/hr (i.e; wet deposition of acids occurs when any form of precipitation removes acids from the atmosphere and delivers it to the earth's surface and as Laidlaw (2005) reports, the rate that SO₂ dissolves (converts) into the aqueous phase is relatively slow.
- Through fall quality (i.e; samples collected from under tree canopy from which it would be expected to compose inputs of dry deposition) measurements shows no significant difference between sites and suggest that dry deposition is undetectable against background elemental sulphur cycling. Examples are provided in Figure 22 for sulphur and Figure 23 for hydrogen.
- Analysis of tree foliage to test the hypothesis of acid rain effecting elemental ratios showed possible effects of acid rain in some comparisons. Results also showed temporal variation and included higher S/N ratios at the Firetrail Track site at the end of the high exposure period July (the end of summer and dominant southerly sea breezes).
- Soil analysis showed high variability of soil pH at each site and no discernable difference between sites. Cation exchange or leaching as a result of acid rain was not supported by test results, and that variation in results was more readily explained from the type and duplex nature of the soils themselves.

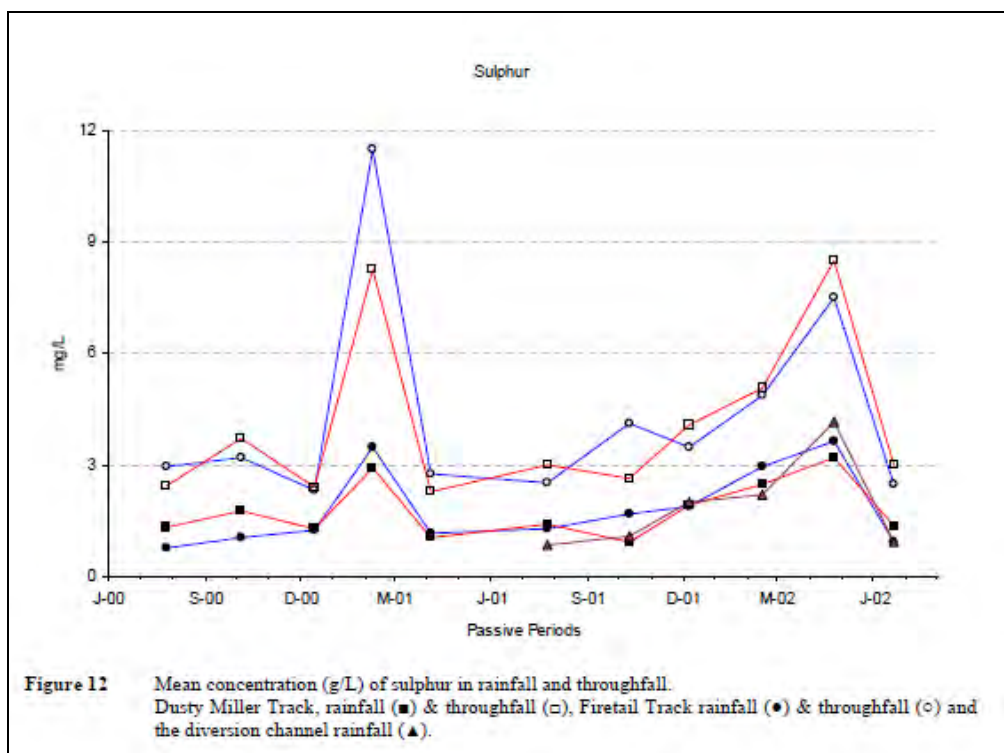


Figure 22. Sulphur concentrations of rainfall and through fall at the study sites as presented by Laidlaw (2005).

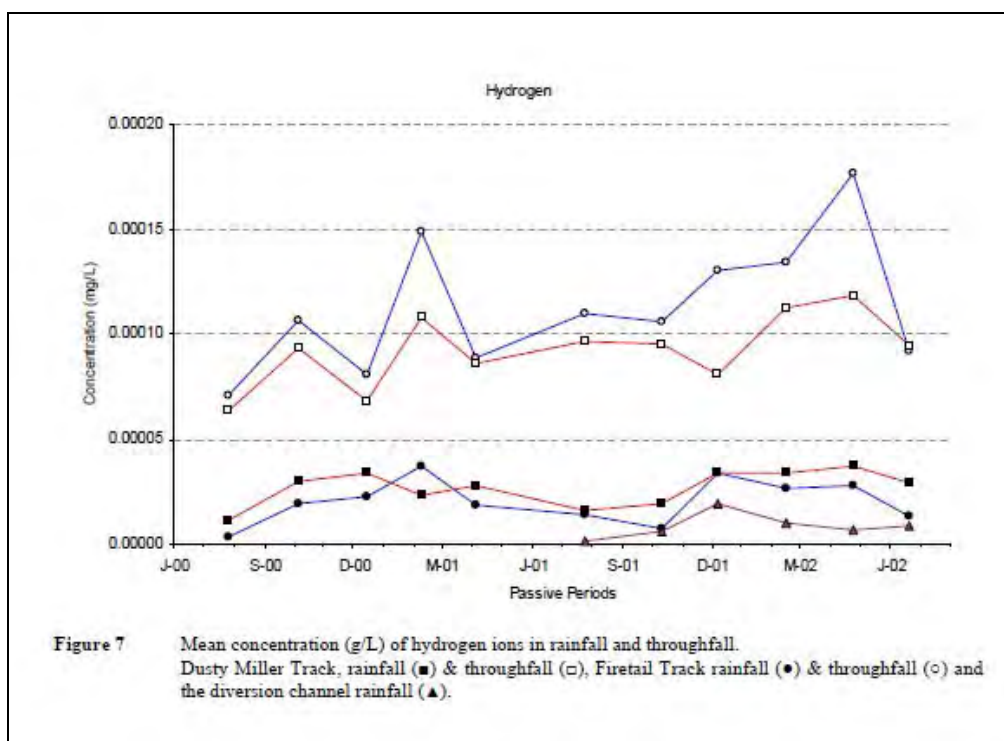


Figure 23. Hydrogen concentrations rainfall and through fall at the study sites as presented by Laidlaw (2005).

In conclusion, the report suggests that the *“magnitude of acidification resulting from SO₂ released by the Anglesea power station is low and represents a small proportion of the total acidification due to the natural processes in the woodland ecosystem surrounding the power station. Overall the soils and woodland communities of the Anglesea area can accommodate this small increase in acidity with natural processes of acidification and nutrient cycling”* (Laidlaw 2005).

The findings of the Laidlaw (2005) are generally supported by vegetation surveys also undertaken to assess impacts of emissions. Doley (2002) summarises his survey findings by saying *“There was no evidence of air pollutant injury to vegetation at the locations most likely to record elevated ground level concentrations, namely the Forest Road and Noble Road air monitoring sites. There was no evidence of air pollutant injury in the Bald Hill area, or at other locations examined in this survey.”*

Alcoa's EIP published in 2008 also reports that vegetation surveys in 2006 and 2007 did not detect any visible injury to vegetation. Similarly, a survey in November 2008 found no signs of effects of emissions on vegetation (Hill 2008).

Adverse effects are possible from sulphur emissions and Alcoa's own operating procedures (load reduction protocol), as described in their EIP, have been developed to meet sulphur emission limits, but effects of emissions seem less discernable in the greater environment.

Of the emissions, some sulphur in either wet or dry forms does deposit in the Anglesea River catchment. Exact quantities will vary from year to year depending on weather conditions, but modelling between 2004 and 2006 estimated deposits of sulphur in the Anglesea River Catchment were 1667, 1674, and 3887 tonnes respectively. This equates to approximately 4 to 10% of annual emissions deposited, while the remainder are dispersed further afield.

Long term impacts of sulphur deposition into the greater environment have been investigated and monitoring results indicate measureable sulphur concentrations at sites downwind of the stack in the Anglesea catchment. The effects of the deposition are somewhat more marginal and uncertain, and given the context of other factors in the Anglesea catchment, make quantitative assessment difficult.

The World Health Organisation (WHO) air quality guidelines for Europe (2nd edition) list an annual average limit for sulphur dioxide to protect forest and natural vegetation at 20 µg/m³ annual average (or 7.6 ppbv annual average). Monitoring reported by Laidlaw (2005) indicates that this limit is probably not being exceeded. Water quality data analysed (see Figure 29 and Section 6.4.2) also does not give any clear signal or correlation of significant changes in water quality relative to modelled deposition areas.

Hermon (2002) reported chloride/sulphate ratios ranging between 0.26 at site SF1 (July – October, 2001) and 19 at site MF6 (November 2001) (see Figure 29). The chloride/sulphate ratio was observed to increase over the duration of the study at sites MF3 and MF6, indicating a decrease in sulphate concentrations at these sites within the study time.

Data supplied by Alcoa have chloride/sulphate ratios ranging between 0.1-6. The chloride/sulphate ratio of seawater is 7.13 (Libes 1992). A decrease in the ratio from that of seawater indicates the

enrichment of sulphate concentrations. This assumes the chloride ion is derived primarily from seawater at these sites, and that it behaves conservatively.

Sulphate concentrations for Marshy Creek (inside the plume area) are significantly less than the sulphate levels measured in Salt Creek. If significant $\text{SO}_2/\text{SO}_4^{2-}$ deposition occurs it is expected that Marshy Creek and its tributaries would show the higher levels of sulphate due to deposition from the plume (if other contributions are equal). Pope (2006 thesis) referenced an uncapped artesian bore located right near Marshy Creek (Figure 24).

In the Anglesea catchment, Marshy Creek flowed more consistently than Salt Creek. This may be related to an uncapped artesian bore in the lower Marshy Creek catchment, 3.3 km upstream of junction, in the Edwards Creek sub-catchment ($38^{\circ}22'18''\text{S } 144^{\circ}10'44''\text{E}$). This bore flowed at a mean rate of $0.0027\text{m}^3/\text{s}$ through the study, but was not always realised as surface flow at the Marshy Creek site downstream. Despite the longer periods of no flow at the bottom of Salt Creek,

Figure 24. Extract from Pope (2006) on the subject of an uncapped artesian bore as a possible source of sulphates.

Alcoa's testing of this bore water indicates sulphate levels in excess of 100 mg/L, so artesian water may also be contributing sulphate to Marshy Creek. Apportioning the contribution of sulphate to streams and tributaries from plume deposits and contribution to acidity is not possible without knowing the sulphate contributing from natural sources.

Given the proximity of the adjacent catchments, Spring Creek and Thompson Creek (their upper catchments are on the east side of Forrest Rd), measurements of acid flows in these catchments may help determine relative sources of acidity in the Anglesea River catchment. In other words, if acid rain or dry deposition is a significant contributor to the observed acid drainage in the Anglesea catchment, some signal of atmospheric sourced acidity is likely to be measured in other catchments downwind of the emissions source.

Conclusions

The acidification resulting from SO₂ released by the Anglesea power station seems low and represents a small proportion of the total acidification compared to the natural processes occurring in the catchment.

Key Points

Anglesea coal has relatively high sulphur content. This means that emissions from burning coal could contribute to acidity due to acid rain.

Once SO₂ is in the atmosphere it can undergo processes and reactions including gravitational settling, adsorption into larger particles, and reaction with atmospheric water and rain (sulphuric acid generation – acid rain).

Emissions modelling by Alcoa (atmospheric dispersion at Anglesea) indicates that of the 37Kt of sulphur emitted each year, about 1.7-3.9Kt may deposit in the Marshy Creek catchment while the bulk of emissions are blown out of the catchment.

Wind roses for nearby Aireys Inlet show westerly prevailing wind patterns, with coastal influences of afternoon sea breezes.

The Anglesea River catchment generally extends north and west from the power station site so stack emissions would mainly be deposited outside the catchment.

Measured sulphur concentrations from sites in the catchment show some deposition (wet or dry) from stack emissions.

Evidence of chloride/sulphate ratios lower than seawater in streams and tributaries indicate sulphate enrichment. However, greater sulphate concentrations in Salt Creek rather than Marshy Creek (which is in the plume area) indicate that higher sulphate concentrations may be from pyrite oxidation.

There is evidence of artesian water contributing sulphate to Marshy Creek, which has elevated sulphate concentrations.

The measurable effects of sulphur deposition on vegetation and soil are within the scale of natural variation, and adverse effects indicating substantial acid rain have not been identified.

Given Anglesea's background geological conditions, it is hard to substantiate or quantify the effects of sulphur emissions.

Knowledge Gaps

Proportional contribution of sulphur emissions to acid drainage in the Anglesea catchment.

Apportioning the contribution of sulphate to streams and tributaries from natural sources and plume deposits.

4.3 Acid generation and transport in the Anglesea catchment

Before reduced sulphides (such as pyrites) can generate acid, oxygen and water must be present. While oxygen concentration in rainwater is generally high, when rain infiltrates into the ground oxygen concentrations start to decrease as it is consumed by soil microorganisms and/or chemically reacts with soil and other geological strata. Typically, infiltration that reaches a water table has low dissolved oxygen and groundwater itself tends to have low to zero dissolved oxygen. This creates an anaerobic (no oxygen) environment. Pyrites typically are therefore stable or non-acid generating when they are below the water table.

In the region above the water table (vadose zone), pore spaces in strata and soil units allow for air and water to be present. Oxygen from air is probably limited because the flux of air through the vadose zone is minimal, however the flux of water through a vadose zone can be significant (i.e; infiltration and recharge) which creates a scenario for much greater rates of sulphide oxidation and acid generation. This assumes the water still has some level of dissolved oxygen or other chemicals to drive oxidation reactions.

The Victorian EPA lists activities that may contribute to disturbance and subsequent oxidation of sulphide bearing soils and rock. These include excavation of land, lowering of the groundwater table, planting vegetation or crops that may lower the water table, coastal or inshore dredging and drilling.

The rate of oxidation (as described by the US EPA 1994) depends on:

- reactive surface area of pyrite (such as grain size);
- form of pyritic sulphur (such as marcasite and pyrite);
- oxygen concentrations;
- solution pH (increased at lower pH);
- catalytic agents (such as Fe^{3+});
- flushing frequencies;
- the presence of *Thiobacillus* bacteria (which can accelerate reactions); and
- duration of exposure to air and water.

The transportation of 'acid' from its geological sources to water courses is the infiltration of water (typically precipitation, i.e. rain) into the strata, then its discharge to surface waters. Similarly, if marshes in the Anglesea catchment had 'dried out', the same hydrological process of rewetting, oxidation and transport of acid downstream would occur.

The hydrological cycle (Figure 25) is presented to show concepts relating to the generation and transport of acid.

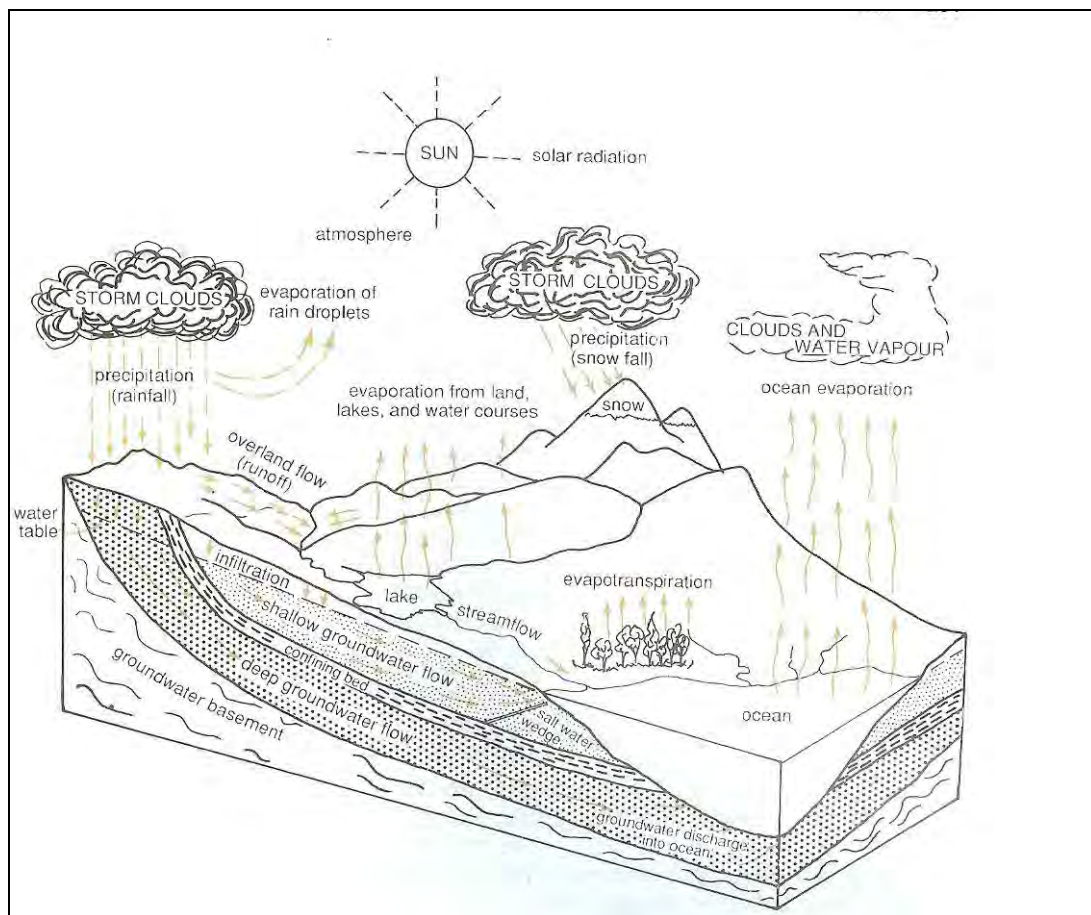


Figure 25. The hydrological cycle (Cochrane et al 1995)

Hancock (1967) noted that shallow coals were responsible for the loss of drilling mud, indicating a reasonable level of porosity and hydraulic conductivity. The significance of this is that coal (recorded in bore logs throughout the catchment) has properties that allow water to flow through it and create a scenario for pyrite oxidation, if oxygen is present in the water.

Infiltration and recharge calculations are difficult in a geological setting like the Anglesea catchment. Barwon Water and GHD's recent works have approximated infiltration and recharge in the catchment using refinement of previous studies estimates (GHD 2008). Measurements of infiltration rates for the catchment were not found during the review. Barwon Water's work acknowledges some base flow from the Lower EVF to streams and creeks above the swamps. This further supports a mechanism involving interaction or connectivity between recharge, groundwater and surface water flows. As shown in the bore log from AL622, interactions between unsaturated aquifers (such as those containing coal) and streams are a likely mechanism for generating and transporting acid.

A simple conceptual model for the catchment is shown in Figures 26 and 27 (Tutt 2008).

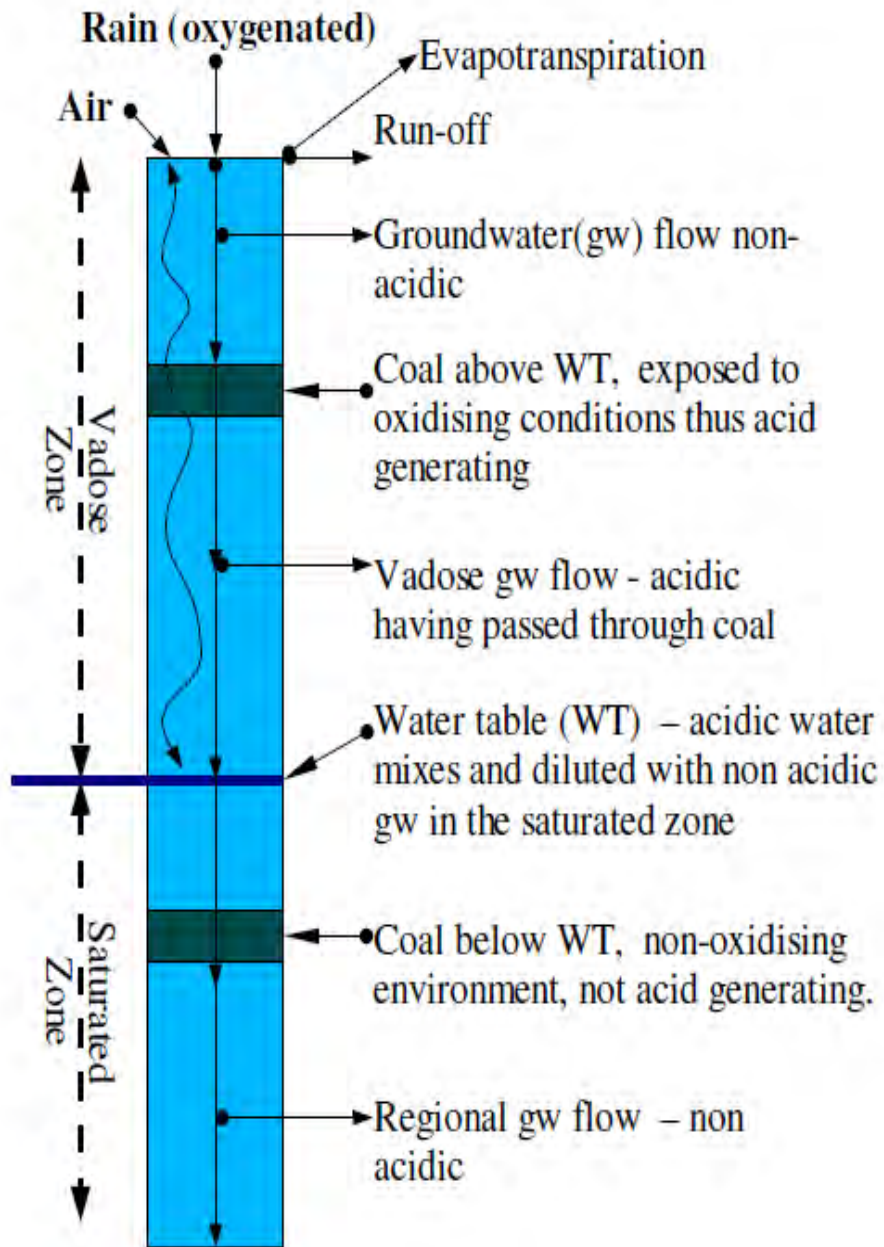


Figure 26. Concept model of acid generation and transport from Tutt (2008).

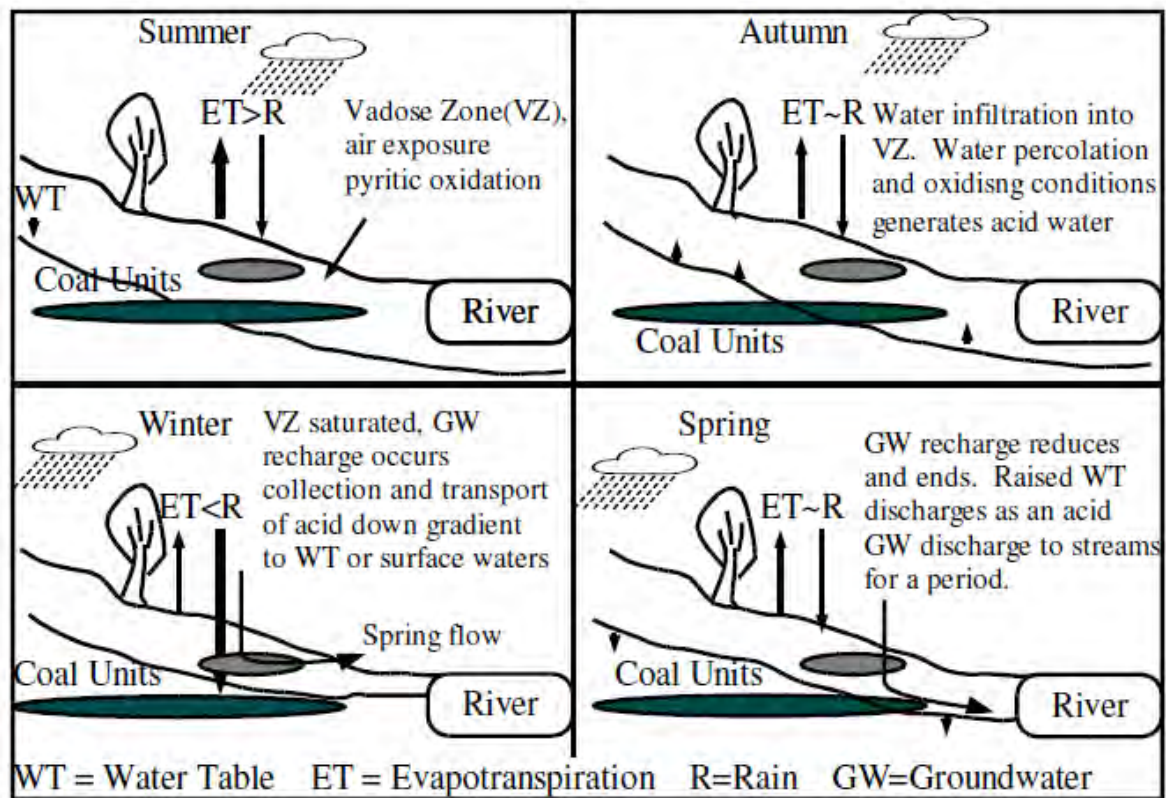


Figure 27. Concept model of acid generation and transport from Tutt (2008).

This conceptual model was used to explain and possibly to predict acid events in the catchment (Tutt 2008). The model has as its input, of rainfall and a major natural export, evapo-transpiration (ET). It shows that over autumn, winter and spring when ET rates decrease, infiltration of rain occurs. It is important to note that different intensities of rain will affect the proportional rates of infiltration versus runoff. Following infiltration, water drives the acid reactions (Section 4.1 and 4.2.) and transports acid via underground flow down the gradient. In some instances, the flow may enter surface waters as an obvious spring flow or enter surface waters as a base flow.

Other studies have investigated the relationship between catchment geology, marshes, rainfall and acid water, and water quality monitoring has also been used to draw explanations of the low pH acidic water flows. For example, Hermon (2002) measured pH (Figure 28) and chloride/sulphate ratios (low ratios indicate relative higher levels of sulphate) (Figure 29) at various locations throughout the catchment, with results indicating low pH waters were present at times throughout the catchment (generally decreasing down each tributary, accumulating acid).

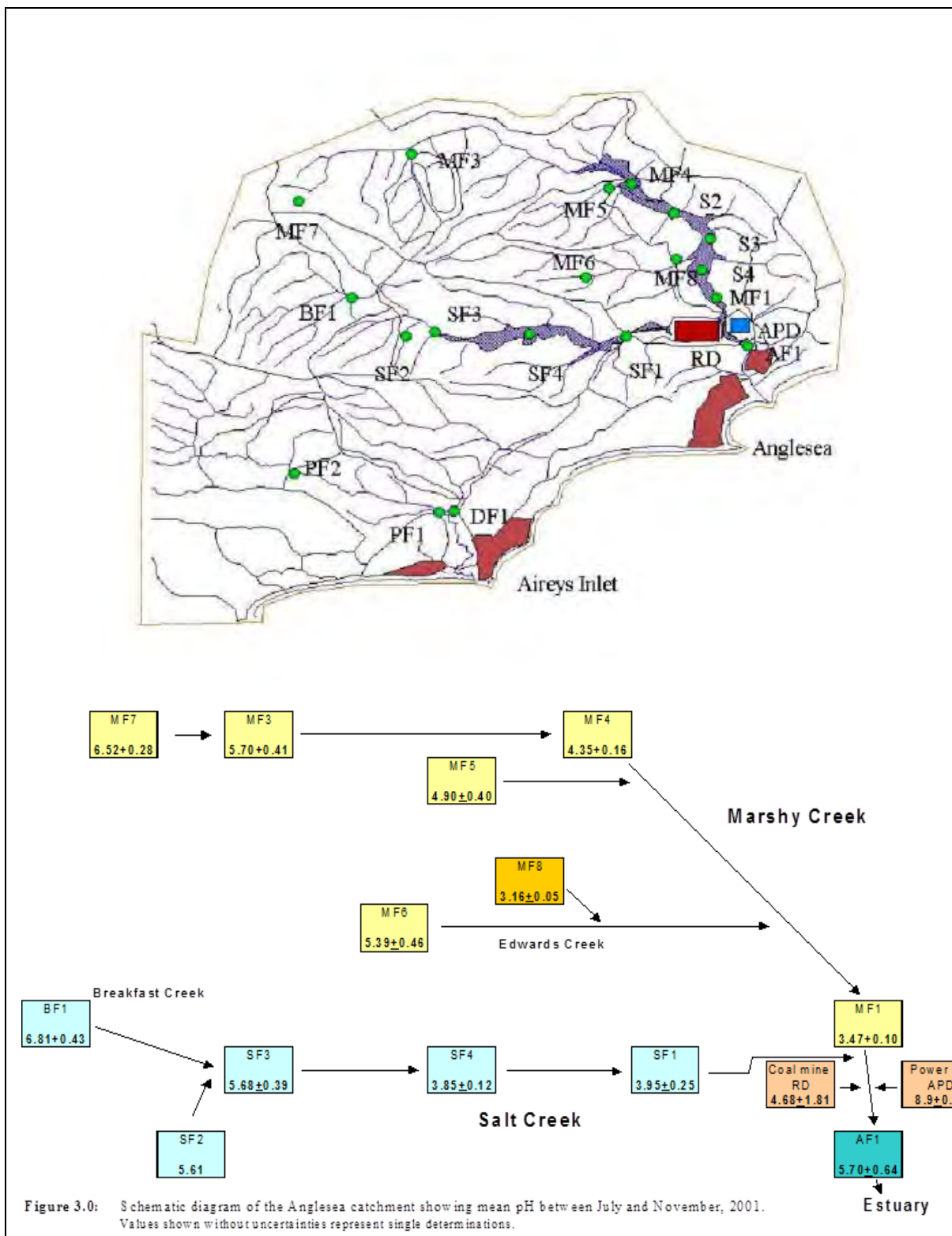


Figure 28. Map showing locations and pH measurements of water samples as part of Hermon (2002) investigations into acid flows at Anglesea.

Figure 29 from Hermon (2002) shows the variation of chloride/sulphate ratios across the catchment and the low ratio at SF1 is a typical sign of acid sulphate drainage. Also of note is the large variation at points such as MF3 and MF6, indicating that some process is occurring at points in the catchment to alter sulphate concentrations in stream water at different times.

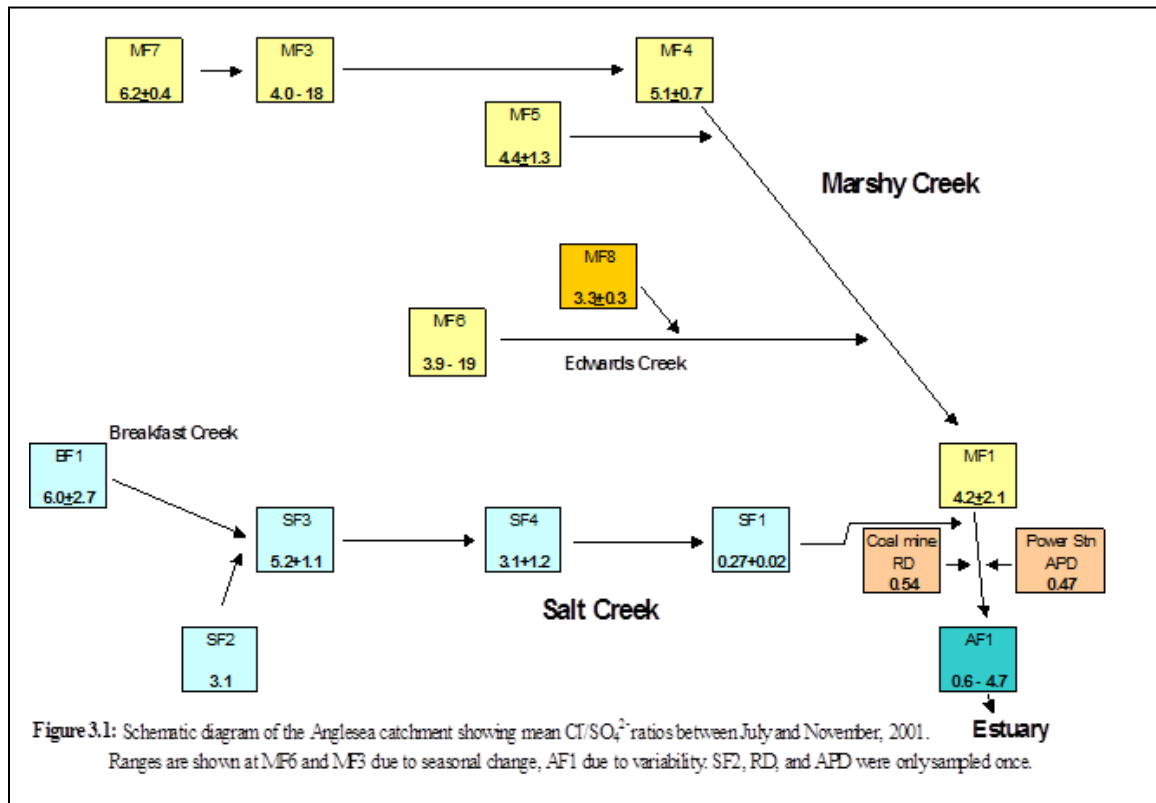


Figure 29. Schematic map of chloride to sulphate ratios measured as part of Hermon's (2002) investigations.

4.3.1 Acid transport and fish death events

Rainfall data for 2000 and 2009, and 2010 are presented in Figures 30 and 31. Monthly cumulative rainfall is presented in Figure 32 showing years 1999, 2000, 2009 and 2010, and daily rainfall data for September 2010 is shown in Figure 33.

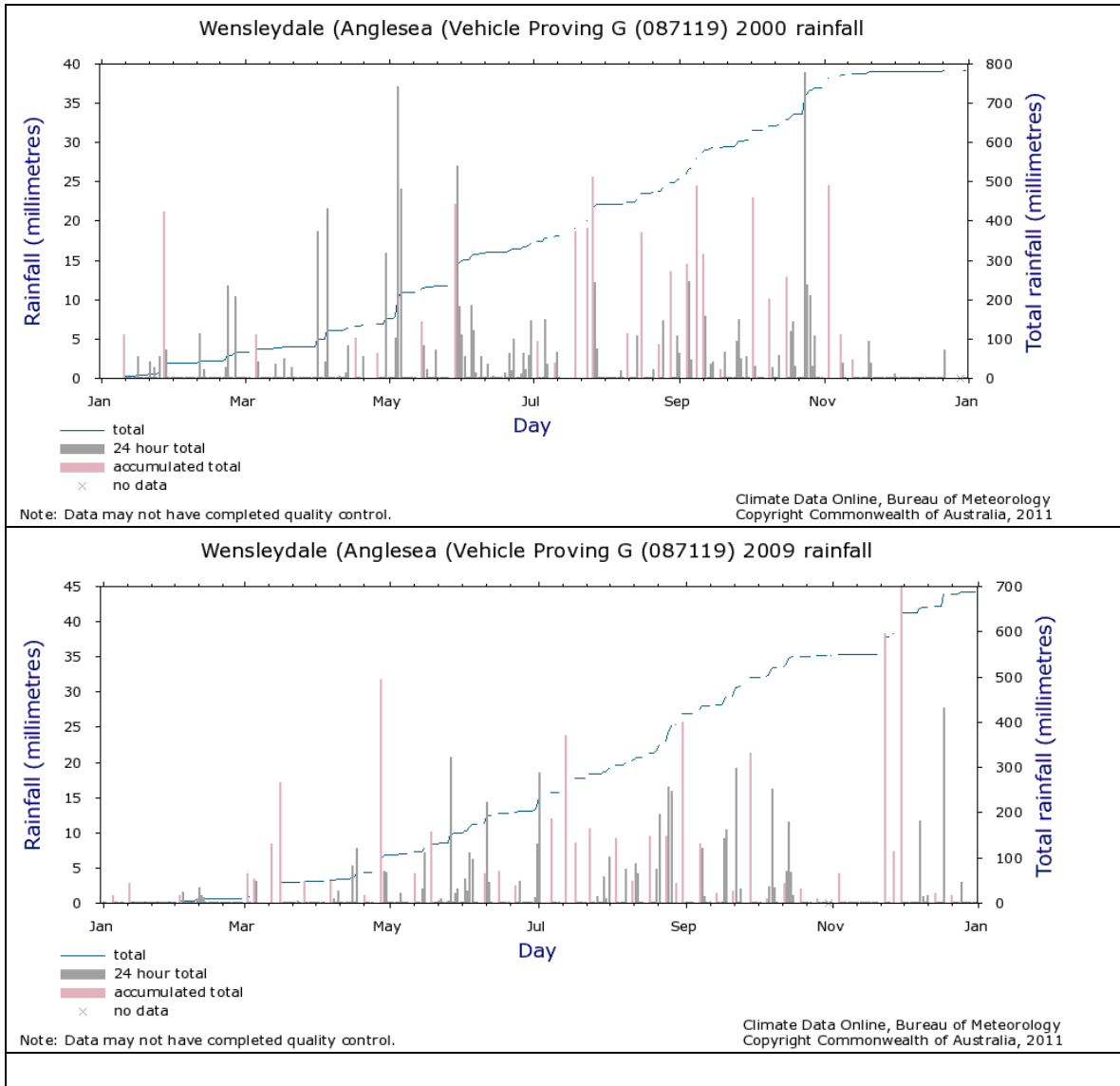
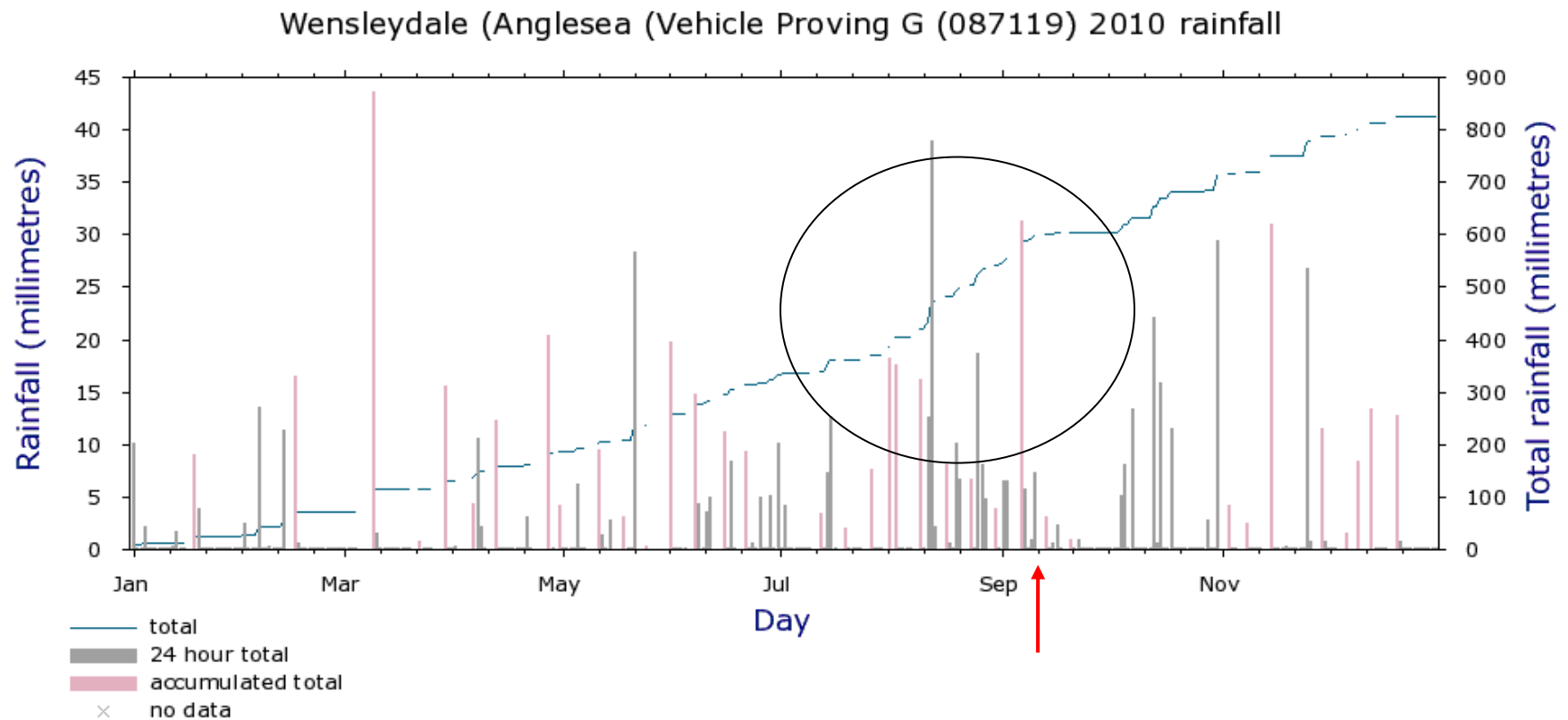


Figure 30. Rainfall data for years 2000 and 2009 (note that pink lines are 3-4 day accumulated totals).



Note: Data may not have completed quality control.

Climate Data Online, Bureau of Meteorology
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*X axis increments are in approximately 10 day blocks

Figure31. Daily and Cumulative rainfall for 2010 from Anglesea Vehicle Proving Ground in the upper reaches of the catchment (Source BOM website). The circle marks the increased gradient of the cumulative rainfall, red arrow marks approximately 13 September – fish death event. (Note that pink lines are 3-4 day accumulated totals)

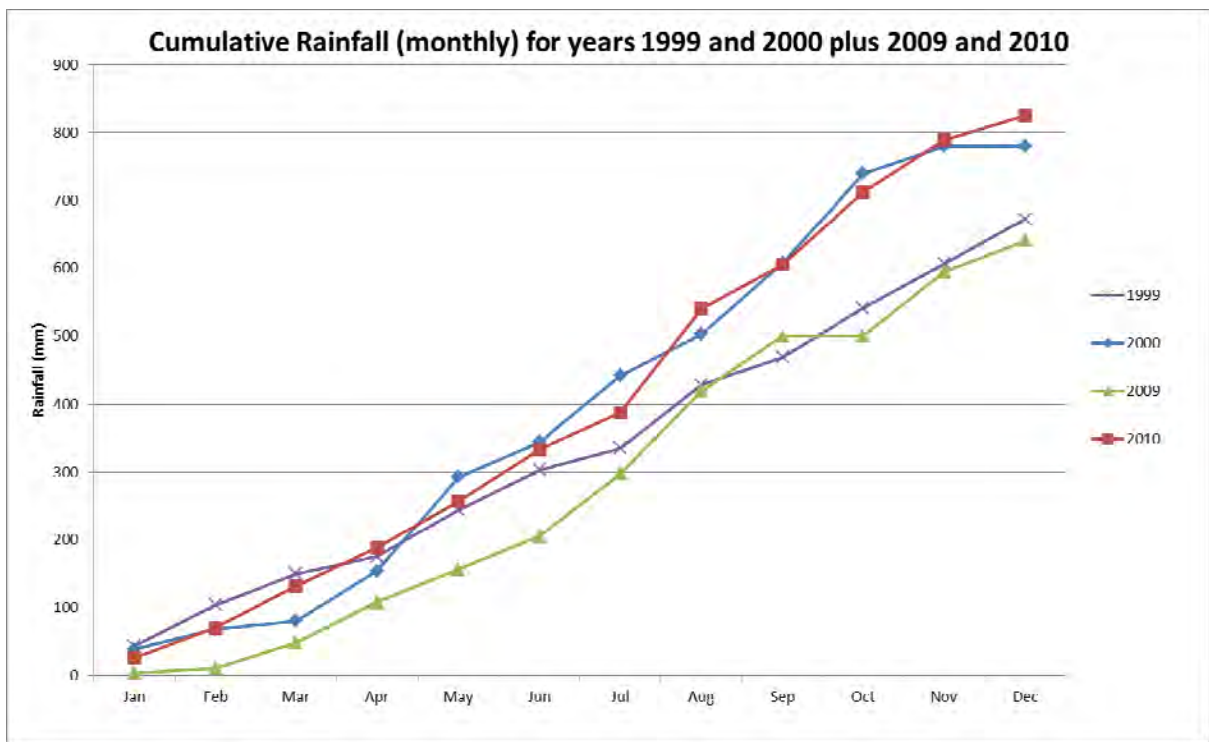


Figure 32. Cumulative rainfall (monthly) for years 1999, 2000, 2009 and 2009.

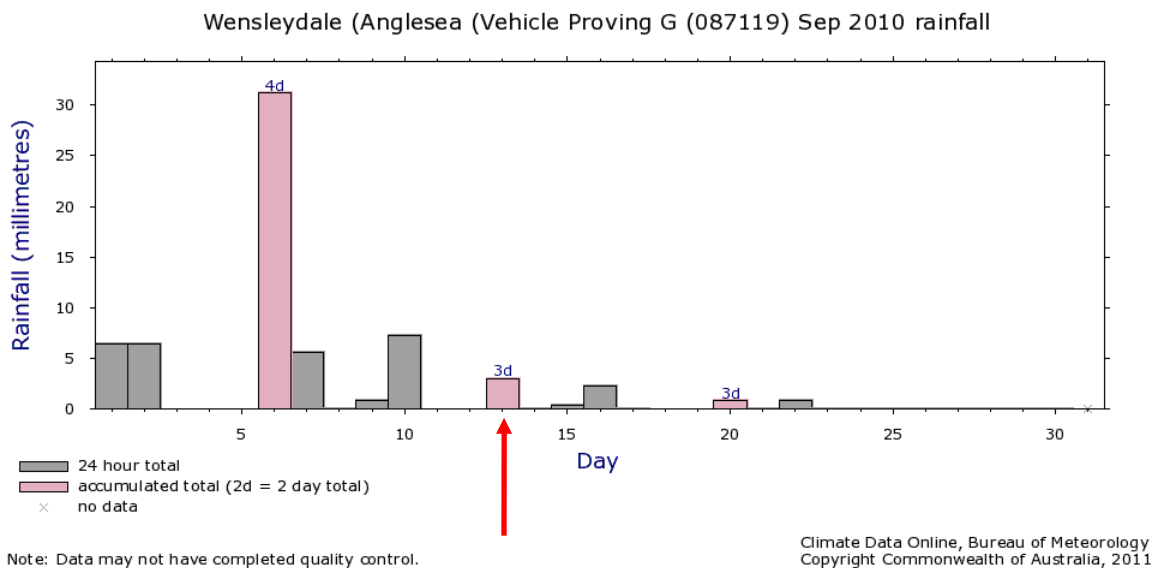


Figure 33. Daily rainfalls for September 2010, arrow shows 13 September when EPA responded to fish deaths.

The years of the fish kills (2000 and 2010) experienced higher rains than preceding years (108 and 185mm respectively). By June each year, the catchment received over 300mm of rain and then in spring the continuation of 'good rain' is depicted in the increased gradient of 2000 compared to 1999, and 2010 compared to 2009.

Tutt (2008) presented a seasonal water balance model showing why the acid event of 2000 was severe. The model demonstrated that the flush of acid from the catchments is made worse when an extended dry period is followed by soaking rains through autumn to spring.

Similar to the 2000 event described by Tutt (2008), rainfall data for 2010 shows considerable rain immediately prior to the fish deaths. There was a dry period before the soaking rains. Alcoa's monitoring program noted that prior to winter/spring 2010, both tributaries had not flowed for some months. In particular, Salt Creek, which began flowing in August had not flowed for approximately 32 months. This event presents a similar 'dry-wet' pattern to the 2000 and 2007 events as reported by Alcoa (Alcoa submission to the review).

The rainfall leading to 13 September could be described as a 'soaking' period because the increased gradient of cumulative rainfall spans approximately 40 days in which time approximately 200mm of rainfall was recorded. The initial flow of Salt Creek following the soaking rain is shown in Figure 34 taken from Pope's 2010 EPA report into the fish deaths.

The catchment 'soaking' and infiltration of water to aquifers is also supported in Figure 33. Daily rainfall for September, which shows small amounts of rain in the order of 5mm/day falling in the week before estuary acidification (fish deaths 13 September). Small and steady amounts of rain may have been 'optimal' for infiltration and could likely have created a slow flush of acidic waters from the vadose zone and surface water interactive aquifers to the streams and creeks, and ultimately to the estuary.

It is impossible to say which of the many factors that can influence oxidation rate are critical at Anglesea. Flushing frequency may be important as a build up of acid could occur and be transported to the estuary in the next significant infiltration and flush event.

Pope (2006) documented that the first significant flows in two years from the Salt Creek catchment occurred at the time of the acid event in 2000, and corresponding water quality results of low pH and high sulphate concentrations (1000mg/L) were measured. As mentioned earlier, Alcoa monitoring indicated that before the 2010 acid event, Salt Creek had not flowed for 32 months.

Measurements by Parsons (2011), Figure 34, also shows that following rain in early January 2011, pH decreased 3.5 at monitoring point SP3. This is more typical of the water quality of the catchment creeks rather than Alcoa discharge (which had pH 7.7 on 20-1-11), and is best explained by relative flow proportions at the time (limited flow data was located for the review).

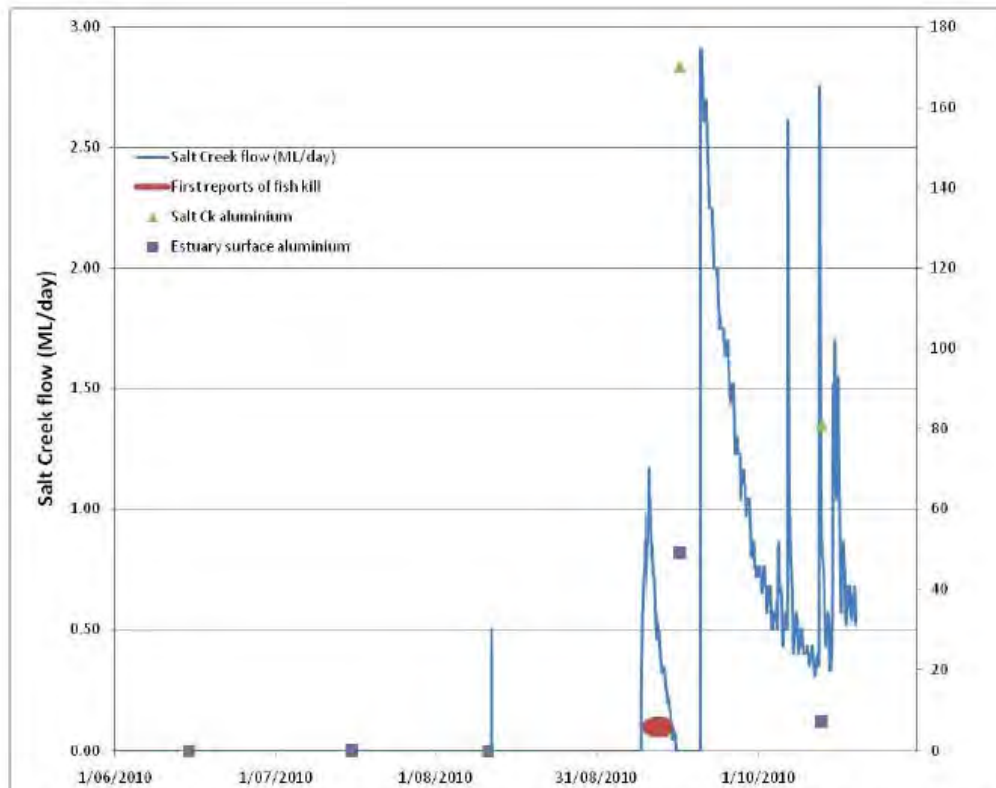


Figure 3. Flow in Salt Creek and aluminium concentrations in water at the time of the fish kill (data from Alcoa of Australia and Barwon Water).

Figure 34. Salt Creek flow and aluminium concentrations in water at the time of the estuary acidification and fish kill taken from Pope (2010).

The Anglesea estuary is different to many in Australia because Alcoa's licensed discharge to the river provides a regular "flow to the river" (Pope 2006, Parsons 2011) and the discharge quality is generally much more alkaline or higher in pH than the river water. Parsons' (2011) data presented in Figure 4 shows the signal of alkaline mine water at monitoring point SP3 to be pH 7, while both Salt Creek and Marshy Creek were at pH 3 on or around 8 January 2011. Following substantial rain in the week of the 8-15 January 2011, it would be reasonable to assume flow increased from the catchment, and that this would concur with the pH at SP3 dropping to the pH range of 3-4 (i.e; the water quality reflected the greater portion and influence of "catchment flows" at this point in time and its likely alteration of estuary water quality conditions).

Conclusions

Rainfall intensity and timing is the key determinant of whether or not an acid flush occurs.

An acid flush is likely after an extended period of low rainfall or drought.

Quantification of infiltration and recharge rates in the Anglesea catchment, and flows in tributaries and the Anglesea River, should provide an insight into the acid flush mechanism.

Key Points

Transportation of 'acid' from its geological sources to water courses is by infiltration of water (typically rain) into the strata, and its subsequent discharge to surface waters. Similarly, if marshes in the Anglesea catchment had 'dried out', the same hydrological process of rewetting, oxidation and transport of acid downstream would apply.

The annual hydrologic cycle appears to be the key mechanism for generating and transporting acid in the Anglesea catchment (i.e; drying out of coal/pyrite and sediment).

The type of rainfall is also important in determining whether an acid flush occurs. In other words, rain that infiltrates and transports acid to surface water systems via groundwater.

The years of the fish kills (2000 and 2010) experienced higher rains than the preceding years.

Small and steady rain of 5mm per day in the week before estuary acidification (fish deaths 13 September 2010) may have been optimal for infiltration and are likely to have created a slow flush of acidic waters from the vadose zone (underground flow) and surface water aquifers to the streams and creeks, and ultimately into the estuary.

Pope (2006) documented that the first significant flows in two years from the Salt Creek catchment occurred at the time of the acid event in 2000, with water of low pH and high sulphate concentrations.

Alcoa monitoring indicated Salt Creek had not flowed for 32 months before the 2010 acid event.

A seasonal water balance model by Tutt (2008) showed why the acid event of 2000 was severe. It explained that the flush of acid from the catchments is made worse when an extended dry period is followed by soaking rains through autumn to spring.

Knowledge gaps

Measurements of infiltration and recharge rates for the Anglesea catchment.

Flow data in the catchment (including the river) and sub catchment of both creeks.

Lack of sulphate measurements in water quality monitoring programs as an indicator of acidity source.

5 Dissolved metals

Low pH water can mobilize acid soluble metals, including iron (Fe), aluminium (Al), copper (Cu), zinc (Zn) and others depending on the mineralogy of the area. The mixture of acid and dissolved metals can affect aquatic organisms through pH stress, toxic effects and other effects such as the impact of flocculated metals (e.g. covering the gills of fish).

In this section evidence is reviewed from each of the below studies to establish the sources of acid in the catchment. Eight data sets were available for review:

- Atkins, L. and Bourne, A.R. (1983). Alcoa of Australia Limited Anglesea (Vic) mining lease environmental study Volume 2. Environmental Survey of metals in the Anglesea River (1981-1982). Report Document January 1983.
- Meyrick, J. (1999). Trace element distribution and speciation in the Anglesea River. BSc (Hons) Thesis, Deakin University.
- Gower F. (2000) *Anglesea river report*. Report for Alcoa World Alumina Australia.
- Hermon, K. (2002). The cause/s of the acidification of the Anglesea River Victoria. BSc Thesis, Deakin University.
- Pope, A. (2006). Freshwater influences on the hydrology and seagrass dynamics of intermittent estuaries. PhD Thesis, Deakin University.
- Pope 2010 Anglesea fish deaths. Report for EPA Victoria.
- CAPIM (2010). Anglesea River Water and Sediment Results undertaken on 17 December 2010.
- A water quality data set 2000-2011 supplied by Alcoa Australia.
- Parsons' 2011 data set supplied as a public submission.

All these data sets have been used but the quality of data has not been verified in this review.

Tables and figures presented here are taken directly from the relevant documents and presented as figures.

5.1 Environmental survey of metals in the Anglesea catchment - Atkins and Bourne (1983)

This report presented data for aluminium, iron, zinc, lead and copper concentrations in water samples, estuarine sediments and estuarine flora and fauna. Conductivity, pH, salinity and water temperature data was reported for 10 sites, and chromium concentrations measured in the flora.

5.1.1 Water samples

Sampling sites for this study in Salt and Marshy Creeks are shown in Figure 35 and trace metal results in Figure 36.

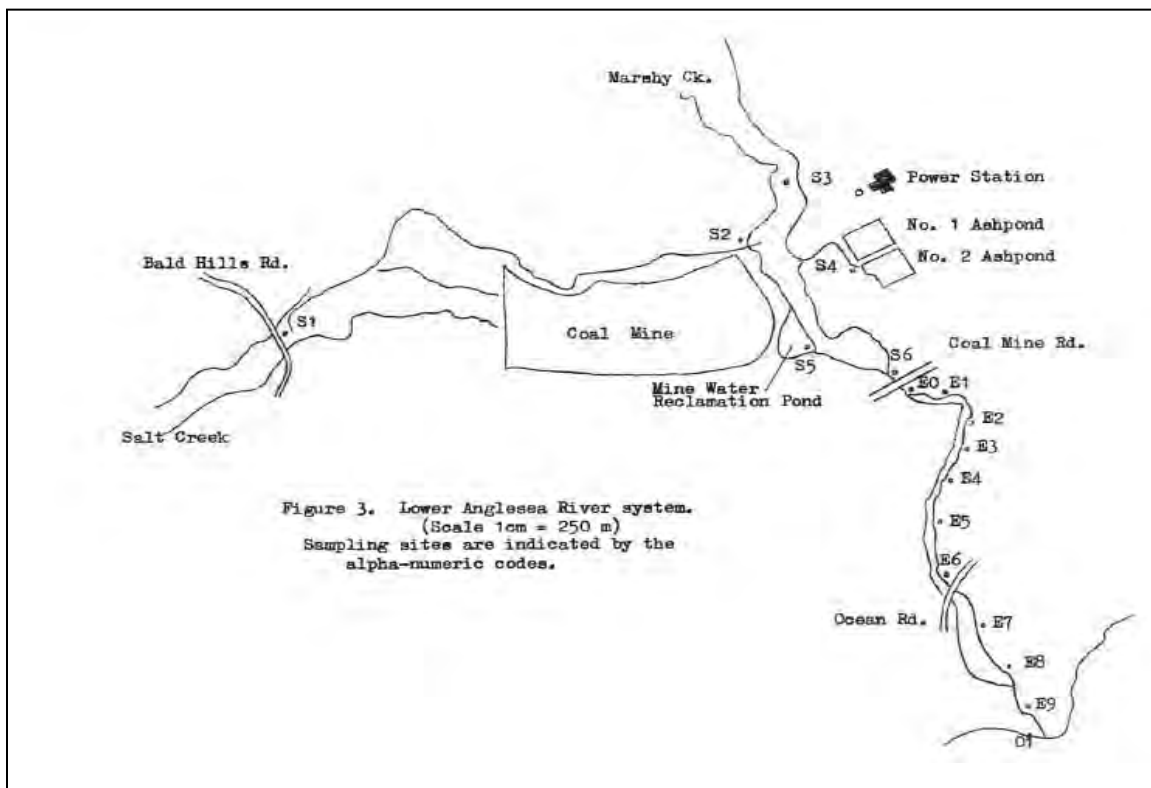


Figure 35. Map of Atkins and Bourne (1983) sampling locations.

T A B L E 5a				
Concentrations of metals ($\mu\text{g/ml}$) in Anglesea River System waters and ALCOA effluents.				
Concentrations of Iron ($\mu\text{g Fe/ml}$).				
STREAM	Feb.	March	April	Mean
Salt Creek	1.9	0.9	1.1	1.3
Marshy Creek	53.2	45.8	37.2	45.4
No. 2 Ashpond	1.5	1.2	1.2	1.3
Mine water Reclamation Pond.	1.5	2.5	1.7	1.9
Lower Swamp Drainage to Estuary.	2.0	1.7	2.0	1.9

Figure 36. Concentrations of metals in the Anglesea River system from Atkins and Bourne (1983).

All zinc and aluminium concentrations were below instrumental detection limits (zinc 0.1 µg/l, aluminium 1 µg/l). The report states that iron concentrations were two to eight times greater than other comparable streams based on the literature, but iron concentrations (37.2 to 53.2 µg/l) appear very elevated compared to data quoted for other inland waters (Figure 38).

Conductivity measurements indicate that dissolved salts in Salt and Marshy Creeks are low (< 1.5 mScm⁻¹), while at this time effluent from No2 ash pond effluent provided a major source of dissolved salts (1.5 - 5 mScm⁻¹). Although iron and zinc concentrations are not particularly elevated (Figures 36, 37 and 38) aluminium concentrations were above EPA recommended levels at the time.

T A B L E 5b			
Comparative data on the concentration of Aluminium, Iron and zinc in Alcoa effluent from the No. 2 Ashpond.			
E.P.A. licence Limits	E.P.A. Licence Monitoring (by SRWCS)	E.P.A. Recommended Levels	
		Fresh Water	Estuar Water
6.0 µg Al/ml	0.5 µg Al/ml	-	0.2
1.2 mg Fe/ml	0.44 µg Fe/ml	0.03	0.05
0.4 µg Zn/ml	0.04 µg Zn/ml	0.03	0.02

Figure 37. Concentrations of aluminium (Al), iron (Fe) and zinc (Zn) in the Anglesea River system from Atkins and Bourne (1983).

TABLE 6

Concentrations of Al, Fe and Zn in a variety of inland waters.

ALUMINIUM:

<u>Author</u>	<u>Location of Sample</u>	<u>µg Al/ml (total)</u>
Hydes & Liss (1977)	Great Cuse, Yarra Rivers, Gt. Britain.	0.002 - 0.005
	Conway Valley streams, Gt. Britain.	0.013 - 0.038
	Granitic spring waters, U.S.A. (pH 7.6)	0.01
	Mine water, U.S.A. (pH 3.9)	0.143

IRON:

		<u>µg Fe/ml (total)</u>
Environment Protection Authority (1976b)	Maribyrnong R.,	0.350
Jones & Walker (1979)	Murray R., SA-Vic border	0.200, 0.800
Ellaway et al. (1980)	Yarra R., Vic.	0.909, 0.929
Hart & Davies (1981)	Lake Tarli Karng, Vic.	0.230, 0.360

ZINC:

		<u>µg Pb/ml (total)</u>
E.P.A. (1976a)	Rororoit Creek, Vic.	0.173
E.P.A. (1976b)	Maribyrnong R., Vic.	0.010
Hart & Davies (1981)	Lake Tarli Karng, Vic.	0.003
	Tarago Reservoir, Vic.	0.014, 0.010
	East Basin Lake, Vic.	0.008, 0.006

Figure 38. Concentrations of aluminium (AL), Iron (Fe) and zinc (Zn) in a variety of inland waters from Atkins and Bourne (1983).

5.1.2 Estuarine sediment samples

Estuary sampling sites are shown in Figure 25 and trace metal results from Atkins and Bourne (1983), shown in Figure 39 are summarised as follows:

Al 0.21 - 2.84% (2.1 – 28.4 mg/g)

Fe 0.14 - 4.49% (1.4 – 44.9 mg/g)

Zn 22 - 306.6 µg/g

Cu 1.7 - 15 µg/g

Pb 1 - 39.2 µg/g

Estuarine sediment metal concentrations are low compared to the ANZECC/ARMCANZ (2000) interim sediment quality guidelines – low and high (Zn 200 & 400 µg/g, Cu 65 & 270 µg/g, Pb 50 & 220 µg/g).

Results of the Physical and Chemical measurements on sediments of the Anglesea River Estuary.														
SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LONGITUDINAL CO-ORDINATE	8	8	8	8	8	5	5	5	3	3	2	2	1	1
CROSS-SECTIONAL CO-ORDINATE	1	4	7	10	13	4	6	8	1	3	2	3	1	2
DEPTH (MAHD)	1.05	0.85	0.75	-0.05	-0.10	-0.88	-1.63	-0.53	0.80	-0.38	-1.75	-2.15	-1.00	-1.30
GRAVEL (%)	0	0	0	0	0	0	0	0	1.0	0.2	2.2	1.8	32.8	53.8
COARSE SAND (%)	34.0		31.4	33.1	9.7	12.3	0.5	0.8	17.6	65.3	11.5	71.2	46.7	24.1
FINE SAND (%)	63.4		60.8	63.0	81.8	36.5	46.2	40.1	46.6	16.7	22.8	6.4	5.0	4.5
SILT (%)	0		0.7	0.8	0.2	10.0	26.2	23.3	6.1	2.1	16.3	3.2	4.1	2.6
CLAY (%)	2.2		7.2	3.2	7.5	18.2	8.2	8.2	15.8	8.8	21.1	8.6	7.1	7.8
ORGANIC MATTER (%)	0		0	0	0.2	11.8	7.5	6.0	8.9	2.0	5.9	1.9	0.7	1.8
SEDIMENT INCLUSIONS (%)	0		0	0	0	5.7	9.1	20.6	1.0	4.3	12.2	4.7	2.6	3.4
Al (%)	0.27	0.21	0.22	0.32	0.22	1.67	2.84	1.57	1.16	0.60	2.39	1.11	1.02	1.14
Fe (%)	0.64	0.54	0.52	0.63	0.14	2.12	4.69	2.96	2.73	1.31	3.46	1.17	1.63	1.33
Zn (%)	49.2	31.8	22.0	25.3	47.9	57.6	102.7	75.5	79.9	32.1	78.5	306.6	129.1	37.4
Cu (ug/g)	4.1	3.5	4.0	3.3	4.0	5.6	9.0	7.4	5.3	2.6	15.0	2.5	2.0	1.7
Pb (ug/g)	1.0	2.1	0.8	1.0	1.1	6.5	39.2	18.1	5.6	8.8	8.1	1.2	1.5	1.7

Figure 39. Sediment metals concentrations from Atkins and Bourne (1983).

5.1.3 Flora samples

Seagrass species, *Zostera muelleri* and *Ruppia maritima*, were obtained from two sampling sites as shown in Atkins and Bourne (1983) (Figure 40), one at the upper end of the estuary (E2) and one near the estuary mouth (E8). Trace metal results are in Figure 41.

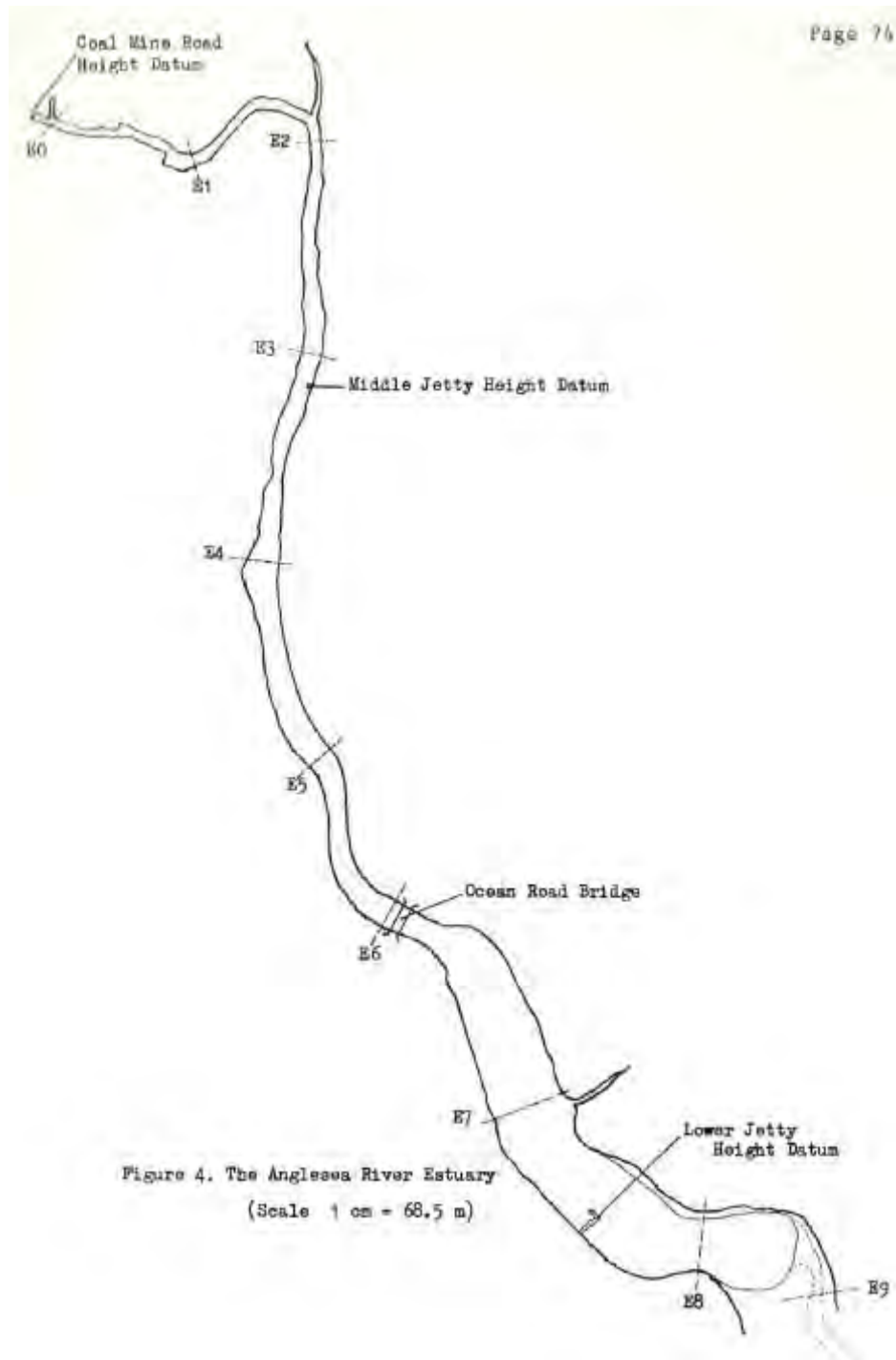


Figure 40. Flora samples site from Atkins and Bourne (1983).

TABLE 11

Concentrations of metals in seagrasses of the Angelsea River Estuary.

SPECIES	METAL	METAL CONCENTRATION ($\mu\text{g METAL/g DRY WT.}$)					
		12/3/81		4/6/81		12/8/81	
	Site	E2	E8	E2		E2	E8
<i>Zostera muelleri</i>	Al	418	2124	28949		6246	2468
	Fe	350	258	12038		2669	28619
	Zn	92	211	266		215	515
	Cu	11.2	16.5				
	Cr	16.8	8.3				
	Pb	9.4	81.7				
	Site	E8				E3	E8
<i>Ruppia maritima</i>	Al	1611				21805	1537
	Fe	1243				20903	1879
	Zn	248				300	389
	Cu	19.2					
	Cr	7.1					
	Pb	26.1					

Figure 41. Concentrations of metals in seagrass from Atkins and Bourne (1983).

Concentrations of aluminium and zinc differed markedly between locations and sampling dates, with elevated concentrations at both E2 and E8 (top and bottom of the estuary) on different dates. The report noted that aluminium and iron concentrations in *Z.muelleri* were 60 and 19 times (respectively) the concentrations measured in this seagrass from other nearby locations (Figure 42).

TABLE 12

Concentrations of Al, Fe and Zn in *Zostera muelleri* - Orway Region Estuaries 12/8/81 and literature value (Harris et al 1979)

LOCATION	METAL CONCENTRATION ($\mu\text{g METAL/g DRY WT.}$)				
	Al	Fe	Zn	Cu	Pb
Spring Creek, Torquay	< 100	154	69	—	—
Painkalae Creek, Aireys Inlet	< 100	150	28	—	—
Erskine River, Lorne	< 100	260	82	—	—
PORT PHILLIP BAY <i>Z. muelleri</i> detritus		9000			
WESTERN PORT					
Max.		1697	67	10.6	8.4
Min.		331	21	2.4	1.6
Median		693	30	4.4	2.3

Figure 42. Comparative metals concentrations in flora from nearby locations from Atkins and Bourne (1983).

Zinc, copper, chromium and lead concentrations were only measured once, at E2 and E8 for *Z.muelleri* and only at E2 for *R. maritime*. Concentrations of these metals were quite variable. The report noted that zinc, copper and lead concentrations in *Z.muelleri* were respectively 7, 3 and 19 times the concentrations in Western Port Bay which was considered a relatively uncontaminated site. The large changes in aluminium and iron concentrations over such a short sampling period suggest metals are not being directly taken up. It appears that flocculation of metals onto seagrasses is occurring.

5.1.4 Fauna samples

Metal concentration data is reported for the freshwater mussels, *Xenostrobus securus* and *Gari donacoides*. However, as these organisms have not been previously used as biological monitors and no comparisons with organisms from adjacent estuaries were made no interpretation of this data is possible.

5.2 Trace element distribution and speciation in the Anglesea River - Meyrick (1999)

The aims of this study were to determine the concentrations and speciation of various trace elements in the Anglesea River. Aluminium, iron, manganese and zinc were analysed, as well as some preliminary results for cadmium, copper, nickel, lead and selenium. Total, filterable and a new technique called DGT were used to compare the speciation. Metal concentrations were compared above the mine, in the mine and in the river below the mine.

Sampling sites in Salt Creek, Marshy Creek and the Anglesea River are shown in Figure 43.

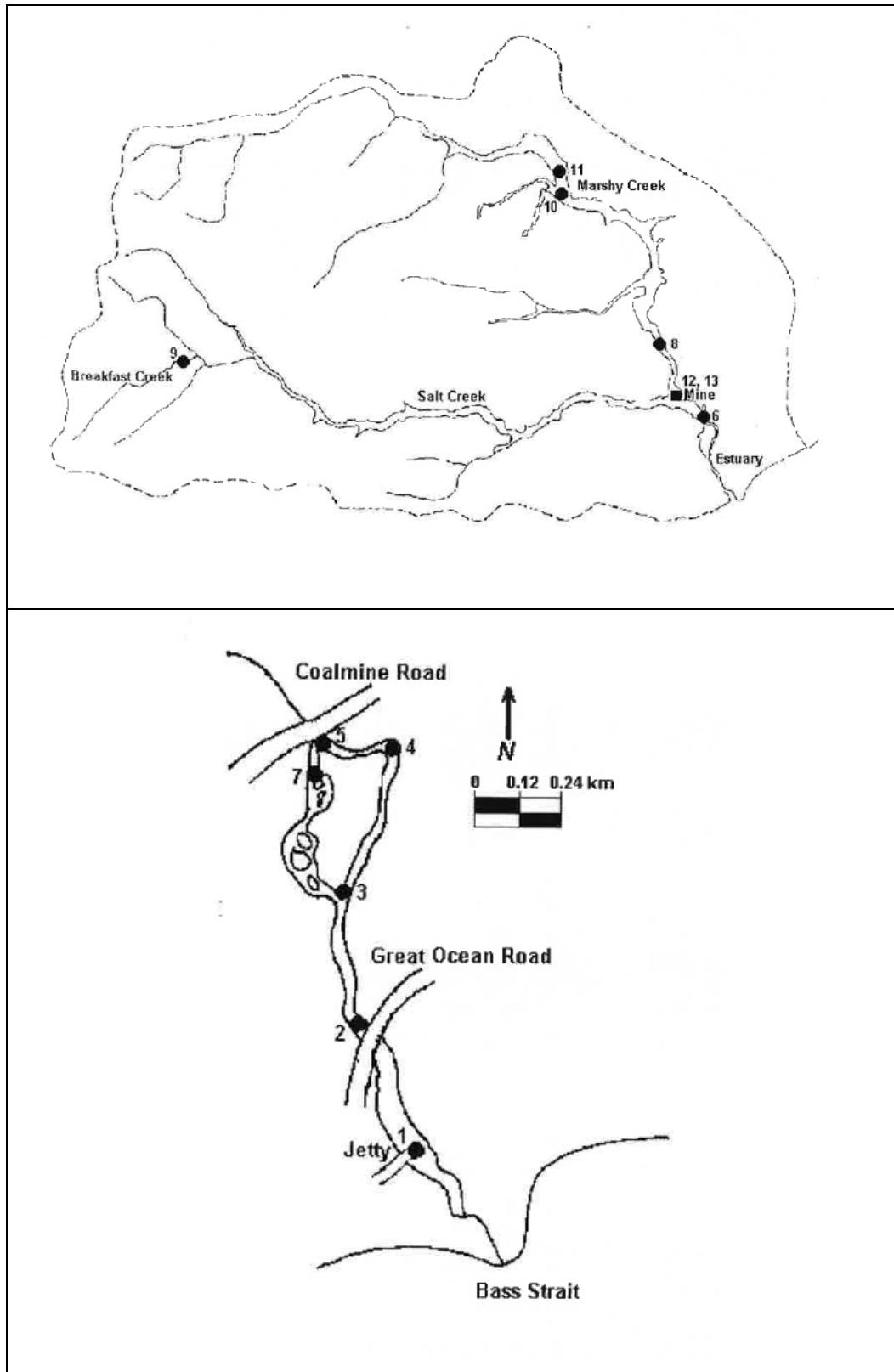


Figure 43. Map of water sampling sites from Meyrick (1999).

Comparisons of metal concentrations above and below the marsh were also made, and one site below the Marsh in Marshy Creek was found to be elevated in iron, manganese and zinc.

The aluminium concentration discharge from the mine water (0.59 mg/l) appears greater than in Marshy Creek directly above the mine (0.02 mg/l). By the head of the estuary, aluminium concentrations are below those of Marshy Creek above the mine (0.02 mg/l). This indicates dilution of mine water by ash pond inputs or that flocculation is occurring. Aluminium concentrations at the head of the estuary are below that given by ANZECC/ARMCANZ (2000) water quality guidelines for protection of freshwater ecosystems.

The estuarine chemistry studied showed non-conservative behaviour for all metals. This means that as fresh and salt water mixed, metals are precipitated out of solution.

5.3 Anglesea river report. Alcoa World Alumina Australia, Gower (2000)

At the end of winter 2000, heavy rainfall resulted in flows recommencing in the Anglesea catchment after four years of below average rainfall and drought conditions. Fish deaths coincided with the first catchment flows entering the estuary of the Anglesea River. This resulted in the estuary being closed to the public. The estuarine reaches of the river displayed a blue/green appearance and a white precipitate was observed (Gower, 2000).

Investigations by Alcoa Australia, Deakin University and the EPA showed that the water flowing from the catchment was acidic, with high conductivity and high concentrations of aluminium, iron, sulphate and manganese. These metal concentrations exceeded ANZECC/ARMCANZ (2000) trigger values applying to protecting typical slightly-moderately disturbed systems.

Most of the aluminium originated naturally from Salt Creek, one of the two main tributaries of the Anglesea River. This was accompanied by high acidity and high sulphate, manganese, and zinc concentrations (Figure 44).

It is important to note that a similar pattern of high acidity and high aluminium, sulphate, manganese, and zinc concentrations were recorded in Distillery Creek, a tributary of Painkalac Creek which is located south west of the Anglesea catchment.

Figure 44. Table 1.2: EPA stream sampling data collected 27/9/00 (Source: Gower, 2000, reproduced from Hermon, 2002). Note that Site 5 (Distillery Creek) is not part of the Anglesea catchment but in the adjoining Painkalac Creek catchment.

Test done	Site 1	Site 2	Site 3	Site 4	Site 5
Acidity mgCaCO ₃ /L	500	27	110	120	410
Carbon-Total Org.(mg/L)	18	5.2	6.9	9.9	9.8
Aluminium(mg/L)	87	0.53	16	17	58
Arsenic(mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005
Cadmium(mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium (mg/L)	51	15	160	140	13
Chromium(mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01
Copper(mg/L)	0.027	0.02	<0.01	<0.01	<0.01
Iron(mg/L)	0.42	1.2	0.17	0.59	1.7
Lead(mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005
Magnesium(mg/L)	120	30	120	210	55
Manganese(mg/L)	4.5	0.55	1.9	2	0.77
Mercury(mg/L)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Potassium(mg/L)	12	8.6	27	59	4.8
Selenium(mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005
Silicon(mg/L)	34	10	17	15	19
Sodium(mg/L)	96	200	340	1100	88
Zinc(mg/L)	1.7	<0.05	0.57	0.58	2.4
Bicarbonate Alkalinity(mg/L)	<3	<3	<3	<3	<3
Chloride(mg/L)	94	310	330	1500	95
Sulphate(mg/L)	1000	61	1100	940	580
Total Alkalinity(mgCaCO ₃ /L)	<3	<3	<3	<3	<3
Temperature (°C)	11.4	10.4	12.4	12.7	11.8
COND	2202	1759	3740	9370	1835
pH	3.86	4.05	4.63	4.71	3.66

Site 1 = Salty Creek

Site 2 = Marshy Creek

Site 3 = Anglesea River @ Coalmine Road

Site 4 = Anglesea River Estuary @ Jetty

Site 5 = Distillery Creek

5.4 The causes of acidification of the Anglesea River, Hermon (2002)

In September 2000, acidic waters flow into the Anglesea River estuary resulting in a fish death event and closure of the estuary to public use. The purpose of this report was to identify the causes of the acidification event.

5.4.1 Water samples

Sampling sites used in Hermon's study are shown in Figure 45 and trace metal results in Figures 46, 47 and 48.

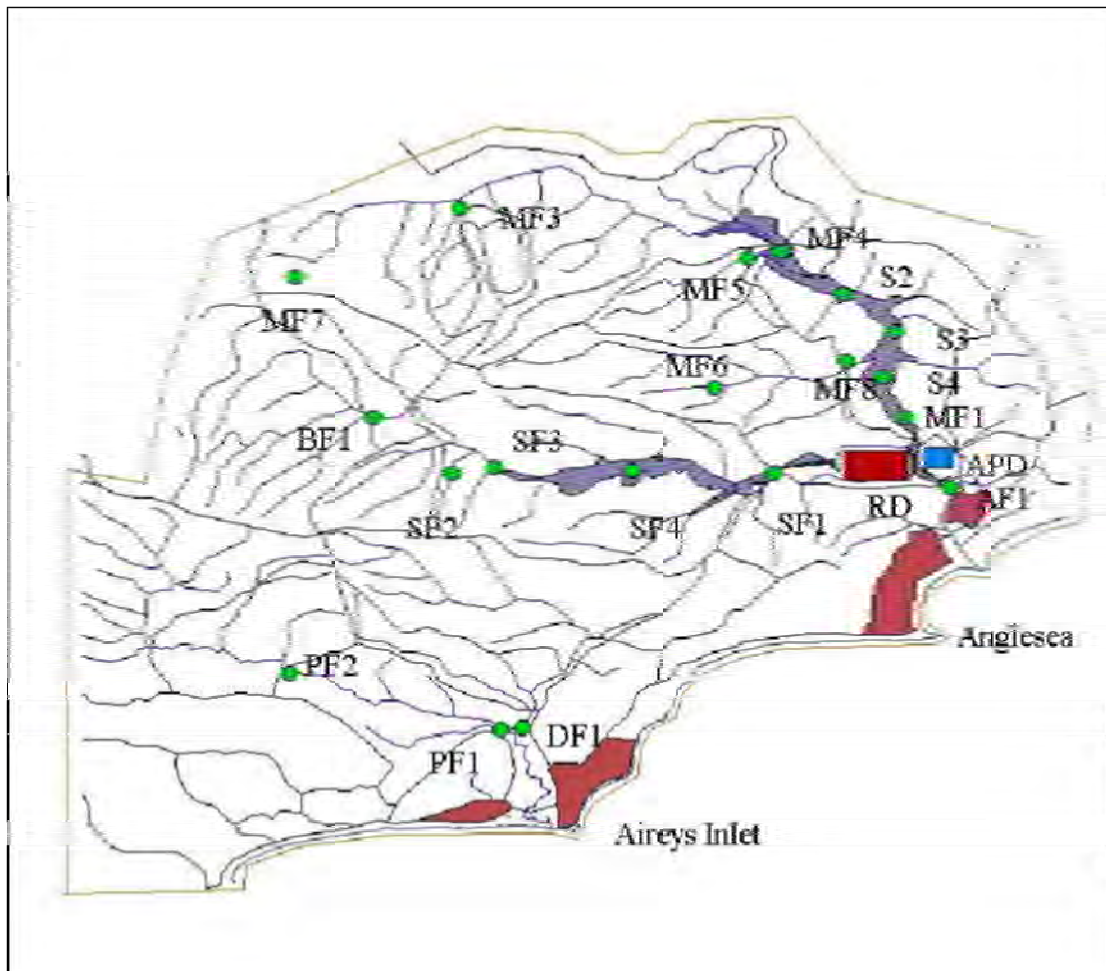


Figure 45. Sampling sites in Hermon (2002).

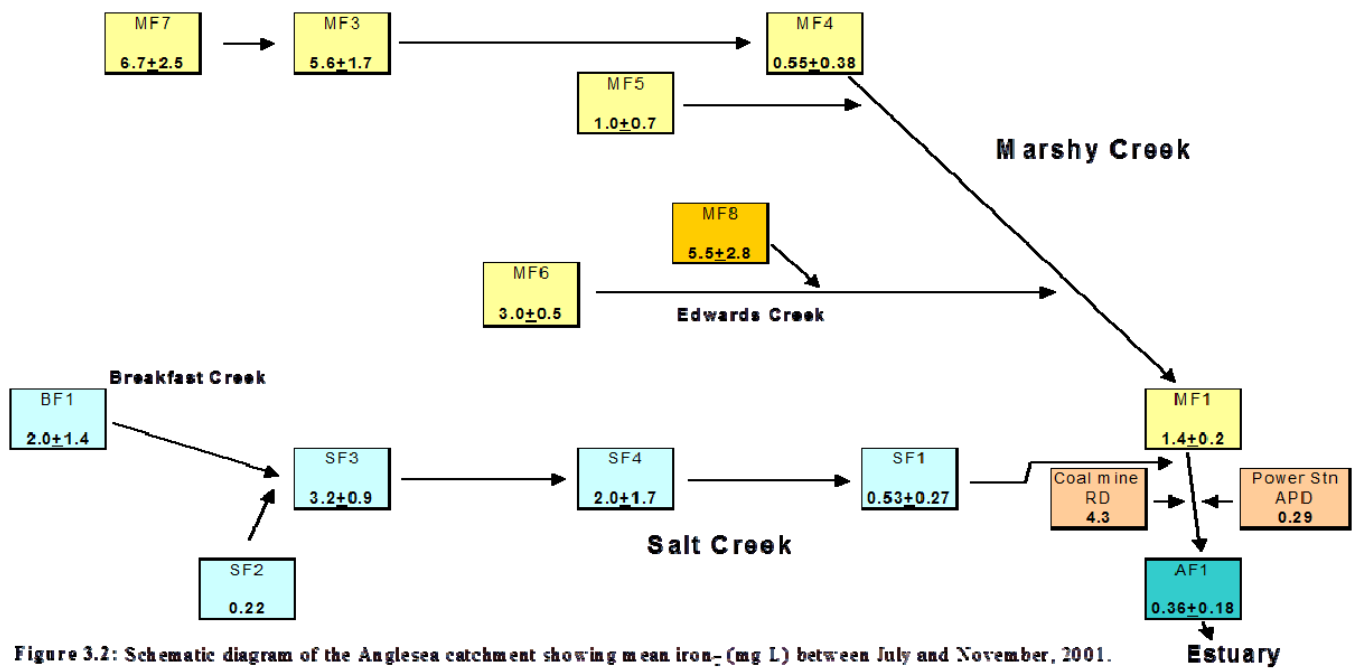


Figure 46. Iron concentrations (mg/L) measured by Hermon (2002).

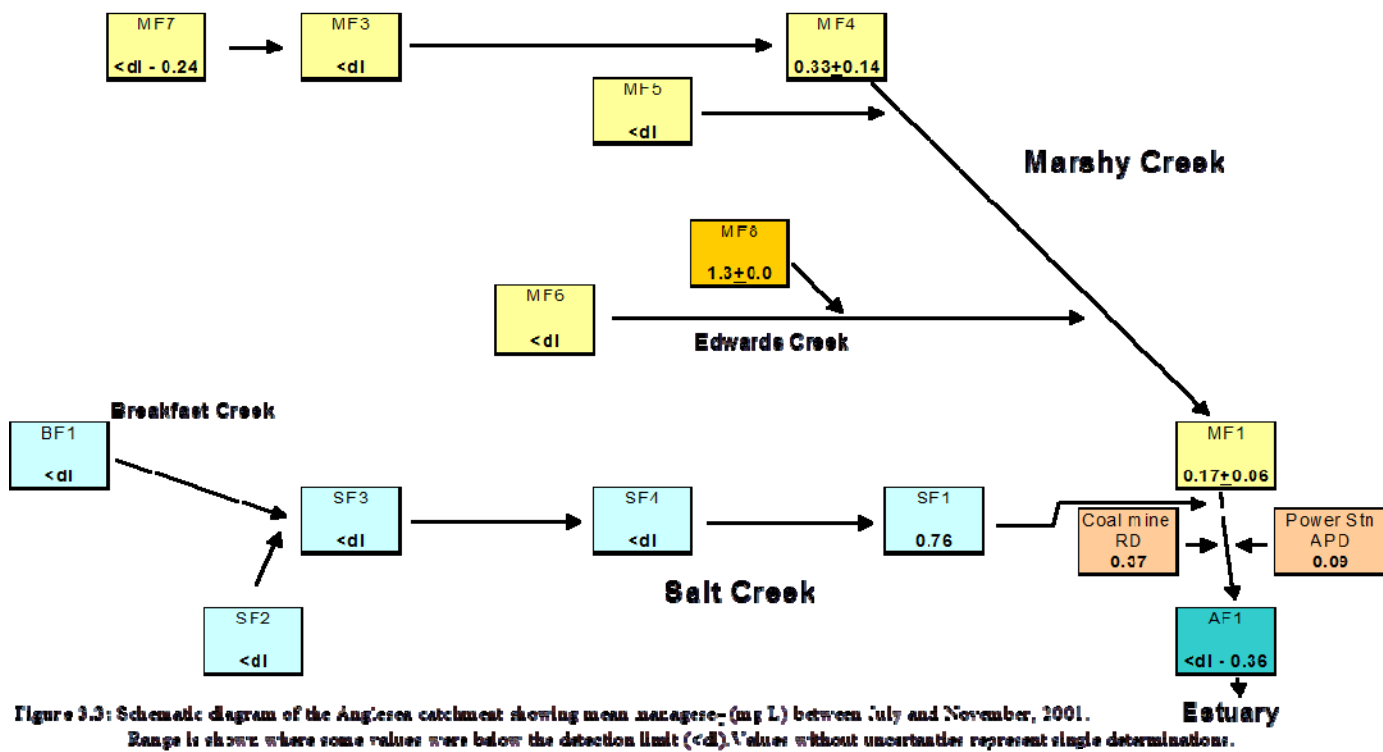


Figure 47. Manganese concentrations (mg/L) measured by Hermon (2002).

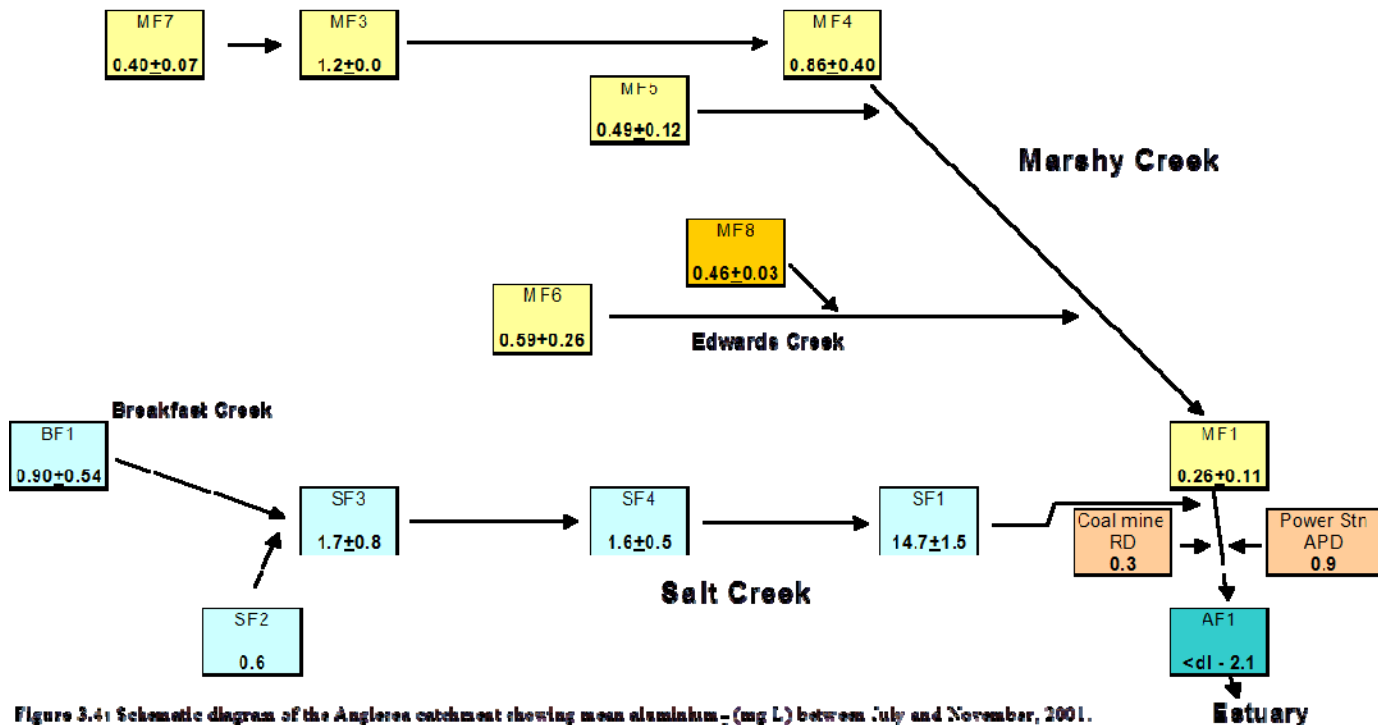


Figure 3.41 Schematic diagram of the Angleron catchment showing mean aluminium - (mg/L) between July and November, 2001. Sites where no standard deviation is given were only sampled once. Range is shown where some values < detection limit (ie: <dl).

Figure 48. Aluminium concentrations (mg/L) measured by Hermon (2002).

Iron concentrations ranged from 0.2 mg/L in upper Salt Creek (site SF2) to 6.7 ± 2.5 mg/L in the natural spring (site MF7) located in the upper reaches of Marshy Creek. In general, higher concentrations were reported in Marshy Creek than in Salt Creek. Comparison between the total and filterable fractions indicates that the dissolved fraction is a high proportion of the total.

Manganese concentrations (Figure 47) ranged from below the detection limit in the upper to middle Salt Creek sub catchment area to 1.3 mg/L at the uncapped bore (Site MF8). The filterable 'dissolved' manganese fraction ranged from 90 to 100% of the total, suggesting a high proportion of the metal is present as dissolved forms, such as Mn^{2+} , or is organically-bound in dissolved or colloidal phases.

Aluminium concentrations typically ranged between 0.26 and 1.7 mg/L throughout the catchment. Site SF1 represented the base of the Salt Creek sub catchment adjacent to the old Roche coal mine, where the mean aluminium concentration was 14.7 ± 1.5 mg/L (Figure 48). As with iron and manganese, most aluminium is in the dissolved form.

Conductivity measurements showed no obvious seasonal trends, although there was a clear spatial trend, with higher conductivity in the Marshy Creek sub catchment than the Salt Creek sub catchment. Conductivity was highest in waters discharged from the mine site, peaking at over 5000 $\mu S/cm$ in ash pond discharges. Spatial trends in conductivity are illustrated in Figure 49.

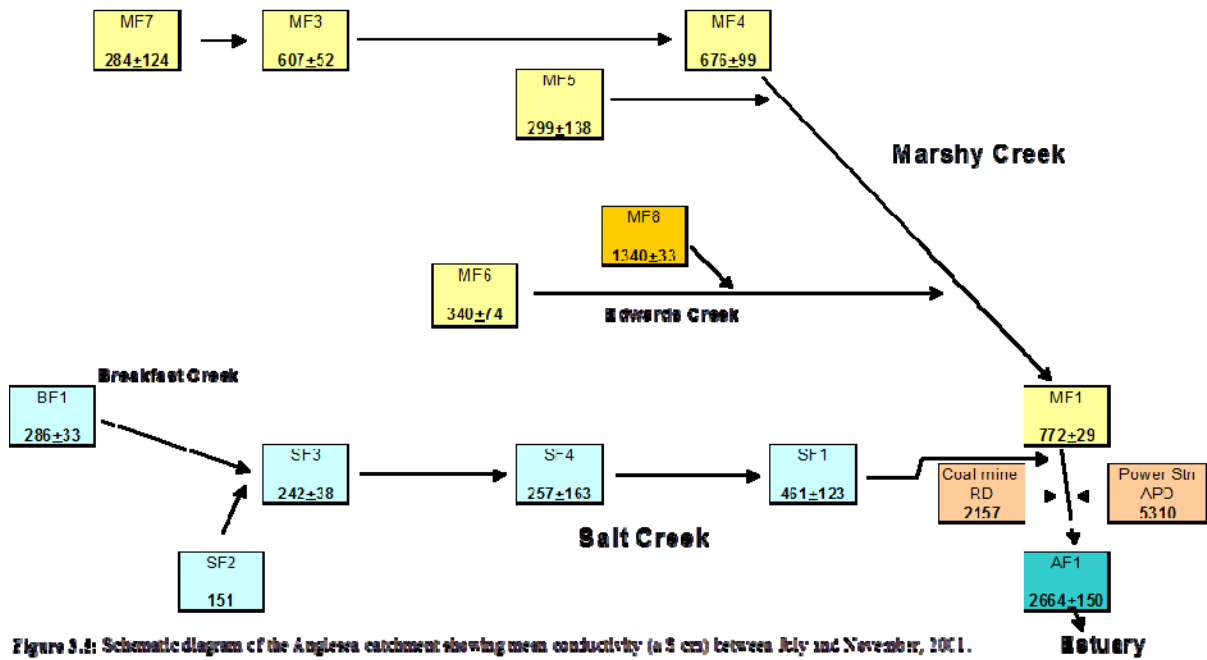


Figure 49. Conductivity measurements by Hermon (2002).

5.4.2 Marsh samples

Analysis results from the marsh sediments are provided in Figure 50. The sediment from Site S4 had the highest organic content and the highest concentrations of iron and manganese and are potentially a large source of trace metals.

Figure 50. Analysis of marsh sediments collected from Marshy Creek in 2001 from Hermon (2002).

Sample	S2	S3	S4
Moisture content % wet weight	84	84	74
Dry/wet ratio no unit	0.17	0.16	0.26
Fraction OM % dry weight	43	36	68
AVS mg/kg dry weight	*	*	*
Iron Total mg/kg dry weight SEM	na	na	Na
mg/kg dry weight	5800	9100	10 600
Mn Total mg/kg dry weight SEM	48	45	350
mg/kg dry weight	55	36	240
Al Total mg/kg dry weight SEM	9100	10 600	6400
mg/kg dry weight	na	na	Na

* All values < 11 mg/kg dry weight but samples
were possibly stored too long (see discussion).

n/a results not available

5.5 Freshwater influence on hydrology and sea grass dynamics of intermittent estuaries - Pope (2006)

This three year study investigated impacts of changed flow regimes in small western-Victorian estuaries (including the Anglesea catchment). Ecosystems with artificially increased and reduced freshwater inflows were compared using a whole-system, process-based approach. Studies on such systems are rare despite their vulnerability and ecological importance.

5.6.1 Key findings - metals

Sampling sites in Salt and Marshy Creeks are shown in and Figure 51. Trace metal concentrations (aluminium, iron and zinc), conductivity and suspended solids were measured at these sites.

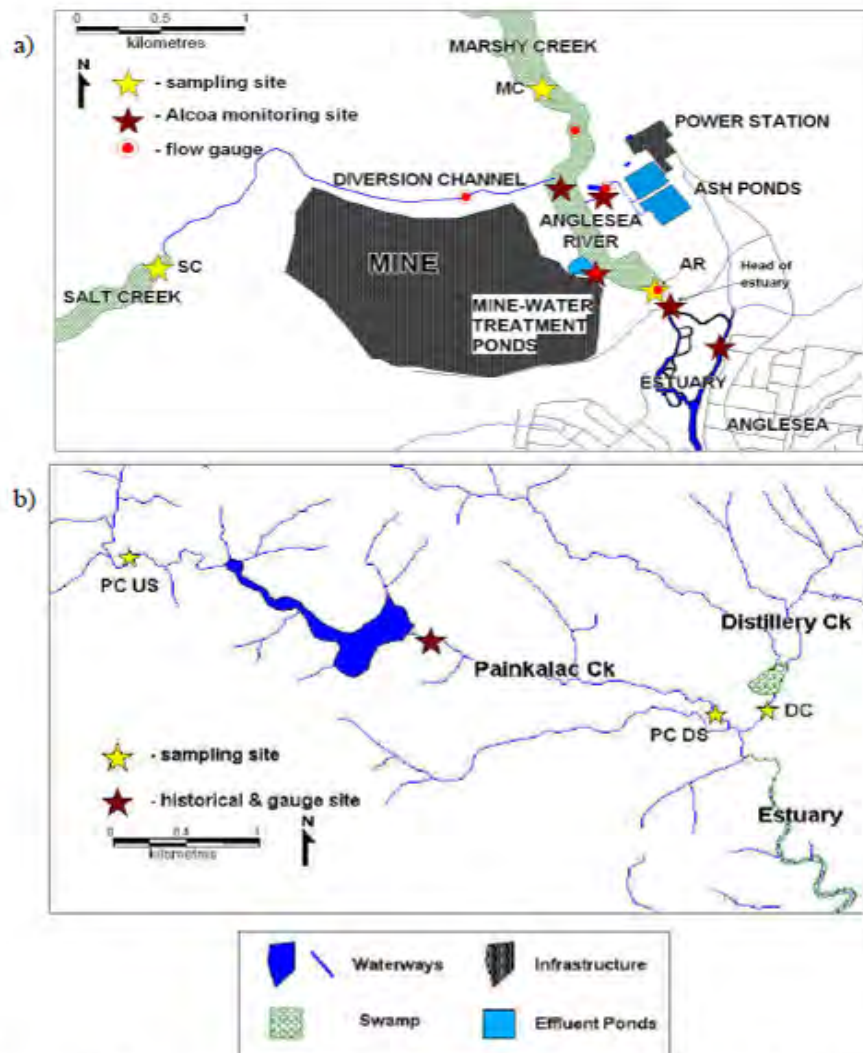


Figure 3.1a). Water quality sampling locations in the lower Anglesea catchment. Data for effluent from the ash ponds and mine are primarily unpublished data from Alcoa's monthly monitoring program. b). Water quality sampling locations in the Painkalac catchment.

Figure 51. Sampling sites in Salt and Marshy Creeks from Pope (2006).

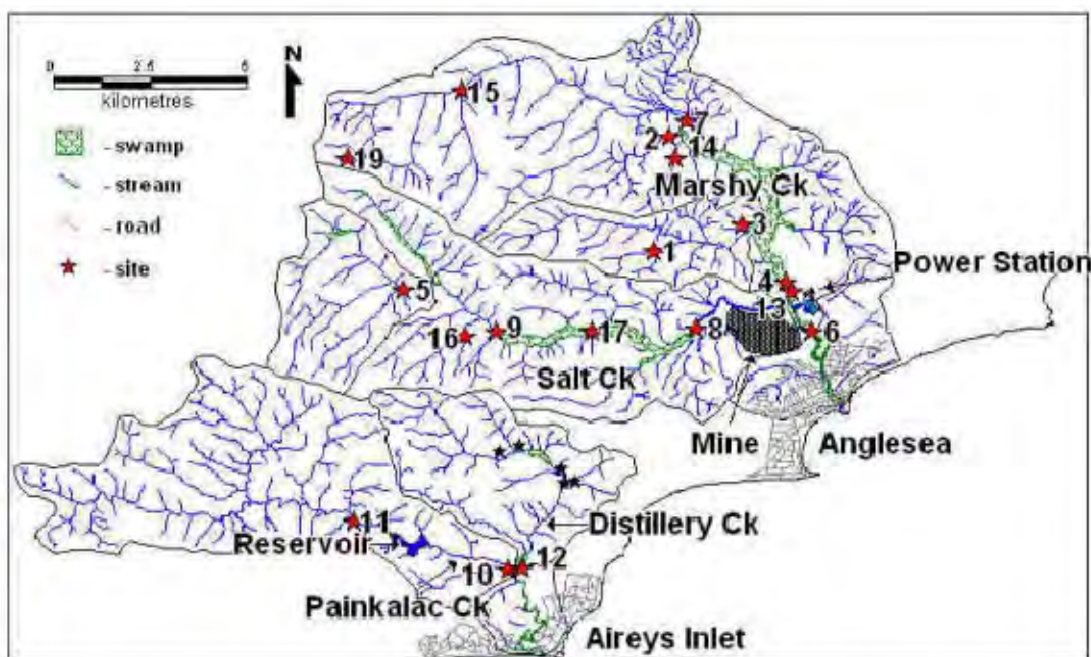


Figure 3.2. Freshwater sampling sites throughout the catchments of Anglesea and Painkalac. One-off sites in the Distillery Creek sub-catchment are shown as black stars.

Figure 52. Sampling sites in Salt and Marshy Creeks from Pope (2006).

Aluminium, and zinc concentrations, conductivity and suspended solids concentrations increased with increased flow, while iron concentrations increased at lower flows. The low pH and high aluminium, and zinc concentrations in Salt and Distillery Creeks (Figure 52) indicate oxidation of sulphide minerals. Pope hypothesized that the gradual decrease in metal sulphate concentrations was consistent with an initial slug of ions being released after the first substantial flow in this catchment for some time, and produced by the wetting and drying of sulphidic soils. This is supported by conductivity data of 1100-2100 $\mu\text{S}/\text{cm}$ during high flow conductivity, which reduced to 400 $\mu\text{S}/\text{cm}$ at low flows. Pope also noted that discharges from the ash pond increased the conductivity of the Anglesea River to 2500 $\mu\text{S}/\text{cm}$ greater than the discharge during the first flush.

Pope had access to a water quality data set compiled by Alcoa that include aluminium, iron and zinc concentrations, as well as suspended solids and conductivity. He notes that Alcoa's long term data set indicated that while the very high aluminium concentrations recorded in 2000 have not occurred since 1979, there have been lesser events where elevated metal concentrations have occurred.

5.6 Anglesea River water and sediment results – CAPIM (2010)

As a result of the 2010 fish death event Surf Coast Shire commissioned the Centre for Aquatic Pollution Identification and Management (CAPIM) to undertake water and sediment sampling to determine heavy metal levels and provide advice on public health issues. Five samples were taken from five sites in the estuary and river.

The ranges of metal concentrations were:

Aluminium - 0.93-0.19 mg/l

Zinc - 0.099-0.145 mg/l

Nickel - 0.07-0.08 mg/l

Boron- 4.9-6.89 mg/l

The estuary at this time was mainly fresh with conductivities of 4000-6000 mS/cm compared to that of seawater (50000 mS/cm). The concentrations of all these elements were above the ANZECC/ARMCANZ (2000) water quality guidelines to protect moderately disturbed freshwater ecosystems. Boron is common at high concentrations in seawater so some of the boron from Sites 1-4 would have been derived from seawater. However, boron at Site 4 (at head of estuary) was still well above the recommended guideline value for the protection of freshwater ecosystems (0.37 mg/l).

5.7 Anglesea Fish Deaths - Pope (2010)

In response to the September 2010 fish death event, EPA Victoria commissioned Pope to assess the likely causes of the fish deaths and review recent investigations that related to the likely causes.

Pope notes that toxic effects from metals, particularly aluminium, are common in flows from acidic soils. Aluminium becomes more toxic to fish as pH decreases (low pH indicates high acidity). In 2010, flows from the Salt Creek sub catchment of the Anglesea River had concentrations of soil-derived aluminium many times higher than the national guideline, and higher than those measured during the 2000 fish kill. High levels of aluminium in fish tissues, particularly the gills, is supporting evidence for the likely influence of metal toxicity as a cause of death.

Flows from both the Salt and Marshy Creek sub catchments are intermittent, often ceasing to flow in drier months. The Salt Creek flow is more intermittent than that of Marshy Creek. There are often times in dry periods when upper tributaries in the catchment flow don't reach the downstream end of the sub catchments and subsequently dry out. In these periods, acids are generated and metals mobilized but neither are exported from the sub catchments.

The movement of acids and metals through the system varies considerably with rainfall. It is also dependent on local geology, shallow aquifers and the water content and holding capacity of the peat swamps. Consistent with the longer period with no outflows from the Salt Creek sub catchment, and possibly also due to differences in geology, the first substantial flow from the sub catchment contained high concentrations of aluminium (170mg/L) and zinc (2.7mg/L), shown in

Figure 53. These concentrations were many times higher than the trigger values in the ANZECC/ARMCANZ (2000) water quality guidelines for protection of freshwater ecosystems.

Monitoring since 2003 has recorded elevated concentrations of aluminium in Marshy (2007-9) and Salt (2004 and 2007) Creeks. Unfortunately, a lack of flow data before the Barwon Water monitoring program (apart from records of zero flow) means there is no knowledge of the amount of acid or metals associated with these measurements, nor is it possible to examine likely inputs to the estuary. It is possible that such flows have become more common in the current dry period but further analyses would be required to confirm this.

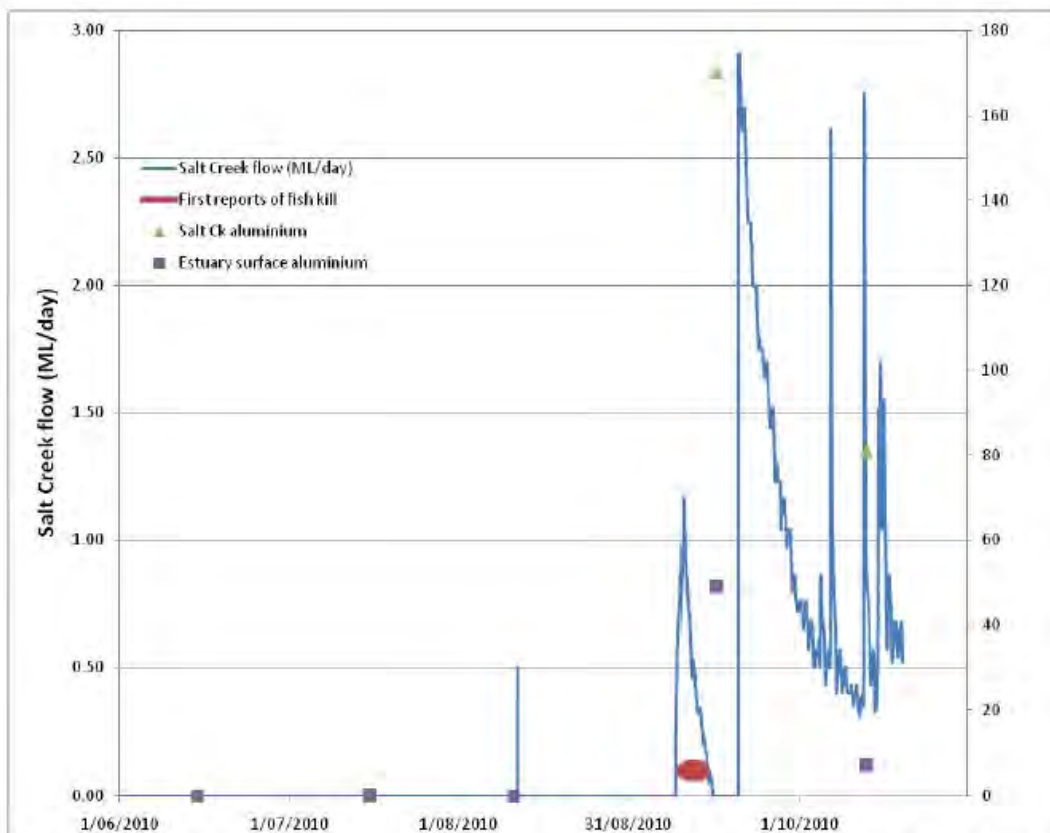


Figure 3. Flow in Salt Creek and aluminium concentrations in water at the time of the fish kill (data from Alcoa of Australia and Barwon Water).

Figure 53. Flow and Aluminium concentrations for Salt Creek from Pope (2010).

5.8 Alcoa water quality sets 2002-2011

Most data provided in this section is sampled as part of Alcoa's compliance with EPA licensing and is analysed by an independent NATA registered lab. The pH analysis is conducted by Alcoa who are NATA registered for this parameter.

5.8.1 Catchment water quality data 2002-2011

Sampling sites in Anglesea River catchment are shown in Figure 54. Trace metal concentrations (aluminium, iron and zinc), pH, conductivity and suspended solids were measured at these sites.

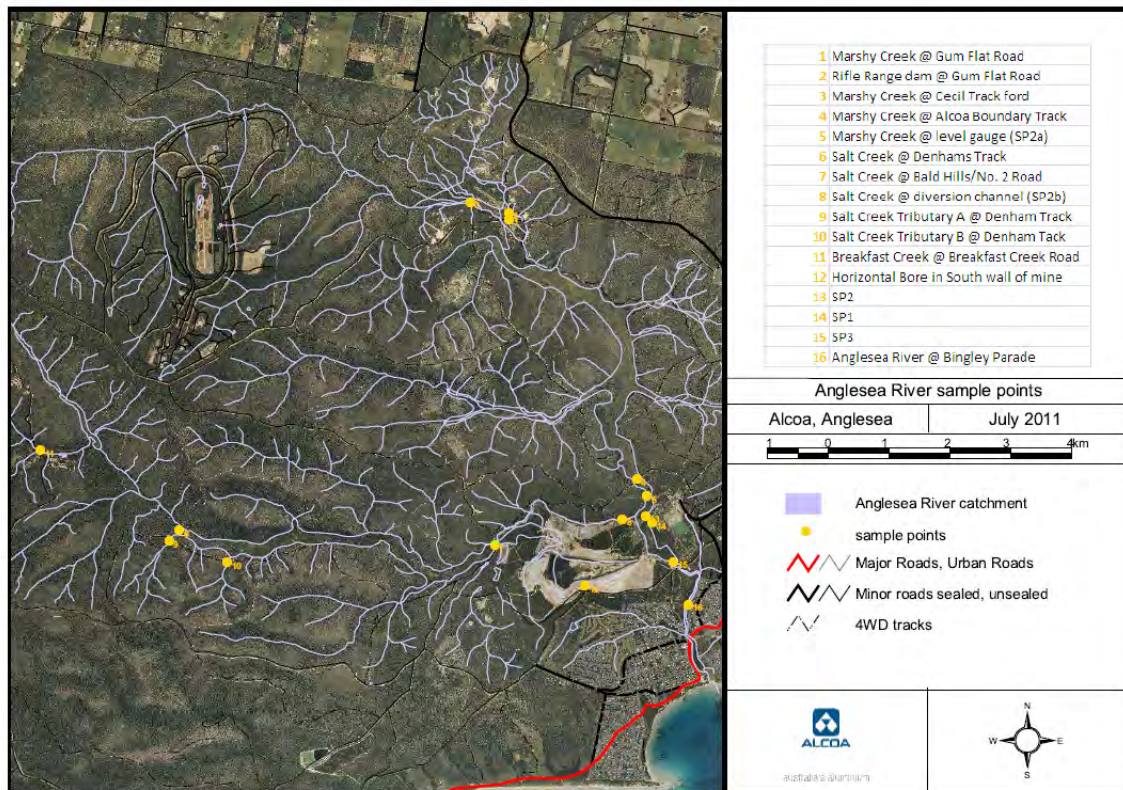


Figure 54. Map of Alcoa sampling points (source Alcoa).

The discrete set of conductivity data (13 August 2009 to 17 May 2011) shows upstream conductivity in Marshy Creek (1320-2800 $\mu\text{S}/\text{cm}$) and Salt Creek (1220-2330 $\mu\text{S}/\text{cm}$) to be mostly lower than downstream of the ash pond discharge (1770-5620 $\mu\text{S}/\text{cm}$), while the ash pond water had higher conductivity, hence dissolved solids (3670-6530 $\mu\text{S}/\text{cm}$). Further downstream in the Anglesea River at Bingley Parade the conductivity levels increased (1730-32,000 $\mu\text{S}/\text{cm}$), indicating another source of salts, possibly from saltwater intrusion.

The discrete set of aluminium concentrations (24 April 1983 – 17 May 2011) shows upstream values of 0-180 mg/l in Marshy and Salt Creeks, and 0.1-73 mg/l downstream of the ash pond discharge, with the ash pond water having concentrations of 0-11 mg/l. Further downstream in the Anglesea River at Bingley Parade the concentrations were 0-49 mg/l.

The discrete set of iron concentrations (30 March 1972 – 17 May 2011) shows upstream values of 0.1-190 mg/l in Marshy and Salt Creeks, and 0.2-1.2 mg/l downstream of the ash pond discharge, with the ash pond water having concentrations of < 0.1-1.1 mg/l. Further downstream in the Anglesea River at Bingley Parade the concentrations were 0-141.4 mg/l.

The discrete set of zinc concentrations (17 November 2009 - 17 May 2011) shows upstream values of 0.005-2.7 mg/l in Marshy and Salt Creeks, and 0.01-0.71 mg/l downstream of the ash pond discharge, with the ash pond water having concentrations of 0.028-0.320 mg/l. Further downstream in the Anglesea River at Bingley Parade the concentrations were 0.01-0.71 mg/l.

Watershed data (2 November 2000 – 19 June 2001) also indicates that Marshy and Salt Creeks can have high conductivities (up to 1960 $\mu\text{S}/\text{cm}$) and substantial aluminium (up to 30 mg/l), but may be as high as 170 mg/l and have iron up to 8.2 mg/l.

The plotted water quality data for discharges from the ash pond shows that for the last five years concentrations have been below licensed EPA discharge levels for aluminium, iron and zinc (Figure 55).

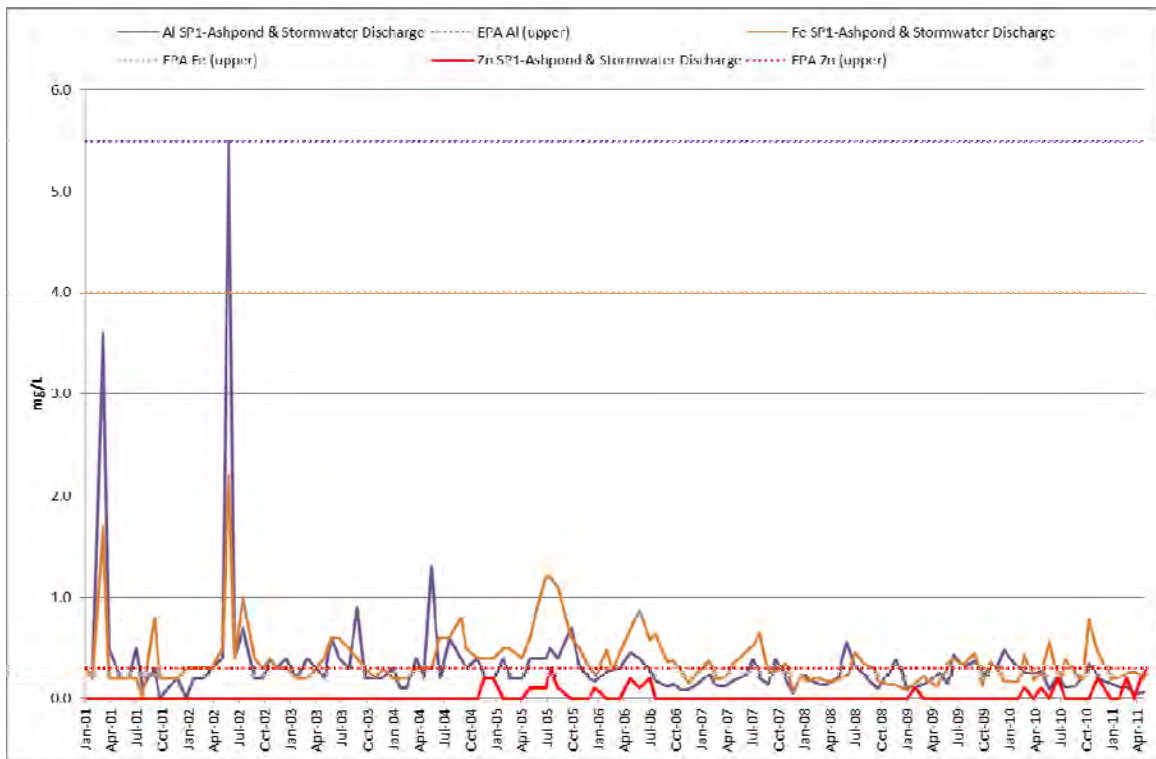


Figure 55. Aluminium, iron and zinc water quality results from the ash pond compared against upper limits of EPA discharge levels (Source Alcoa).

5.8.2 Measurements during flood and fish death event 2000

Data from samples taken in the 2000 flood and fish death event show that the tributaries to Salt Creek on the high ground (Figures 56 - sites 9, 10 and 11) have low aluminium and sulphate concentrations (Table 1). Further downstream (Figure 56 - sites 6 and 7), the aluminium and sulphate concentrations in Salt Creek become much higher (Table 1).



Figure 56. Image of Salt Creek showing sample locations.

Table 1. Water quality monitoring results post 2000 fish kill event, yellow highlights sites in image.

Sample Site	Date	pH	Conductivity	Sulphate	Al	Fe	Zn
Breakfast Creek @ B/Creek Rd (11)	6/11/00	6.7	420	17	0.7	0.8	<0.1
(A) Tributary Under Denham Track (9)	7/11/00	5.8	165	10	2.1	0.2	<0.1
(B) Tributary Under Denham Track (10)	7/11/00	5.3	181	12	2.4	1.0	<0.1
Salt Creek Off Denham Track (6)	7/11/00	3.4	1080	340	36	5.6	1.5
Salt Creek @ No 2 Rd (7)	6/11/00	4.0	1000	400	29	0.2	0.8
Marshy Creek @ Gum Flat Rd	6/11/00	4.4	970	45	1.7	0.3	0.2
Marshy Creek @ Level Gauge	6/11/00	3.7	1100	53	0.5	0.5	<0.1

5.8.3 Discharges from ash pond (SP1) 2010-2011

Recent data supplied on the composition of this effluent (5 May 2011) indicates that of the 23 trace metals measured, aluminium, nickel and zinc marginally exceed ANZECC/ARMCANZ (2000) trigger levels for the protection of freshwater aquatic ecosystems in moderately disturbed systems. Boron (3.2 mg/l) vastly exceeded the guideline value 0.37 mg/l, although data supplied for Marshy Creek taken at the same time showed higher concentrations of aluminium, nickel and zinc. Marshy Creek data also indicated chromium concentrations were higher than guideline values. Boron in Marshy Creek was noted to be lower (0.14 mg/l) than the guideline. Salt Creek was not flowing at the time of sampling.

Alcoa also evaluated the mass loading of aluminium from the creeks and SP1 (Table 2). These loadings were determined at various times over the past 18 months, including when Alcoa's discharge was the only contributor to the Anglesea River, and at other times where there was both

moderate and heavy flow from both Salt and Marshy creeks additional to Alcoa's constant input. The flow rates for the creeks are based on water height measurements taken on the day used with gauge tables for both sites provided by Thiess.

The data indicates that during periods of high flow when fish deaths are likely to occur, the contribution of aluminium from discharges from the ash pond are relatively small. The September 2010 data suggests that aluminium in the zone where the effluent mixes with the Anglesea River may be redissolved, as shown by the differences in aluminium concentrations recorded at SP3 compared with the sum of the inputs. The lower aluminium concentrations in the river are attributable to stormwater inflows and possibly tidal inflows diluting the upstream loading.

Licensed discharges are discussed more fully in section 6.3.

Table 2. Mass loading calculations of aluminium from Salt and Marshy Creeks and Alcoa effluent (SP1).

Aluminium Loading							
		Salt Ck	Marshy Ck	SP1	Sum of Aluminium from inputs	SP3	River
22/02/2010	Aluminium g/m3			0.30		0.29	0.37
	Flow ML/Day	0	0	3.71		3.71	
	Daily Aluminium contribution in grams from each source			1,113	1,113	1,076	
16/09/2010	Aluminium g/m3	170	2.1	0.12		73	49
	Flow ML/Day	4.89	6.65	4.00		15.54	
	Daily Aluminium contribution in grams from each source	831,300	13,965	480	845,745	998,640	
20/01/2011	Aluminium g/m3	61	1.2	0.15		33	33
	Flow ML/Day	21.8	12	4.04		37.84	
	Daily Aluminium contribution in grams from each source	1,329,800	14,400	606	1,344,806	1,248,720	
17/02/2011	Aluminium g/m3	80	0.78	0.11		1.9	0.33
	Flow ML/Day	2.08	0.337	4.05		6.47	
	Daily Aluminium contribution in grams from each source	166,400	263	446	167,109	12,293	
Flow at SP3 is estimated using the sum of flow for the two creeks and SP1							
The flows at the two creeks were calculated using rating tables provided by Thiess							
Marshy Creek 01/07/2009 to present - Salt Creek 19/03/1979 to present							

5.7.4 Emissions to air

Alcoa provided data on emissions of trace metals into the air during coal burning (Figure 57). Based on plume modelling, only 4-10% (200 kg/year) would be deposited in the Anglesea catchment where it becomes bound to vegetation, clays and organic rich soils. As the amounts of metals are generally low and only a proportion is deposited across the catchment, emissions are an insignificant source of metals. Comments on health based compliance with policy is beyond the scope of this review.

Figure 57. Alcoa's reportable emissions to air for three fiscal years.

Alcoa National Pollutant Inventory – Emissions to Air information

SUBSTANCE	2004/05 Total emissions to air (power station + mine) tonnes/year (SHUTDOWN YEAR)	2005/06 Total emissions to air (power station + mine) tonnes/year	2006/07 Total emissions to air (power station + mine) tonnes/year
Arsenic	8.01E-03	8.66E-03	9.26E-03
Beryllium	5.39E-03	7.72E-03	6.16E-03
Cadmium	4.25E-03	4.19E-03	3.12E-03
Carbon Monoxide	6.57E+01	7.27E+01	6.99E+01
Chlorine (usage)	0.00E+00	0.00E+00	0.00E+00
Chrome (III)	1.51E-01	1.72E-01	1.66E-01
Chrome (VI)	5.89E-03	6.84E-03	6.57E-03
Copper	5.16E-02	5.55E-02	4.03E-02
Fluoride	6.71E-01	7.55E-01	7.05E-01
Hydrochloric acid	8.70E+01	5.76E+00	2.24E+01
Lead	1.46E-02	1.87E-02	2.06E-02
Magnesium Oxide	0.00E+00	0.00E+00	0.00E+00
Mercury	1.64E-03	1.88E-03	1.81E-03
Nickel	9.28E-02	1.12E-01	9.59E-02
Nitrogen oxides	3.26E+03	3.79E+03	3.61E+03
Particulate PM ₁₀	3.19E+02	3.47E+02	3.37E+02
Dioxins & furans	8.30E-07	9.70E-07	9.22E-07
PAH's	7.60E-04	8.85E-04	8.41E-04
Sulphur dioxide	3.36E+04	3.95E+04	3.95E+04
Sulphuric acid (usage)	1.51E+00	1.76E+00	1.68E+00
Total VOC's	2.30E+01	2.62E+01	2.51E+01

5.9 Parsons' data 2011

Parsons' 2011 submission consisted of two parts; a comprehensive data set on pH (30/10/10 – 5/2/11) and trace metal concentrations measured at three sites (Marshy Creek – upstream of Alcoa's operations, Salt Creek – Bald Hills Rd, and the Anglesea River – EPA sampling point SP3). This data included an assessment against ANZECC/ARMCANZ (2000) water quality guidelines for the protection of freshwater aquatic ecosystems. Photographs of flocculation in the river and the chemical composition of the floccs were also provided. Part two consisted of a discussion of the origin of atmospheric inputs of sulphur dioxide and other constituents deposited in the Anglesea catchment.

Parsons provided photographic evidence (Figure 58) of flocculation around SP3, when acidic tributary waters (pH 3-4) are contacting water discharged by Alcoa that has a pH of 7-8. Measurements of pH at SP3 are generally in the range of 4-7. However, it should be noted that Parsons' first photograph is upstream of the Alcoa plant before any interaction with Alcoa's operation and discharge. Water emerges from concrete pipes which will elevate pH and cause flocculation.

Figure 58. Photos of flocculation submitted by Parsons (2011).



Parsons provided data to illustrate that the floccs contain large concentrations of a range of trace elements. Of note is the high concentrations of copper, chromium, iron, selenium, antimony and lead. He also provides data for trace element concentrations in fly ash and, using boron as a tracer, puts an argument that the origin of the flocculated material is from leaching of fly ash material. He has measured boron concentrations of 50 µg/l in Marshy Creek water, 60 µg/l in Salt Creek water and 1000 µg /l in the ash pond. Fly ash has 410 mg/kg of boron. Floc concentrations of boron were reported as mg/l, so no assessment of floc concentrations can be made.

Parsons provided data for rainfall, pH, aluminium, iron and manganese concentrations at SP3 from 30 October 2010 - 5 February 2011. He indicates that after a major rainfall event, the pH at SP3 dropped and there was a dramatic increase in trace element concentrations, which he attributed to the dissolution of flocculated material.

Parsons raises the question of the relative contributions of ash pond discharges and the natural flow of the Anglesea River, and consequences for the health of aquatic organisms within the river. At times of low rainfall, discharges from the ash pond may constitute nearly the entire flow into the river. Parsons states that ordinarily the ash ponds constitute 90% of flow into the estuary. Sufficient data is not available to confirm or refute Parsons' statement as to the frequency of this occurring. Parsons also provides data on water samples measured over the period 30 October 2010 – 6 February 2011 to illustrate that trace metal concentrations regularly exceed the ANZECC/ARMCANZ (2000) trigger levels for protection of freshwater aquatic organisms.

5.10 Trace metal inputs into Anglesea River and Estuary: Synthesis of the evidence

There is clear evidence of high concentrations of aluminium, iron and manganese as well as associated trace elements entering the Anglesea River and estuary, from evidence of high aluminium concentrations in the estuary after rainfall (Pope 2010) and evidence of high concentrations of aluminium and iron flocculating on sea grasses from elevated zinc, copper and lead concentrations measure over short periods in *Z.muelleri* (Atkins and Bourne 1983).

Parsons (2011) provided photographic evidence of flocculation in the region. Personal observations by Maher (2011) confirmed the formation of floccs where acid freshwater is mixing with alkaline estuarine water.

There is little evidence that sediments containing elevated trace metals are being deposited in the estuary (Atkins and Bourne 1983) but available data is nearly 30 years old.

Four sources are potentially contributing trace metals to the estuary; natural sources, the old Roche mine, activities associated with coal mining and power generation activities (ash pond effluent and stack emissions) and storm water runoff from the Anglesea township. No data is available to assess the inputs from township runoff.

5.10.1 Natural sources

There is clear evidence of elevated aluminium, iron and manganese concentrations in streams and tributaries draining into the Anglesea River (Atkins and Bourne, 1983; Pope, 2010; Parsons, 2011). This is expected in flows from acidic soils with underlying coal deposits, acid sulphate soils and marshes rich in these elements (Hermon 2002; Alcoa 2011).

In particular, aluminium and iron are soluble under oxidizing conditions at low pH (Figures 59, 60 from Hermon 2002). Mass balances undertaken by Alcoa (see section 5.8.3) indicate that during periods of high flow when fish deaths are likely to occur, the contribution of aluminium from discharges from the ash pond are relatively small (< 0.06%) with the major source of aluminium and trace metals being from the catchment. Alcoa's September 2010 data also suggests that aluminium in the mixing zone could be being dissolved as shown by the differences in aluminium concentrations recorded at SP3 compared with the sum of the inputs.

Figure 59 shows aluminium speciation as a function of pH. Figure 60 shows stability for iron species in natural waters as a function of Eh and pH at 25°C and 1 atmosphere pressure. Figure 61 shows the stability for manganese species in natural waters as a function of Eh and pH at 25°C and 1 atmosphere pressure.

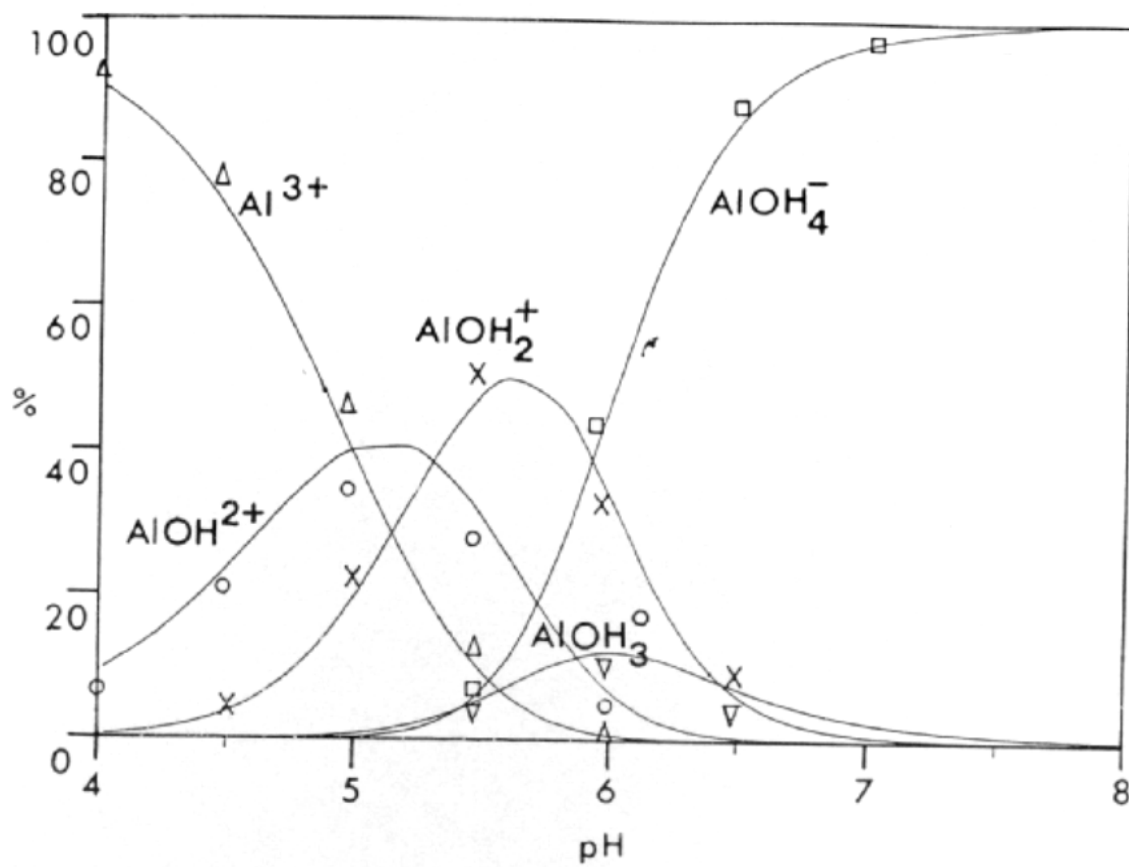


Figure 59. Aluminium speciation from Hermon (2002).

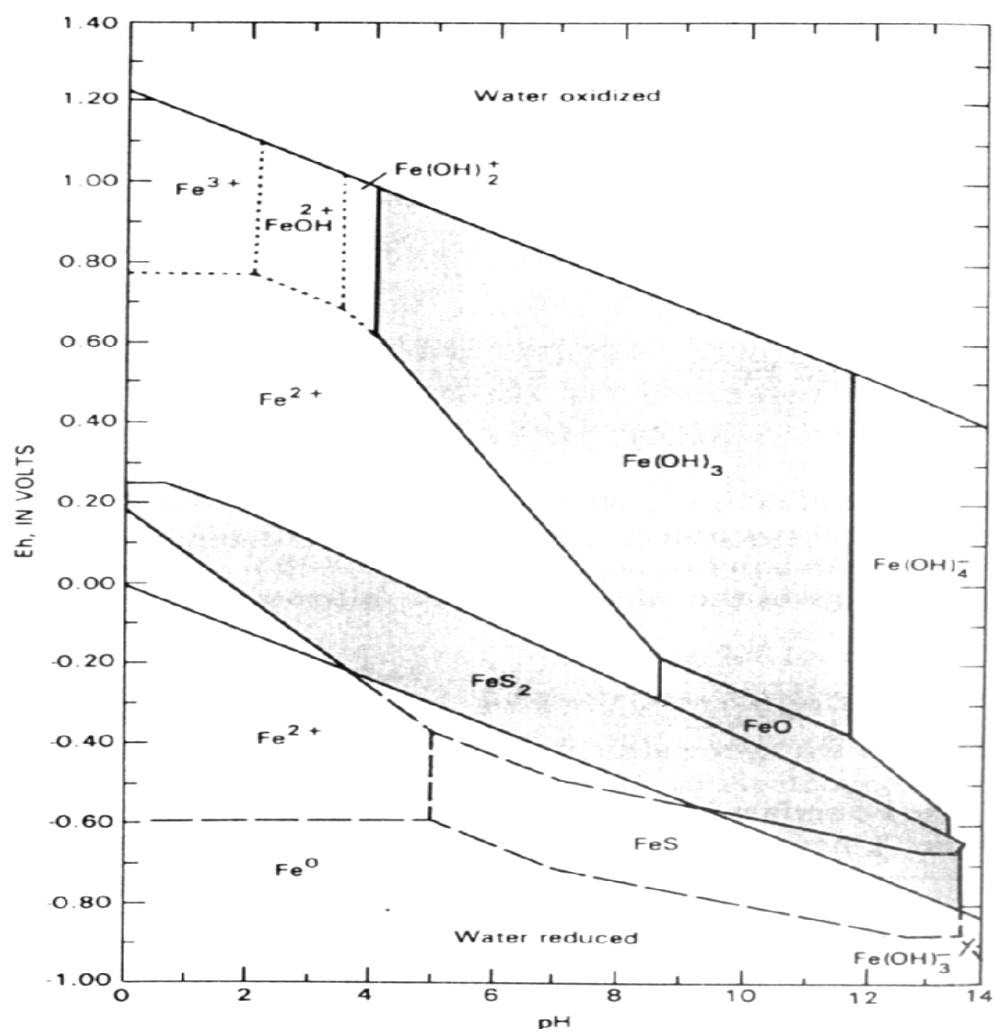


Figure 60. Iron speciation diagram from Hermon (2002).

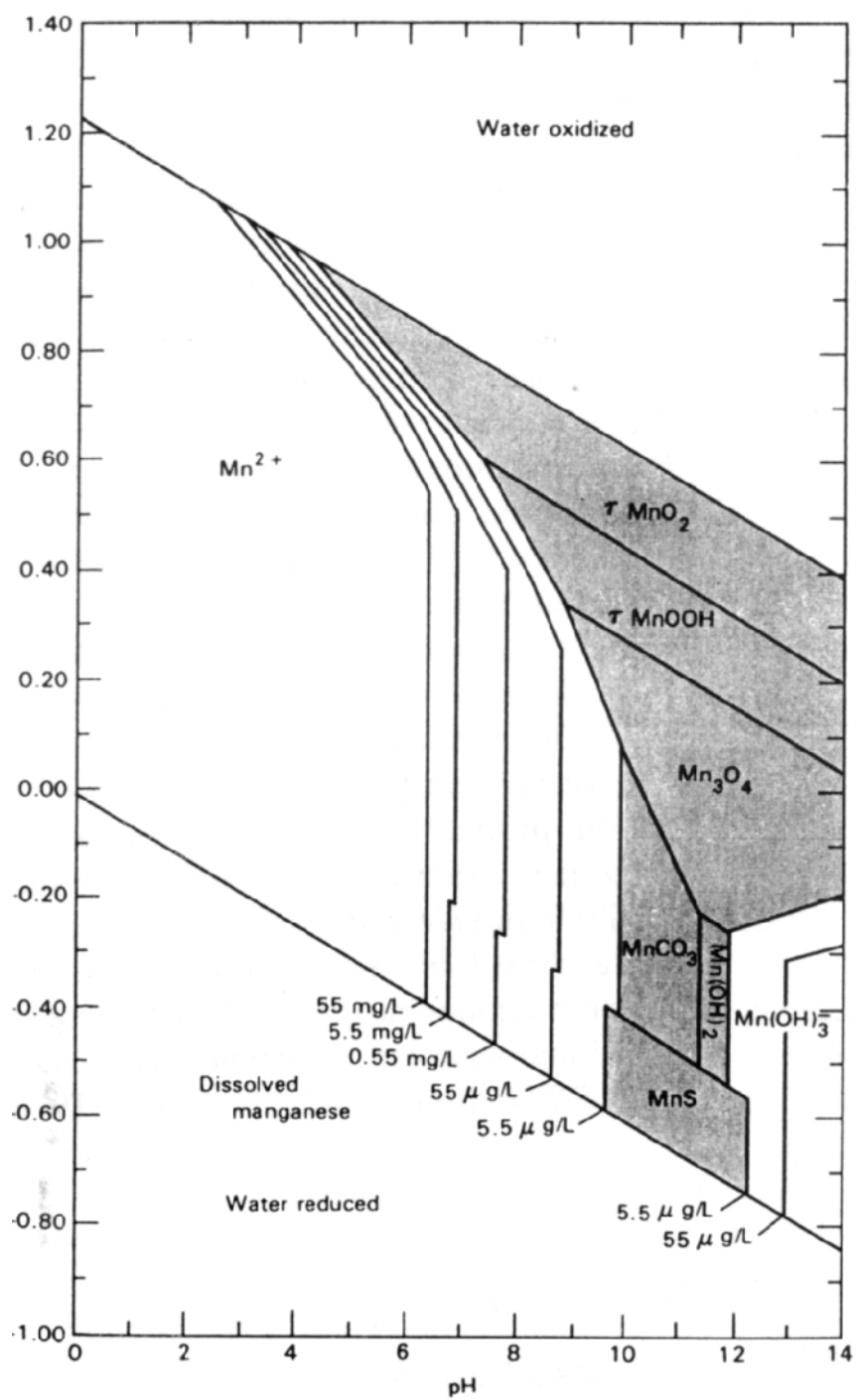


Figure 61. Manganese speciation diagram from Hermon (2002).

5.10.2 Decommissioned Roche coal mine

On decommissioning, the Roche coal mine was filled with ash high in aluminium and sulphates. Water quality data at the sampling site adjacent to the mine (SF1 in Hermon's 2002 report) has much higher aluminium and sulphate concentrations compared to other sites in the Salt Creek catchment. This indicates that flows from Salt Creek percolating through the old coal mine may be a potential source of aluminium (and other trace metals) leaching from ash used to fill the mine, however compared to other sources is likely to be minor.

5.10.3 Power generation activities

Atkins and Bourne (1983) stated that No2 ash pond effluent provided a source of dissolved salts, while Hermon (2002) measured conductivities of over 5000 $\mu\text{S}/\text{cm}$ in ash pond discharges. These results indicate a substantial input of dissolved solids in waters discharged from the mine site. Data supplied by Alcoa on the composition of this effluent (5 May 2011) indicates that of the 23 trace metals measured, aluminium, nickel and zinc marginally exceed ANZECC/ARMCANZ (2000) trigger levels protection of freshwater aquatic ecosystems in moderately disturbed systems, while boron (at 3.2 mg/l) vastly exceeded the guideline value of 0.37 mg/l.

However, data supplied for Marshy Creek taken at the same time showed higher concentrations of aluminium, nickel and zinc. Marshy Creek data also indicated that chromium concentrations were higher than guideline values. Boron in Marshy Creek was lower (0.14 mg/l) than the guidelines. Salt Creek was not flowing at the time of sampling. Parsons provided data to show that after a major rainfall event, the pH at SP3 dropped and there was a dramatic increase in trace element concentration which he attributed to the dissolution of flocculated material.

Given the high concentrations of aluminium, iron and manganese from natural sources, and high concentrations of aluminium, nickel, chromium and zinc in Marshy Creek, it is likely that trace metals are also being flushed from the catchment during major acid flow events. The data supplied by Alcoa (Section 5.7.3) clearly shows that during high flows most of the aluminium is coming from natural sources as the contribution of ash pond discharges are small. Without trace metal load data (flow and trace metal concentration data) it is not possible to definitively evaluate the contribution of the ash pond and dissolution of floccs forming upstream of the estuary to trace metal loads entering the Anglesea River.

Marshy Creek flows relatively often. Salt Creek's flow is very variable (Table 3) and probably dependant on drought conditions. Data is not available to confirm or refute Parsons' statement that the ash ponds constitute 90% of the flow into the estuary. If and when the ash pond does constitute the entire flow, boron would grossly exceed the ANZECC/ARMCANZ (2000) trigger levels for toxicity to aquatic organisms in moderately disturbed freshwater systems. Some other element concentrations may also marginally exceed the guideline values.

At other times when Salt Creek and Marsh Creek are flowing it appears boron concentrations still exceed the freshwater environment trigger values (CAPIM, 2010; Parsons, 2011) indicating a natural source of boron or considerable boron entering from the ash ponds. Data collected by Alcoa (unpublished) indicates that coal contains ~130mg/Kg boron and Salt and Marshy creeks can contain boron concentrations of up to 1 mg/l.

In the Anglesea River estuary, boron concentrations are naturally high in seawater (4-7 mg/l) and boron should not constitute a problem in the estuary to marine life.

Table 3. Days of flow in Salt and Marshy Creeks (Source Alcoa).

Year	Days of Flow	
	Marshy Creek	Salt Creek
2000	276	127
2001	261	263
2004	280	93

5.10.4 Disposal of bore development water

Records show development water, and possibly some residual drilling muds, from Barwon Water's bore field project were sent to Alcoa for disposal between 2008 and 2010 (Table 4). Without some context of quality (both quantitative and qualitative) it is difficult to ascertain the compositional nature of this water with respect to trace metals. However, the Alcoa license limits were met during this period.

Table 4. Summary of bore development water sent to Alcoa ash ponds (Barwon Water).

Southern Bores	Development	Review Comments
GW4	Alcoa. All water sent to ash pond Development undertaken initially from 29/4/2008 to 5/5/2008. Then from 26/5/2008 to 12/6/2008. Development rates variable from 5 L/sec up to max 25 L/sec (depending on technique and stage of development).	Assume 10 L/sec av, pumps run 24hrs and 24 days pumping approx. 20 to 21 ML
GW1	Alcoa – September 2009. All water sent to ash pond. Development undertaken from 15/9/2009 to 9/10/2009. Development rates variable 5L/sec to 15 L/sec generally (depending on technique and stage of development).	Assume 10L/sec average and 24 days pumping = 20 to 21ML
GW5	Alcoa – January 2010. All water sent to ash pond. Development undertaken from 8/1/2010 to 29/1/2010. Development rates variable from 5 L/sec to max 25 L/sec (depending on technique and stage of development).	Assume 10L/sec average and 24 days pumping = 20 to 21ML
Pump Testing		
All water transferred to Alcoa. The pump test commenced on 18 June 2008 and ran continuously at around 50 L/s until 4 July 2008 (there was a period of around eight hours where the pump did not run on 1 July 2008). Six of the 17 days of flows were sent to Alcoa's ash pond system, the remaining 11 were sent to Alcoa's water treatment plant for use in the power station.		27 ML for six days to ash pond.

5.11 River-estuarine processes

Parsons' 2011 photographs indicate that flocculation is occurring in the zone where the Anglesea River and ash pond effluent mix. However, the exact locations from which these pictures were taken are unknown and it is assumed he sampled near SP1. The first photograph is taken from upstream of Alcoa's operations in Marshy Creek just after when water flows through a concrete pipe which is probably elevating pH and causing floccs. Under oxidizing conditions, iron and manganese flocculate above pH 4.5 while aluminium precipitates at pH 5.5-6.5 (Figures 59, 60 and 61). Some flocculation of naturally derived aluminium, iron and manganese in the Marshy Creek (pH 3.5) would be expected when mixed with ash pond effluent (pH 7-9).

Flocculation is also occurring where the acidic Anglesea River enters the alkaline estuary (Maher's personal observations 2011). Atkins and Bourne (1983) note that as the result of estuarine mixing, the transfer of many metals from dissolved to particulate forms occurs. Dissolved metals are removed early in the mixing phase (Duinker et al 1980, Ellaway et al 1980, cited in Atkins and Bourne, 1983). In particular, aluminium is removed by the time a salinity of 8 ppt is reached (Hyde and Liss 1977 cited in Atkins and Bourne, 1983) and aluminium, iron and humic substances are flocculated in proportion to the salinity from 0 to 15-20 ppt (Sholkovitz 1976 cited in Atkins and Bourne, 1983).

The low pH of natural waters and the presence of large quantities of humic material may help stabilize metals in solution (O'Shea and Mancy 1998 cited in Atkins and Bourne, 1983) and elevate the salinity required for the formation of particulate metals (Sholkovitz 1976 cited in Atkins and Bourne, 1983).

Some, if not all, this material would be expected to be re-solubilised during flood events as the pH and salinity drop.

A conceptual model of the possible fate and remobilization of trace metals in this zone is given in Figure 62. Where this occurs will depend on the flow of freshwater into the estuary. At times of low flow, flocculation will occur at the confluence of the river and ash pond input, and during higher flows at Coalmine Rd at the head of the estuary. During substantial high flow, if a layer of fresh water exists over the more saline estuarine water, flocculation will occur at the fresh-sea water interface and flocculation will occur as far as the lens of freshwater extends into the estuary. Also, if fish are in the low pH water, flocculation may well occur on the gills of fish.

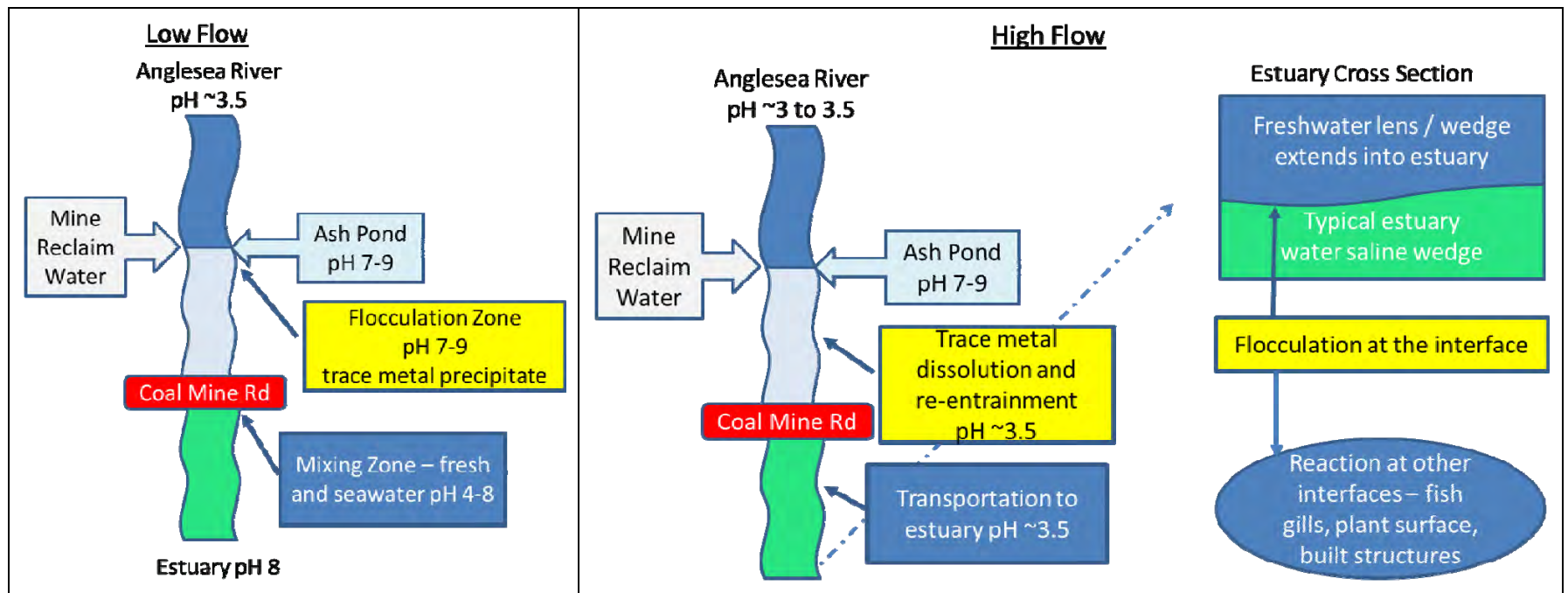


Figure 62. Concept model of fate and remobilization of trace metals in the lower reaches and estuary of the Anglesea River.

Conclusions

Four sources are likely to be contributing trace metals to the estuary; natural sources, the old Roche mine, activities associated with coal mining and power generation activities (ash pond effluent and coal burning) and storm water runoff from the Anglesea township.

Natural sources are contributing the most aluminium, especially during periods of high flow. However, at periods of low flow the ash pond discharge is probably the source of aluminium (and other trace metals).

The relatively small amounts of trace metals deposited over the catchment from emissions from coal burning will become bound to vegetation, clays and organic rich soils, which makes this an insignificant source to the estuary.

Flow and specific trace metal concentrations data isn't synchronized or comprehensive enough to accurately estimate the contribution of trace metals by each source.

Boron concentrations regularly exceed the ANZECC/ARMCANZ (2000) trigger levels for protection of moderately disturbed freshwater ecosystems. Both natural sources and ash pond effluent contribute boron to the Anglesea River. Boron concentrations are naturally high in seawater and should not constitute a problem in estuary to marine life.

At low flows, flocculation occurs in the zone where the Salt and Marshy Creeks and ash pond effluent mix, as well as in the upper parts of the estuary.

During high flows, some (if not all) this flocculated material would be expected to be re-solubilised during flood events as the pH and salinity drop.

During high flow, if a layer of fresh water exists over the more saline estuarine water, flocculation will occur where the freshwater meets the seawater. Flocculation will occur as far as the layer of freshwater extends into the estuary. Also, if fish are in the low pH water, flocculation may well occur on the gills of fish.

Key Points

There is evidence of high iron, manganese and aluminium concentrations in streams and tributaries.

Data from samples taken in the 2000 flood/fish kill event show that tributaries in the upper catchment have very little aluminium and sulphate concentrations, but once the water hits the valley the aluminium and sulphate concentrations in Salt Creek become notably higher.

It is important to note that a similar pattern of high acidity and high aluminium, sulphate, manganese, and zinc concentrations were recorded in Distillery Creek, a tributary of Painkalac Creek which is located south west of the Anglesea catchment

There is evidence of elevated iron, manganese and zinc concentrations leaving marshes, therefore marsh sediments are a potential source of iron, manganese and aluminium.

There is evidence of elevated aluminium and zinc concentrations in streams after the first substantial flow, probably as a result of wetting and drying of sulphidic soils.

Alcoa's long term data indicates that while the very high aluminium concentrations recorded in 2000 have not occurred since 1979, there have been lesser events where elevated metal

concentrations have occurred. Data from the 2010 fish death event indicates higher aluminium concentrations than those recorded in the 2000 fish death event.

There is evidence that No2 ash pond effluent provides a source of dissolved salts through conductivity measurements.

Recent data on ash pond effluent (5 May 2011) shows that of the 23 trace metals measured, aluminium, nickel and zinc marginally exceeded ANZECC/ARMCANZ (2000) trigger levels for toxicity to aquatic organisms in moderately disturbed systems. Boron measured at 3.2 mg/l vastly exceeded the guideline value of 0.37 mg/l.

However, data supplied for Marshy Creek taken at the same time showed higher concentrations of aluminium, nickel and zinc. Marshy Creek also indicated that chromium concentrations were higher than guideline values.

Boron in Marshy Creek was lower (0.14 mg/l) than the guidelines. Salt Creek was not flowing at the time of sampling.

Data indicates that during periods of high flow when fish deaths are likely to occur, the contribution of aluminium from discharges from the ash pond are relatively small (< 0.06%).

There is photographic evidence of flocculation at SP3 when acidic tributary waters (pH 3-4) contact water discharged by Alcoa of pH 7-9 value, although verification of the location of this photographic evidence is required.

There is evidence that floccs contain elevated trace metal concentrations. These floccs were found upstream of Alcoa's operation.

There is evidence that after a major rainfall, pH at SP3 drops and there is a dramatic increase in aluminium, iron and manganese, probably from dissolution of floccs. There are likely upstream sources in this case as well.

The September 2010 data suggests that aluminium in the mixing zone could be being dissolved by the differences in aluminium concentrations recorded at SP3 compared with the sum of the inputs.

There is evidence of trace metal contributions from activities downstream of power generation activities.

There is evidence that trace metal concentrations at SP3 sometimes exceed the ANZECC/ARMCANZ (2000) trigger levels for protection of moderately disturbed freshwater ecosystems.

Boron concentrations regularly exceed the ANZECC/ARMCANZ (2000) guidelines with both natural sources and ash pond effluent contributing boron to the Anglesea River.

There is evidence of high concentrations of aluminium and iron flocculating on seagrasses from elevated zinc, copper and lead concentrations measured over short periods on *Z.muelleri*.

There is little evidence of sediments containing elevated trace metals being deposited.

Alcoa emits trace metals into the air during coal burning, with 4-10% deposited in the Anglesea catchment. This amounts to approximately 200kg per year.

Knowledge Gaps

The relative contributions of specific trace metal loads from the natural flow of the Anglesea River, ash pond discharges and storm water inflows.

The fate and remobilization of trace metals in river-estuarine zone downstream of where the ash pond effluent enters the Anglesea River.

The risk of the Anglesea River freshwater ecosystems to high concentrations of boron.

6 Specific items of concern that may influence acid generation

The mechanisms as outlined for the “acid flush” (catchment acid drainage) are highly dependent on the regional geology and hydrological cycle. As such, any changes in the mechanism will have an effect on the “flush”. Anthropogenic disturbance of acid sulphate soil or rock can also cause acid drainage (EPA 2009).

This section discusses areas of concern raised by the community and factors that may influence acid generation in the Anglesea catchment.

6.1 Fire

Fire can affect the hydrological cycle in a number of ways, including changing evaporation and transpiration rates (evapo-transpiration), and altering soil properties. This, in turn, can affect run-off and infiltration. An altered soil also affects the quality of the water run-off or amount of water infiltrating into it.

The Cooperative Research Centre for Catchment Hydrology website has section dedicated to the effects of bushfires on stream flow and quality (see <http://www.catchment.crc.org.au/bushfire/intro.html>).

There are various types and intensities of fire (e.g. bush fire, controlled burns) and each may change the landscape. A severe fire that burns over a whole catchment will have greater effects than a controlled fuel reduction burn over only a portion of a catchment. For example, severe fires may kill trees and therefore have a large impact, but a controlled burn should not and is therefore described as having a small impact.

There are short and long term effects of fire on the hydrology of a catchment. These depend on the extent of changes to evapo-transpiration (from changes to vegetation) and changes to infiltration and runoff (from changes to soil properties).

Short term impacts may include;

- Increased hydrophobicity (water repelling) of soil;
- Increase runoff;
- Loss of evapo-transpiration (as vegetation is defoliated);
- Loss of the established topsoil layer (‘soil sponge’);
- Increased infiltration (due to the above factor);
- Increased infiltration (via exposed pathways such as cracked soil and burnt out root holes);
- Increased base flow (stream discharge) as a result of reduced evapo-transpiration; and
- Changes to water quality due to an altered leaf litter and soil state.

Typically, after a fire there is a short term increase in infiltration and runoff, followed by a longer term reduction in infiltration and runoff as the forest regrows.

The effects of fire on water quality are relatively well known in relation to run-off because these effects are easily observed and can be significant immediately after fire (i.e; creeks flowing full of

ash). The effects on water quality infiltrating the subsurface are less well known, although some changes are likely. In an acid-generating scenario, water infiltrating with higher oxygen concentrations (possibly due to the loss of organics and microbial fauna in the topsoil consuming the oxygen) may further increase the rate of acid generation.

Long term effects on the hydrological cycle may vary dependent on the intensity of the fire and extent of tree death. These effects may include;

- Increased evapo-transpiration (due to regrowth);
- Increased interception (due to regrowth);
- Reduction in infiltration, therefore recharge of groundwater (due to regrowth); and
- Change of vegetation type leading to changes in evapo-transpiration;

A map showing recent (2009) planned burns in the Anglesea catchment are shown in Figure 63.

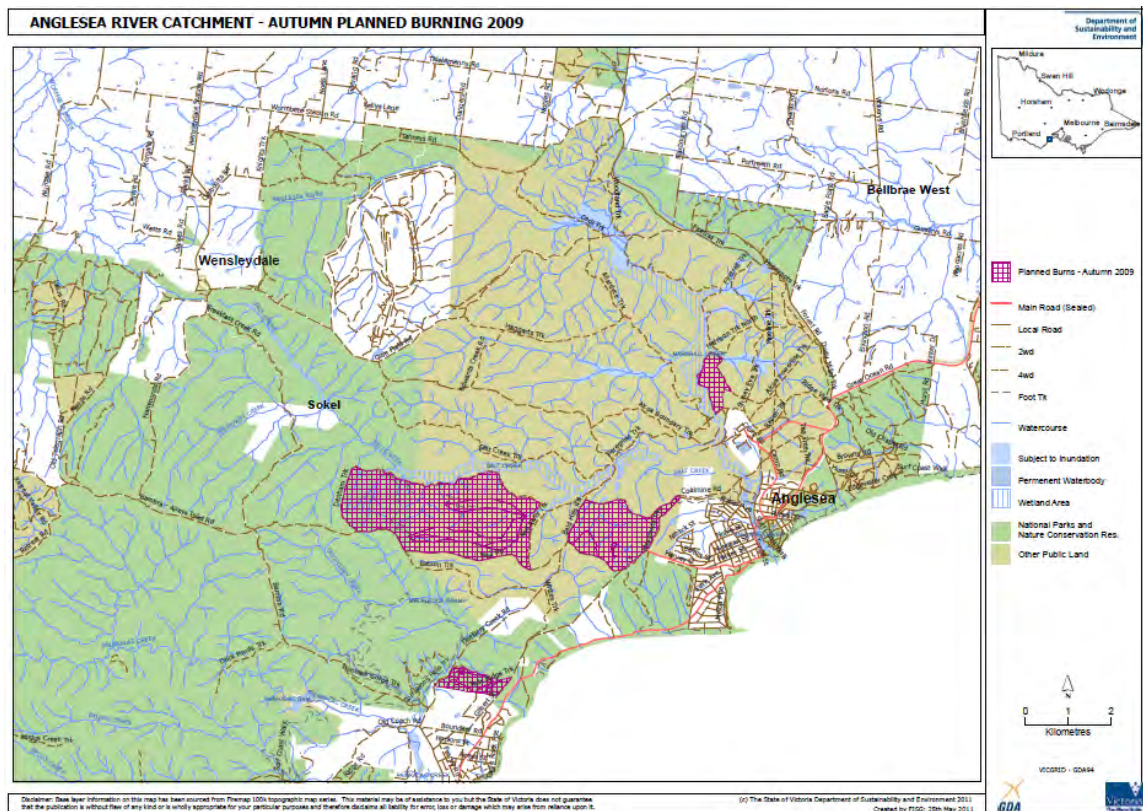


Figure 63. Map of planned burns for autumn 2009 (source DSE).

Based on figures provided (DSE Fire Information Systems Group) over the last three years, the area of fires / prescribed autumn burns in the Anglesea Catchment (Total Area 125 km² = 12,500 Ha) were;

- 2008 = 160 Ha;
- 2009 = 1040 Ha; and
- 2010 = 61 Ha.

The 2009 burn area was approximately 8% of the total catchment area and 20% of Salt Creek catchment (51.2 km² = 5,120 Ha). Of recent fires this “burn” was the most significant in terms of area burnt and therefore may have had a greater effect on the hydrology and infiltration in the Salt Creek tributary. Specific details about intensity or severity of the fire were not established.

A lithological log (5) for bore AL 623 in the approximate area of the 2009 fire area is presented in Figure 64. Coal is recorded at approximately 33m below ground surface (ground surface at 86 m AHD), which is 53m AHD and this is above the level of Salt Creek at this point in the catchment. The 2009 burn is likely to be the best event to investigate the effect of fire on acid drainage. However, this would require further information on the flow and water quality from the Salt Creek catchment. Alcoa monitoring indicates Salt Creek had not flowed for 32 months before spring 2010 (acid event) which incorporates the burns period. Given the observed ephemeral nature of Salt Creek in recent decades, determining the influence of fire is likely to be difficult. Barwon Water's increased environmental monitoring may provide suitable data if further investigations are undertaken.

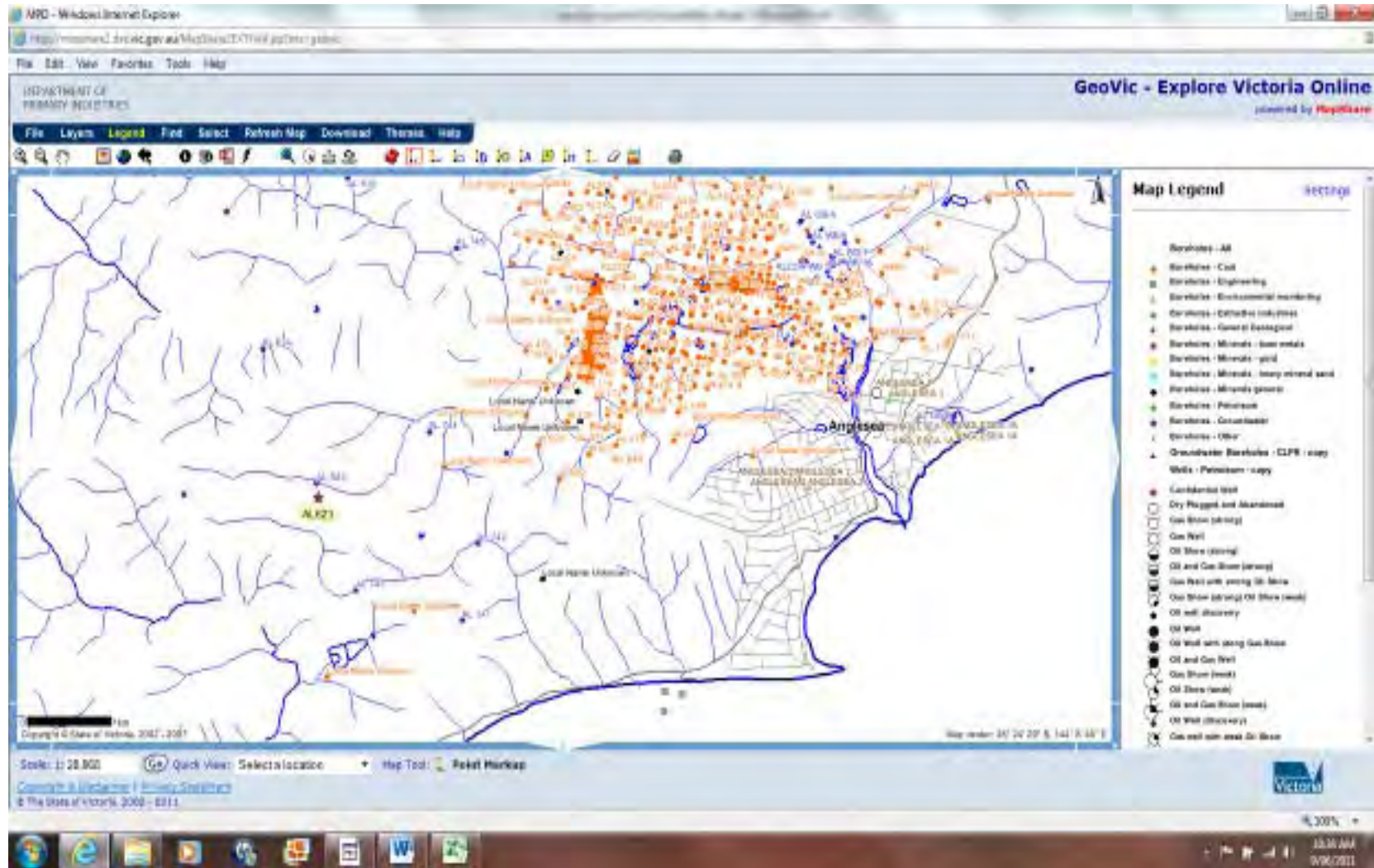


Figure 64. Location of bore AL 623 (marked with small purple star) in the area of the 2009 burn and lithology log.

Table 5. Lithological log AL 623 in the Salt Creek catchment.

Lithological Logs

Geologists Log created by GEO-ENG PTY LTD on October 31, 1963

From	To	Comments
0.0	7.0	*OLD STRATA* : CLAY(1)
7.0	7.6	*OLD STRATA* : YELLOW SANDSTONE(720)
7.6	10.7	*OLD STRATA* : CLAY(1)
10.7	14.3	*OLD STRATA* : IRONSTONE(7)
14.3	31.7	*OLD STRATA* : STICKY CLAY(1)
31.7	32.9	*OLD STRATA* : LIGNEOUS CLAY(0 8)
32.9	37.8	*OLD STRATA* : HARD COAL(0 0)
37.8	52.1	*OLD STRATA* : SAND(2)
52.1	52.7	*OLD STRATA* : COAL BROWN(0 0)
52.7	58.5	*OLD STRATA* : SAND(2)
58.5	61.3	*OLD STRATA* : LIGNEOUS CLAY(0 8)
61.3	65.2	*OLD STRATA* : COAL BROWN(0 0)
65.2	69.2	*OLD STRATA* : STICKY CLAY(1)
69.2	73.5	*OLD STRATA* : COAL BROWN(0 0)
73.5	77.1	*OLD STRATA* : LIGNEOUS CLAY(0 8)
77.1	84.1	*OLD STRATA* : SAND(2)
84.1	86.3	*OLD STRATA* : LIGNEOUS CLAY(0 8)
86.3	89.3	*OLD STRATA* : SAND(2)
89.3	106.7	*OLD STRATA* : CLAY(1)

Other fires in the catchment included bushfires. From 2008 to 2010, the most significant fire (in relation to area) was in 2009 within the Marshy Creek sub-catchment and the area burnt was approximately 545 Ha in size (Figure 65).

The 1983 Ash Wednesday bushfires would be another relevant case study and possibly more definitive in providing an understanding of the effects fire may have on acid drainage due to its scale (Figure 66) and severity (detailed data on the Ash Wednesday bushfire severity in the Anglesea catchment has not been researched as part of the review).

Further investigations and gathering of all available data on climate (rainfall), flow and quality for up to 10 years after the fire would be required. Based on the mechanism for acid drainage (Figure 27) and influences of fire, it may be hypothesised that for a number of years after the Ash Wednesday fire when infiltration / recharge increased (until vegetation reached a “vigorous growth point” equivalent to pre-fire evapo-transpiration), infiltration and base flows increased and acid drainage occurred regularly. Long term Alcoa monitoring data indicates flows from the catchment remained below pH 4 until 1992. After a number of years it could be hypothesised that evapo-transpiration from the catchment reached a level to substantially influence and reduce infiltration, resulting in less acid generation and transport to the streams. Again, long term Alcoa data shows that after 1992, flows from the catchment recorded pH up to 7. This data may be explained by rain events

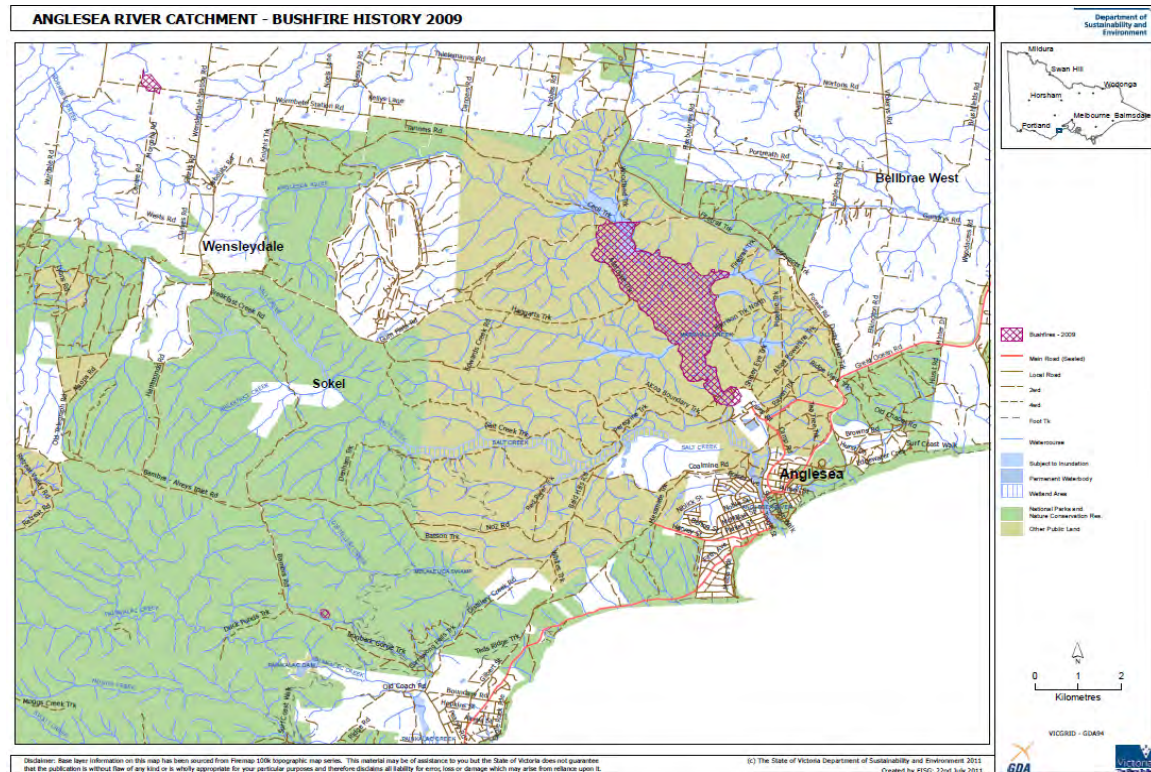


Figure 65. Bushfires in the Anglesea catchment in 2009 (DSE).

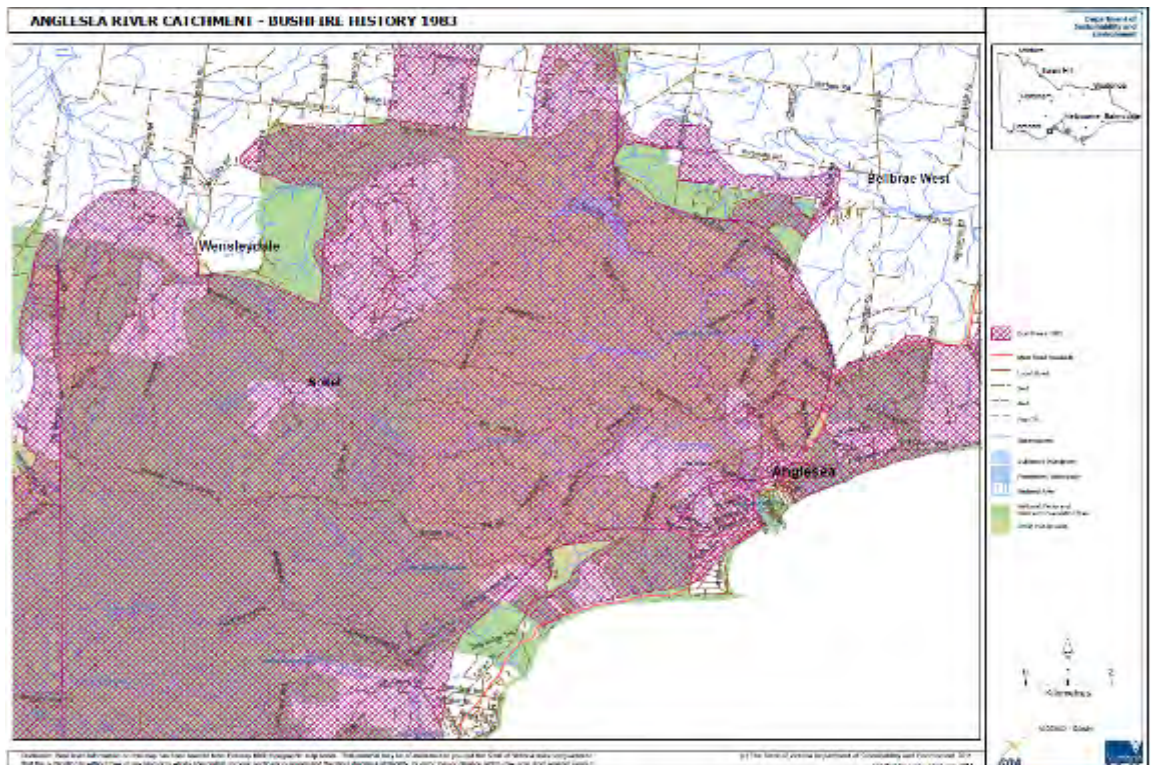


Figure 66. Map of the 1983 Ash Wednesday Bushfire.

which produced overland run-off, but without influence of acidic base flows from infiltration and recharge (which were reduced due to higher rates of evapo-transpiration). However, if and when infiltration did occur, the acid drainage in the catchment would continue and monitoring data again show drops in pH to 3-4 from 1992 onwards.

The ability to substantially measure or quantify the influence of a factor like fire is unknown, but research on the subject may be worth consideration. Furthermore, given that the catchment is now a potable water supply and factoring in comments made in the Technical Audit Panel review on hydrogeological modelling, an increased understanding of infiltration and recharge in the EVF may have many benefits.

Conclusions

Fire can cause changes in evaporation and transpiration rates and alter soil properties. This can then affect run-off and infiltration. Water infiltration is the key to acid generation and transportation.

Further investigation is required using available data on climate, rainfall, water flow and water quality for up to 10 years after the fire to fully understand the influence of fire and implications of any fire management plan using controlled burns.

Key Points

Fire can affect the hydrological cycle in a number of ways, including changing evaporation and transpiration rates (also referred to as evapo-transpiration), and altering soil properties. This can then affect run-off and infiltration.

Fire can cause short and long term effects on the hydrology of a catchment depending on the extent of changes to evapo-transpiration (from changes to vegetation), and infiltration and run-off due to changes in soil properties.

After fire there is usually a short term increase in infiltration and run-off, then longer term reduction in infiltration and run-off as the forest regrows and evapo-transpiration increases.

Significant fires over a substantial area in the Anglesea catchment, such as the 1983 Ash Wednesday fires, would have influenced or altered the hydrological conditions at Anglesea.

In an acid-generating scenario, water infiltrating with higher oxygen concentrations (possibly due to the loss of organics and microbial fauna in the topsoil consuming the oxygen) could further increase the rate of acid generation.

Knowledge Gaps

An understanding of infiltration (water and oxygen) and recharge after fire and effects on infiltration and stream pH.

6.2 Pumping of Bore Water

6.2.1 Pumping by Alcoa

Alcoa pumps bore water from six well bores within the Alcoa lease area. The water is treated and used for cooling tower make-up and general services.

Water Technology's 2010 report investigating river mouth dynamics and modified a water balance for the upper EVF developed by Tutt (2008) (Figure 67).

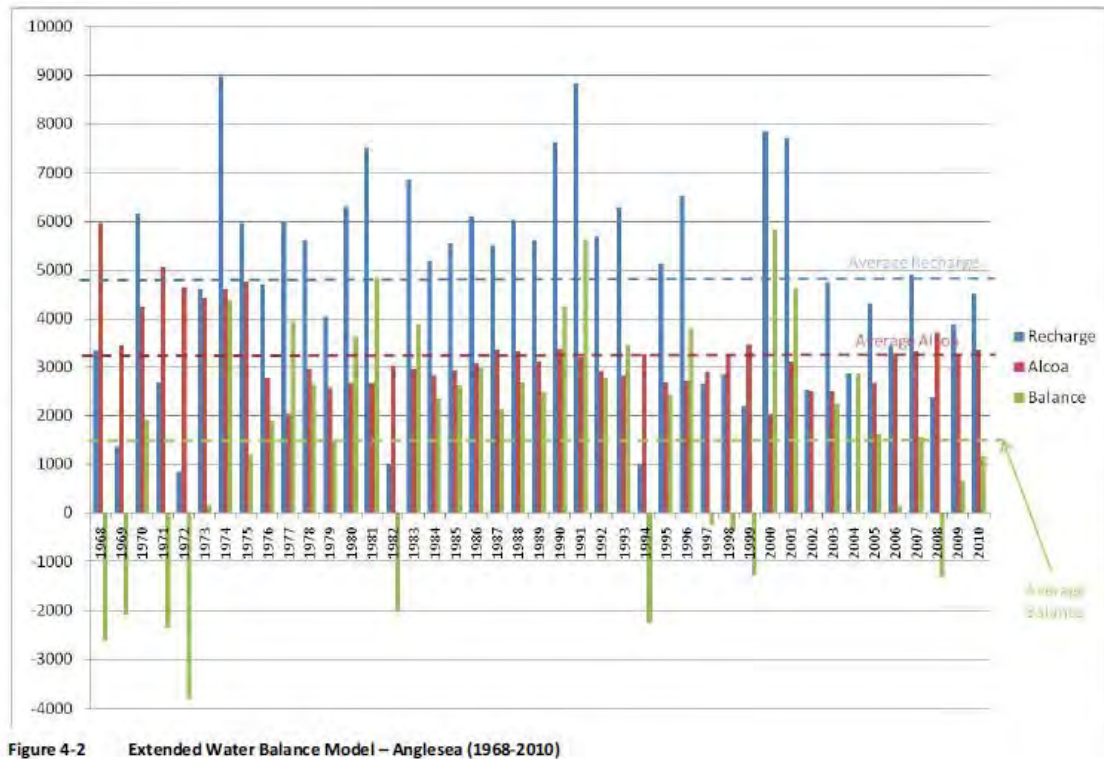


Figure 67. Water balance with recent Alcoa extraction volumes from the upper EVF (Water Technology2010).

The data indicates Alcoa's extraction regime has not varied substantially in recent years, remaining at approximately 3000ML/yr.

The 1998 report by SKM on the effect of groundwater pumping by Alcoa concluded that a “cone of groundwater depression” exists around the mine and power station site. A more recent report on Alcoa groundwater extraction (SKM 2007) confirmed the presence of the cone of groundwater depression and located it around the mine and power station, elongating in a south east direction to the ocean.

Tutt (2008) included extraction in his water balance model. He concluded that given that the “the cone” is located at the base of the catchment, that the mine pit is substantially below river and sea level, and that aquifer hydraulic flow paths were directed to Alcoa extraction bores. Thus acidity generated in the cone of groundwater depression was unlikely to contribute to surface water acidity.

More recent work for Barwon Water also noted that the coal mine and power station operation appear not to have “drained” the marshes in the catchment, that the marshes are in good health and that they seem to have their own perched water table operating (GHD 2008).

These two factors, the cone of depression in the upper EVF and perched shallow aquifers, plus the observation that two tributaries, a river and an estuary are all still present in the landscape demonstrate the complexity of the geological setting. These factors also indicate limited connectivity between the cone of depression and surface waters this far down the catchment, however more information should be collected on the potential drying out of surrounding marshes and the wider catchment area to confirm this.

Also of interest and not as immediately obvious as the “pumping of groundwater”, is pumping recycled mine water. Alcoa EIP (2008) reports pumping volumes are in the order of 1000 to 1500 ML/annum, of which a portion would be ingress of surrounding aquifer water, as well as a portion of rainfall runoff from the mine void’s own catchment. The effect of the mine void itself (primarily located in the Salt Creek catchment) as a feature that removes water from the surrounding environment should also be considered, but seems to have been overlooked in many investigations to date.

As mentioned in the section 4.2.2, the relative proportional geology of the Salt Creek catchment is different to that of Marshy Creek, with a large portion of the upper Salt Creek catchment located in the lower EVF unit. Water quality monitoring from 2000 also shows low pH (3.4), high aluminium (36 mg/L) and sulphates (340 mg/L) in the upper reaches of Salt Creek Marsh. This is located in the lower EVF formation and likely to be well beyond any influence of current or previous mining and water extraction operations (see Figure 68, site 6).



Figure 68. Location Site 6 (Denham Track on Salt Creek) of low pH, high aluminium and sulfate water quality results from testing in 2000. The old Roche mine is located adjacent to site 7 and the current operation is also evident by cleared land, approximately 4 to 5km downstream of site 6.

In reviewing the information, pyrites are likely to have been exposed to oxidising conditions in the cone of groundwater depression. As outlined, it is unlikely that acid water generated in the cone of

depression has the capacity to reach surface water. Tutt (2008) noted that acid water flows had been measured well up into the catchment beyond the influence of Upper EVF extraction.

Conclusion

Alcoa pumping probably had little effect on acid drainage from the greater catchment because pyritic material exposed in the cone of groundwater depression is unlikely to contribute acid into surface water systems. However more information should be collected on the potential drying out of surrounding marshes and the wider catchment area.

Key Points

Alcoa's extraction regime has not changed substantially in recent years, remaining at approximately 3000ML/yr.

A 'cone of groundwater depression' exists around the mine and power station site.

The coal mine and power station operation have not 'drained' the marshes in the catchment. The marshes are in good health and seem to have their own perched water table operating.

The mine pit is substantially below river and sea levels, and aquifer hydraulic flow paths were directed to Alcoa extraction bores. Therefore, any acidity generated in the cone of groundwater depression is unlikely to contribute to the acidity of surface water.

The cone of depression, or the open cut mine itself, may have 'disturbed' seams or pockets of perched water (other than the swamps) because the Salt Creek sub catchment shows signs of possible disturbance compared to Marshy Creek. However, this may be the result of the creeks' differing catchment geology and longer term drying out caused by historical mining.

Knowledge Gaps

Connections between Salt Creek marshes, other possible perched water tables and the current mine void and the cone of groundwater depression, and therefore the effects on water tables and the potential drying out of pyritic material and acid generation.

6.2.2 Pumping by Barwon Water

Barwon Water began operating the Anglesea Bore field in October 2009. The last of seven production bores is now being installed (BW Community Bulletin 2010). A hydrogeological conceptual model of this operation is shown in Figure 69.

The bore field project was developed to meet some of the region's potable water supply demand. Groundwater is extracted from the lower EVF of up to 40 ML/day, 10,000 ML per year and up to 35,000ML over 5 years (BW Community Bulletin 2010). The project underwent various approval processes (supported by various investigations and reports, including computer modelling of the hydrogeology and an environmental impact assessment) before approval for the bulk entitlement extraction was received from the Water Minister on 1 July 2009.

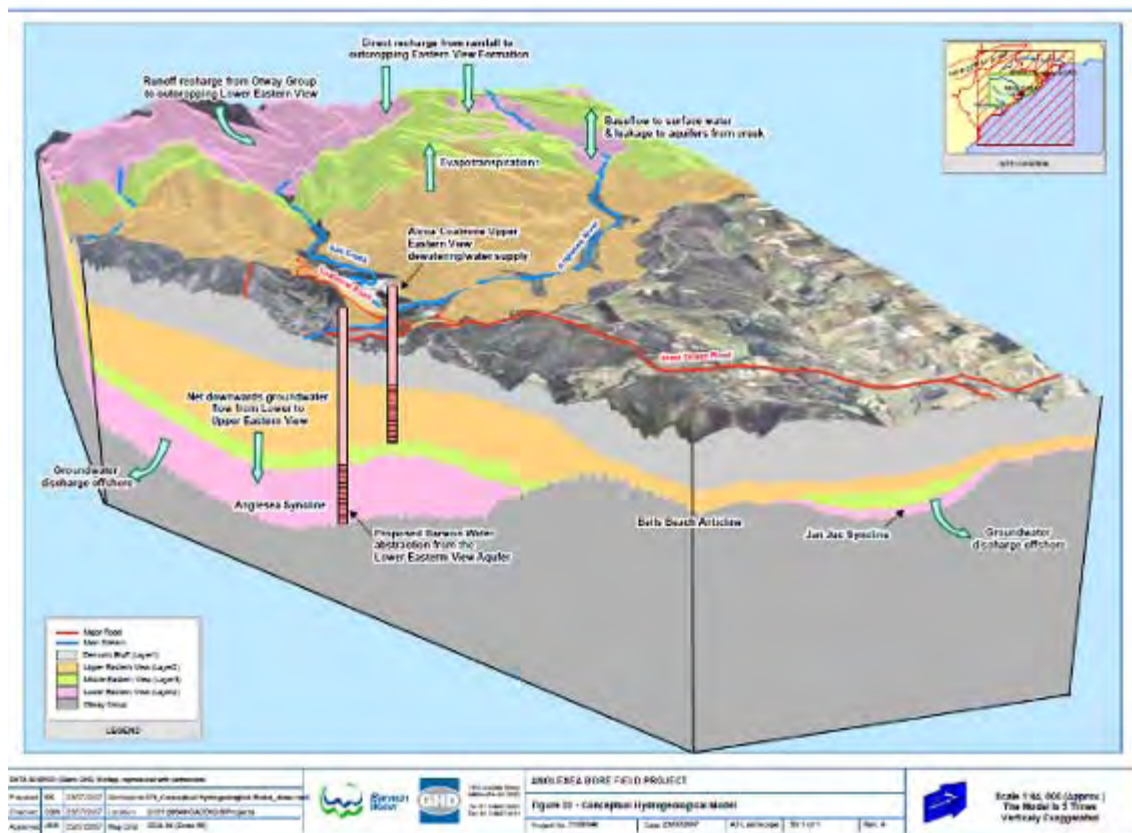


Figure 69. Conceptual hydrogeological model of the EVF and bore field project (GHD 2008).

Impacts of the project were described in a paper presented at the Groundwater 2010 conference by Cunningham and Morgan (2010). Numerical modelling identified potentially base flow dependent surface water features in the upper reaches of the Anglesea River and Salt Creek in the

LEVF outcrop area. These may be effected by draw-down associated with the extraction. Modelling limitations and effects on groundwater dependant ecosystems and long term sustainable aquifer yield are respectively discussed and noted in the paper. The paper also outlines further monitoring and management programs to help improve the impact assessment knowledge base.

This paper and the hydrogeological review (Appendix G of the Bore fields PIA) do not mention any potential effects from draw down that are related to sulphides disturbance.

The Project Impact Assessment (PIA) (Barwon Water, GHD 2008) lists acid sulphate soils (ASS) as a geotechnical risk to infrastructure (pipelines) and identifies potential ASS in the vicinity of the Anglesea River. It recommends an above-ground crossing of the Anglesea River, for reasons including the effect of ASS disturbance.

In relation to water quality of the wetlands and marshes in the upper EVF, the Aquatic Assessment – Groundwater Extraction (Section 8.3 of the PIA) noted pH of less than 4, the presence of acid sulphate soils, and the effects of drying and wetting which may lead to acid generation. The effect of extraction (modelled at 5% reduction inflows to the swamps lands) is described as hard to predict and when considered in conjunction with predicted climate change scenarios, drying out of the swamps lands is somewhat expected. The primary recommendation following this assessment was to initiate and install appropriate monitoring programs to improve understanding of the system as to more accurately assess impacts.

On review, the bore field extraction may alter groundwater levels in the EVF, and therefore interactions with surface water. Identified effects in altered water tables include drying out of swamps and possibly ASS. Drying out of other potential acid-generating strata in the catchment (see Section 4.2 and Figure 13) appears not to have been substantially considered in Barwon Water's investigations and reports to date.

However, bore water pumping by Barwon Water would not have contributed to the fish death event in 2000 because it wasn't being undertaken at the time. According to current modelling, it is also unlikely Barwon Water contributed to the 2010 event because current triggers of the Bulk Entitlement preclude impact in the LEVF outcrop areas. Nonetheless, EVF modelling has limitations which are discussed further in the Technical Audit Panel Review (Technical Audit Panel Review of November 2008). The review states "they do not believe that the current groundwater model is sufficiently well calibrated for prediction of impacts to be considered reliable". This supports the need to investigate further and update the model (which are requirements of the Bulk Entitlement).

Conclusions

Bore field extraction may alter groundwater levels in the EVF and therefore interactions with surface water, altering water tables and creating effects such as drying out of swamps and acid generation in acid-sulphate soils.

The current groundwater model is not well calibrated enough to predict impacts and therefore not considered a reliable model. Further investigation and updating the model is necessary.

Key Points

Barwon Water began operating the Anglesea Bore field in October 2009.

Numerical modelling identified potentially base flow dependant surface water features in the upper reaches of the Anglesea River and Salt Creek in the LEVF outcrop area. These features may be affected by draw-down associated with extraction of water.

Bore field extraction will alter groundwater levels in the EVF and therefore interactions with surface water. Altering water tables can cause swamps to dry out and the possibility of ASS also drying out. Marshes may dry out more often than under natural conditions and this may generate acidity.

Assessments to date have not significantly addressed the bore field project's potential impacts as a result of exposure or disturbance of pyritic strata from the draw-down.

The Technical Audit Panel Review (November 2008) stated it "... does not believe that the current groundwater model is sufficiently well calibrated for prediction of impacts to be considered reliable."

Knowledge Gaps

Alteration of groundwater levels in the EVF and effects including swamps drying out.

Effects associated with exposure / disturbance of pyritic strata due to groundwater extraction.

6.3 Licensed Discharges

Alcoa has the only EPA licensed discharge in the Anglesea Catchment (EPA correspondence). The discharge is to the Anglesea River at a point in the power station / mine site. The discharge to the river averages approximately 4ML/day and is made up of cooling tower water, storm water and ash pond water. EPA sets water quality limits at the end of the mixing zone as shown in Figure 70.

Table 3: Water Discharge Limits¹

Parameter	Unit	Maximum Value	Sampling Frequency
Rate of Discharge	ML/day	32.9	All monthly
Suspended Solids	mg/L	30	
Colour	Pt-Co units	50	
Iron	mg/L	4.0	
Aluminium	mg/L	5.5	
Zinc	mg/L	0.3	
Boron	mg/L	TBD ²	
Parameter	Unit	Range	
pH		5-9	

1: Sampled at SP3.

2: "TBD" means "to be determined".

Figure 70. EPA license conditions for Alcoa water discharge to the Anglesea River.

Long term monitoring results (1972 to 2011, broken into 3 periods for clarity) for pH are shown in Figure 71, 72 and 73. Monitoring locations are river upstream (SP2), Salt Creek (SP2a from 2003) and Marshy Creek (SP2b from 2003) upstream of the power station, Alcoa ash ponds discharge (SP1) and Anglesea River at SP3 (mix of all SP1, SP2a&b).

Evident in the long term pH monitoring is the general trend of low pH of waters upstream of the power station and the fluctuating nature of pH measurements downstream of the power station. The pH of Alcoa discharge has also fluctuated but in the last 5 years it appears to be consistently in the range of pH 7-8 and is not the source of low pH water in the Anglesea estuary.

Results for parameters, aluminium, iron and zinc are shown in Figure 74 for about the last 10 years. Overall, the graph shows concentrations are well below licence limits.

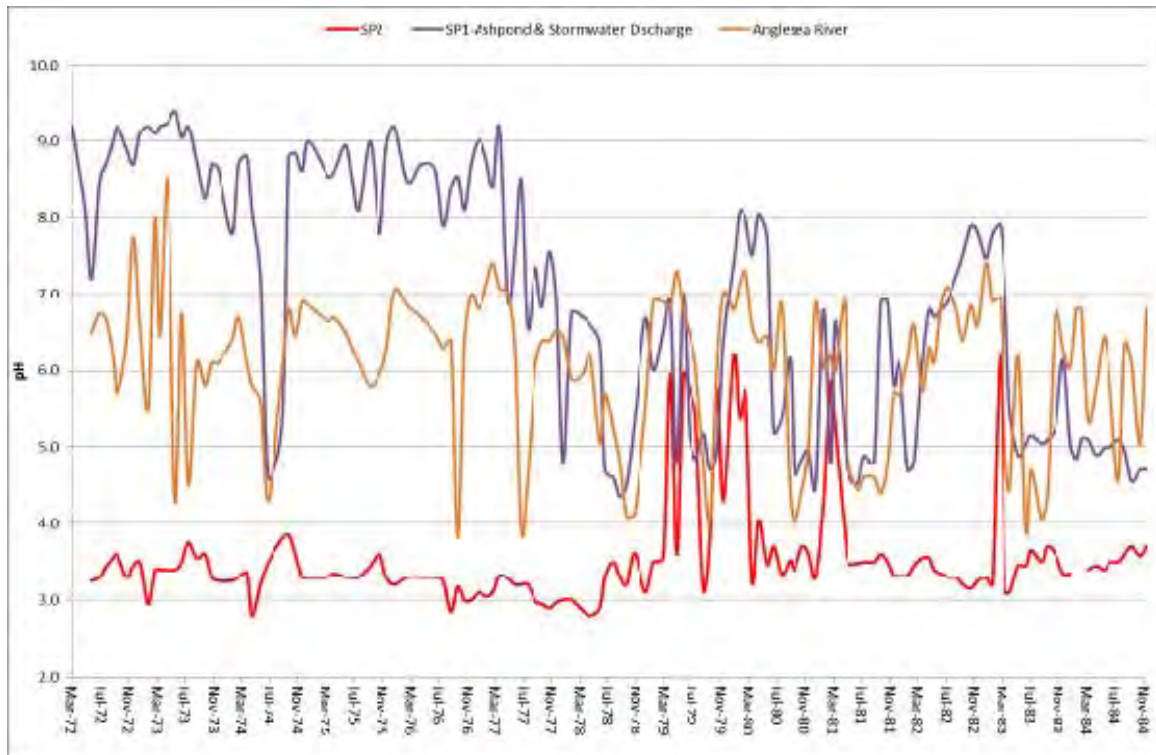


Figure 71. Alcoa pH monitoring data for period 1972 to 1984 for the Alcoa discharge SP1, Creeks upstream SP2 and the Anglesea River.

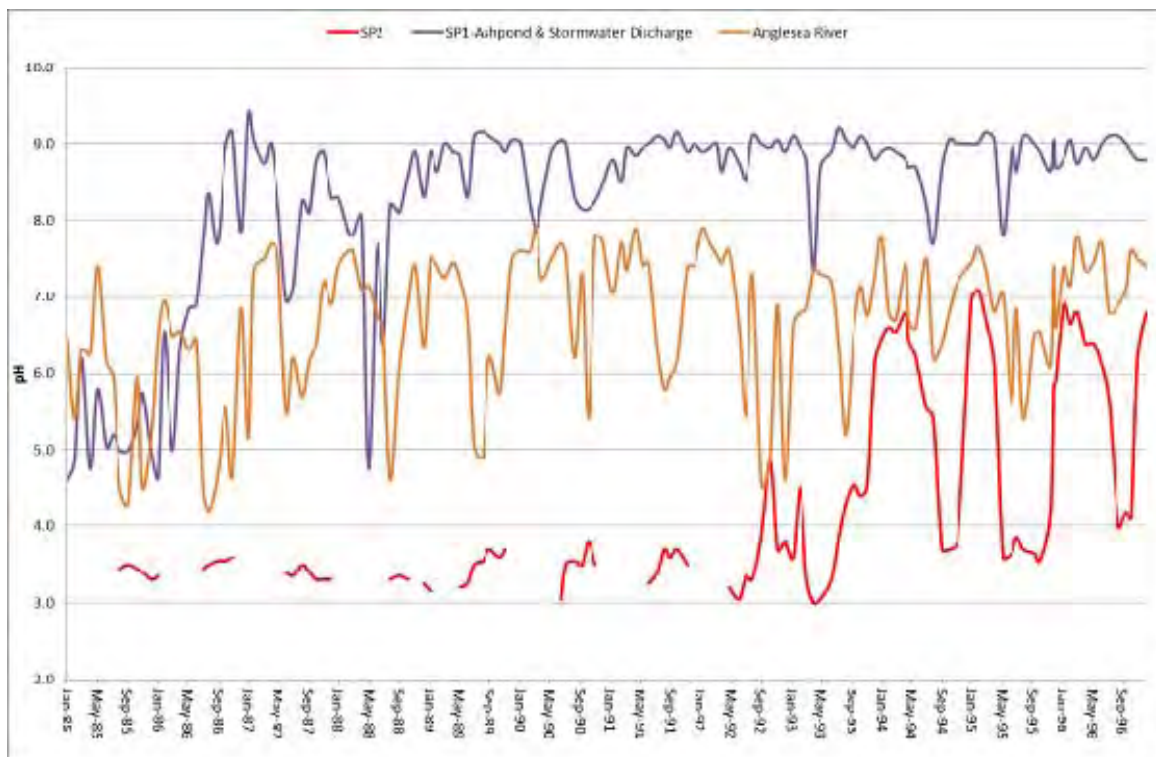


Figure 72. Alcoa pH monitoring data for period 1985 to 1996, for the Alcoa discharge SP1, Creeks upstream SP2 and the Anglesea River.

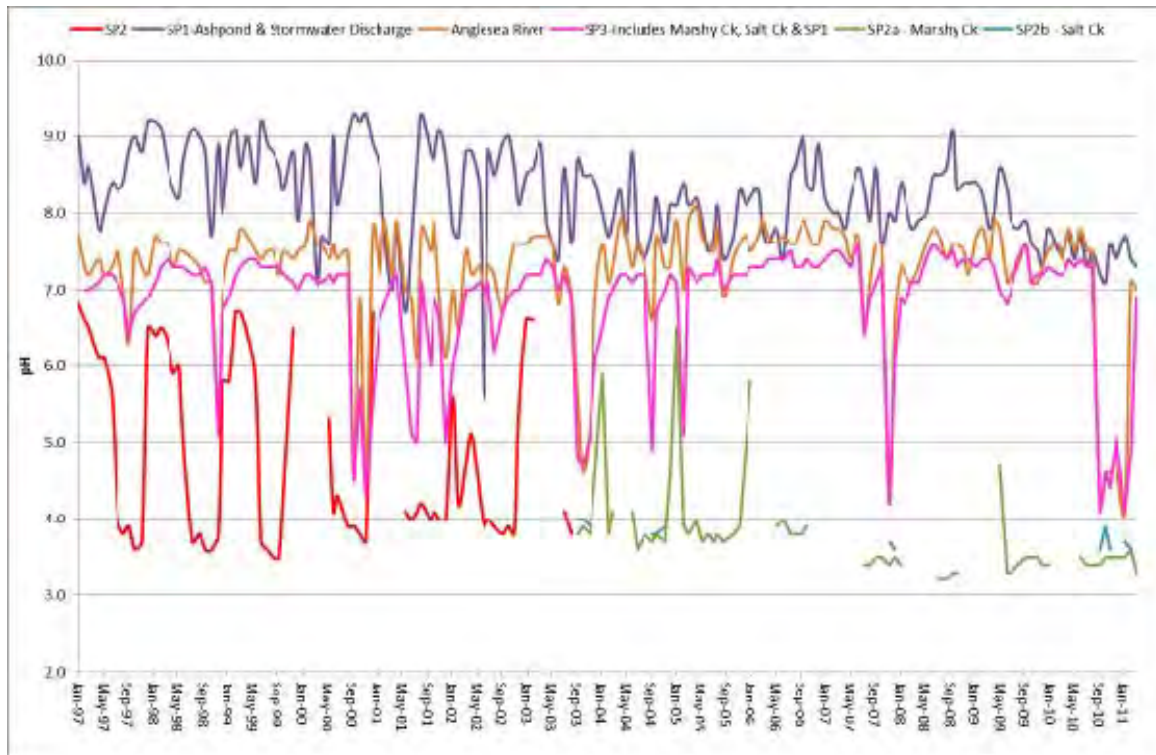


Figure 73. Alcoa pH monitoring data for period 1997 to 2011 for the Alcoa discharge SP1, Creeks upstream SP2 (until 2003), SP2a Marshy Creek, SP2b Salt Creek and the Anglesea River.

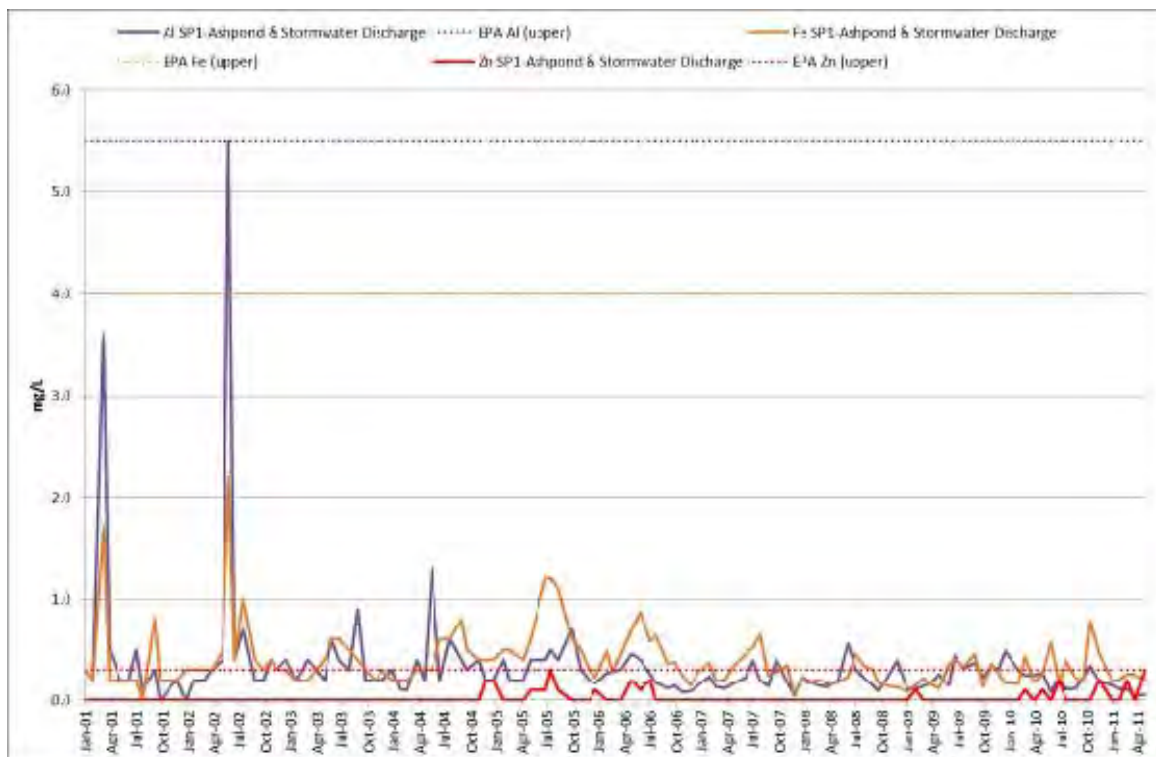


Figure 74. Alcoa discharge monitoring results for aluminium, iron and zinc from 2001 to 2011.

Data on the relative proportions of water sources (i.e; stream flow versus discharge) over time have not been measured. Pope (2006) and Parsons (2011) noted most 'base flow' water entering the estuarine system is from Alcoa's ash pond discharge.

On approximately four occasions between 2008 and 2010, water (bore development water from the lower EVF) from Barwon Waters' bore project was discharged into Alcoa's ash ponds in accordance with terms and conditions agreed by Barwon Water, Alcoa and the EPA.

Conclusions

The pH of Alcoa in the range of pH 7-8 is not the source of low pH water in the Anglesea estuary. Alcoa discharge contributes trace metals to the Anglesea River (Al, Fe, Zn).

Key Points

Alcoa has the only EPA licensed discharge in the Anglesea catchment.

The discharge is to the Anglesea River downstream of the power station / mine site. The discharge is approximately 4ML/d and is made up of cooling tower water, storm water and ash dam water.

Alcoa's discharge has a significant influence on the dynamics of the Anglesea River estuary, in terms of hydraulics, flows and quality.

The pH of Alcoa in the range of pH 7-8 is not the source of low pH water in the Anglesea estuary.

Alcoa discharge contributes trace metals to the Anglesea River (Al, Fe, Zn).

On approximately four occasions between 2008 and 2010, bore development water from the lower EVF from Barwon Waters' bore project was discharged into Alcoa's ash ponds in accordance with terms and conditions agreed by Barwon Water, Alcoa and the EPA.

Knowledge Gaps

Data on the relative proportions of water sources (i.e; stream flow versus discharge) over time.

The majority of land in the Anglesea catchment falls under Alcoa mine lease (7,221 Ha), of which 90% is a reserve with similar status as a National Park and is managed in conjunction with Parks Victoria (Alcoa EIP 2008). The total catchment has an area of approximately 12,000 Ha. Other land uses include built environment (township), mining, Great Otway National Park, other parks and agriculture.

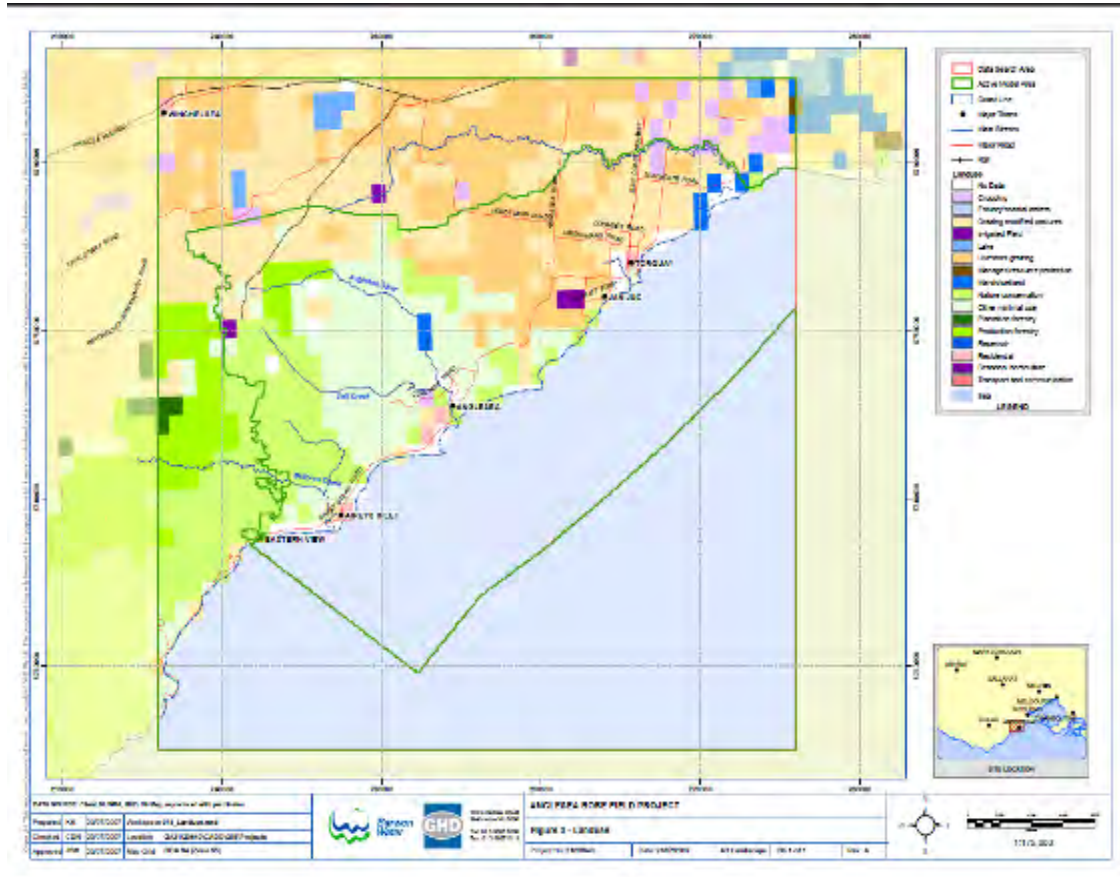


Figure 75. Map of land use from Barwon Waters / GHD hydrogeological review as part of the Project Impact Assessment.

In work completed by Sherwood et al (2004) on the Anglesea estuary, a breakdown of catchment land use was calculated as minimal use 61%, nature conservation 22.8%, forestry 7.1%, dry land agriculture 4.4%, built environment 4.2% and the remaining 0.5% unclassified.

A detailed breakdown of contemporary catchment land use has not been located during the review.

The following subsections discuss some specific land uses that may significantly disturb the catchment and potentially contribute to catchment acid drainage and/or be a source of trace metals.

6.4.1 Resource Extraction – gravel and sand mines

The catchment's gravel and sand resources have been mined for decades. The geological survey map from the 1960s (Figure 76) shows gravel mines at many locations in the catchment, including where mining occurs today in the upper EVF adjacent and bordering the rivers in the catchment.

Limited information has been gathered on the current quarry operations on the northern bounds of the Anglesea River catchment. The quarries are mining gravel from the upper EVF. The hydrogeological review (GHD 2008) lists the quarry as is licensed to extract 250 ML/year of groundwater from the LEVF for industrial purposes. The location of the quarries is shown in Figure 76 and current extractive industry tenements (including area) are shown in Table 6.

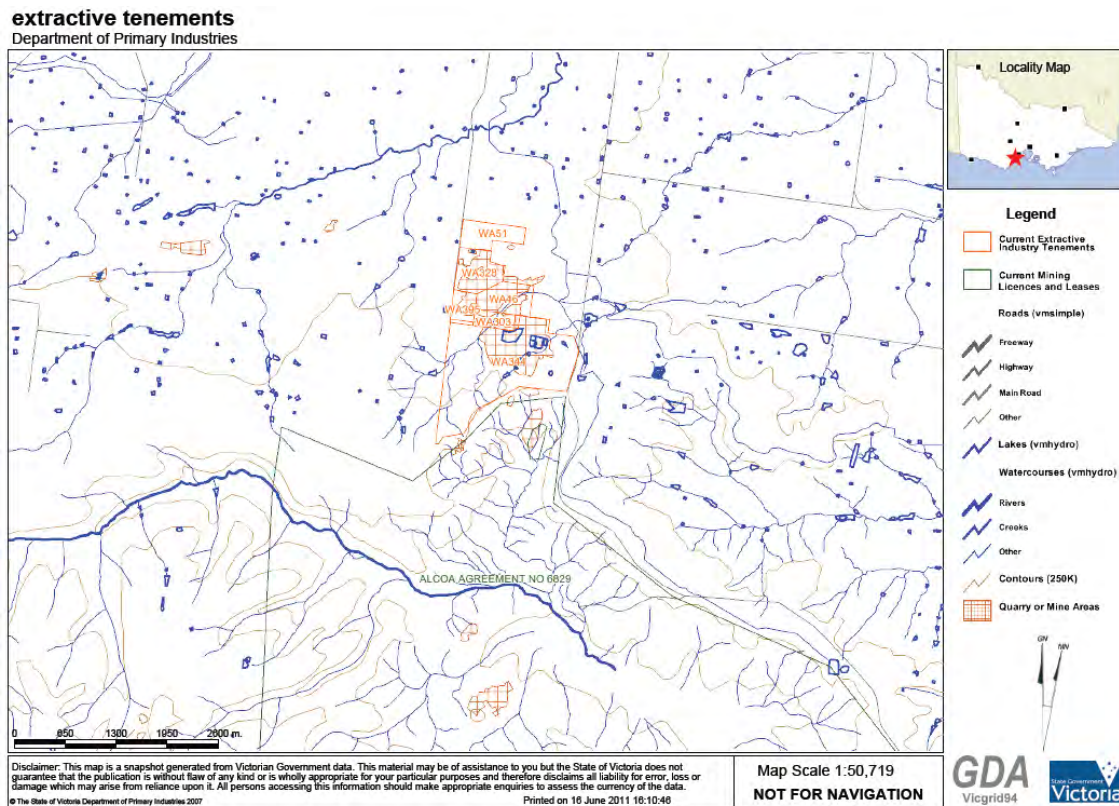


Figure 76. Extractive Industry (gravel and sand mines) tenements adjacent to and boarding the upper reaches of the Anglesea River catchment.

Table 6. Extractive industry tenements in the upper EVF adjacent / bordering the Anglesea Catchment.

Current Extractive Industry Tenements						
Mining Tenement ID	Type Description	Owner	Current Area	Land Status	Mineral Rights	Residual
LAM1	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM2	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM3	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM4	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM5	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM6	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM7	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM8	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM9	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha
LAM10	Open Pit	Alcoa of Australia Pty Ltd	2,000 Ha	Open Pit	Open Pit	2,000 Ha

The process of mining or quarrying can disturb acid sulphate soil and rock (as per EPA 2009) and affect the hydrological cycle in a number of ways including;

- Excavation;
- Altering evapo-transpiration (land clearing / removal of vegetation);
- Altering run off and infiltration rates (change of land form shape and exposure of different geological strata);
- Altering intersected water tables; and
- Altering water tables via groundwater extraction.

The hydrological review (GHD 2008) in its model of catchment recharge shows the existing gravel mining areas have a significantly higher recharge rate than adjacent land (Figure 77). The reason is not provided is most likely due to reduced evapo-transpiration rates for a quarry land use category.

The total area of tenements is 266 Ha and actual mined area approximated from the hashed areas (Figure 77) is 100 Ha. For comparison, Alcoa's brown coal mine has a hashed area of approximately 150 Ha.

The proximity of the mines to gullies and watercourses in the Anglesea catchment is significant. As complex hydrogeological conditions make it difficult to predict aquifers and groundwater flow paths, it is possible that recharge in the quarried area (150-300mm x 100 Ha = 150-300 ML) could make its way through the Anglesea Catchment. Assuming pyritic material is present in the geology around the quarries, there is potential for acid generation and transport. Also, given the area's relative height to surface water courses and the Anglesea River 'recharge' may connect or interact with surface waters.

The effects of previous quarry operations in the catchment are little known, although during operation or when vegetation was absent, increased infiltration rates were likely, and therefore potential rates of acid generation and transport may have been higher around a quarry.

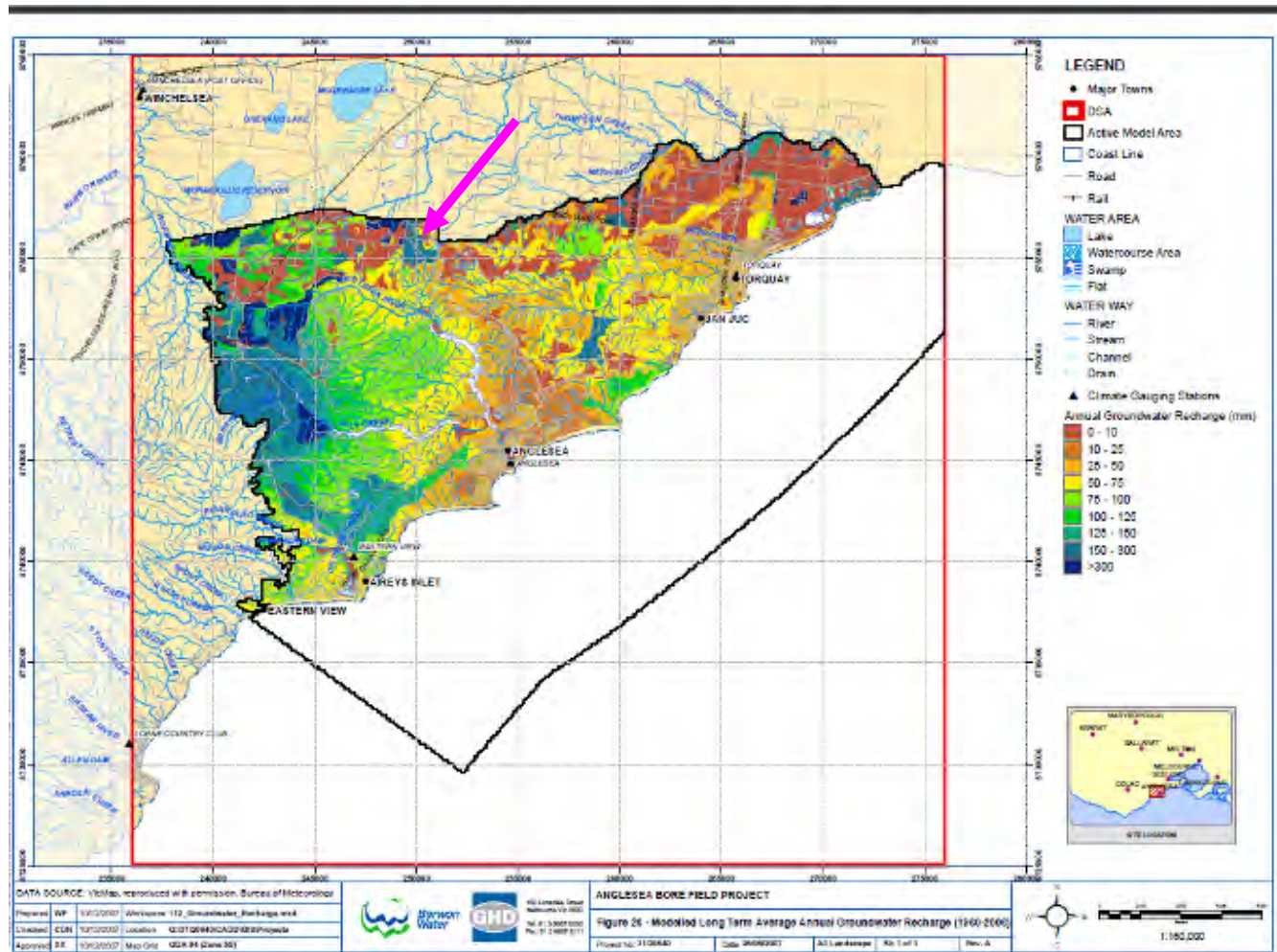


Figure 77. Map showing modelled recharge rates of the EVF, quarries indicated by red arrow (GHD 2008).

Conclusions

Gravel mining has major potential to promote acid generation and transport given the extent of gravel mining, significantly higher recharge rates, proximity of the mines to gullies and watercourses, and relative height compared to surface water courses.

Key Points

Most land in the Anglesea catchment falls under Alcoa mine lease (7,221 Ha), 90% of which is a reserve with similar status as a National Park and managed in conjunction with Parks Victoria (Alcoa EIP 2008).

Other land uses include township, mining (quarries), other parks in the Great Otway National Park and agriculture.

In 2002, the breakdown of catchment land use was calculated as minimal use 61%, nature conservation 22.8%, forestry 7.1%, dry land agriculture 4.4%, built environment 4.2% and the remaining 0.5% unclassified.

Gravel and sand resources are mined at many locations in the catchment (266 ha), including the upper EVF adjacent and bordering the rivers catchment and licensed to extract 250 ML per year.

Quarrying can disturb acid sulphate soils and rock.

Existing gravel mining areas have significantly higher recharge rates than adjacent land.

Given the proximity of the quarries to the Anglesea catchment recharge could be significant.

Given the area's relative height to surface water courses and the Anglesea River means 'recharge' may connect or interact with surface waters.

Assuming pyritic material is present in the geology around the quarries, there is potential for acid generation and transport.

Knowledge Gaps

Effects of groundwater extraction and quarrying on generation of acids and trace metals export.

6.4.2 Previous Coal Mining

The Roche mine open cut coal mine was located at the lower end of the Salt Creek catchment (see Figure 78). Details of the mining operation are limited but production of coal occurred in the late 1950s and early 1960s. Mining may have caused acid drainage by draw down of water tables, and excavation and exposure of pyritic materials. The 1977 1:25,000 topographic map of Anglesea (Figure 78) clearly shows the mine area with water bodies present. The mine (white area) is approximately 1km long on a south west–north east axis and up to about 500m wide, and the larger water body is approximately 300m long and 100m wide. The Roche mine is also shown in coal seam mapping (Figure 79) to the west of the existing Alcoa mine, and Holdgate (2001) reports that extracted coals were from the B and C coal seams, and from two pits (which may explain the two lakes in the topographic map).

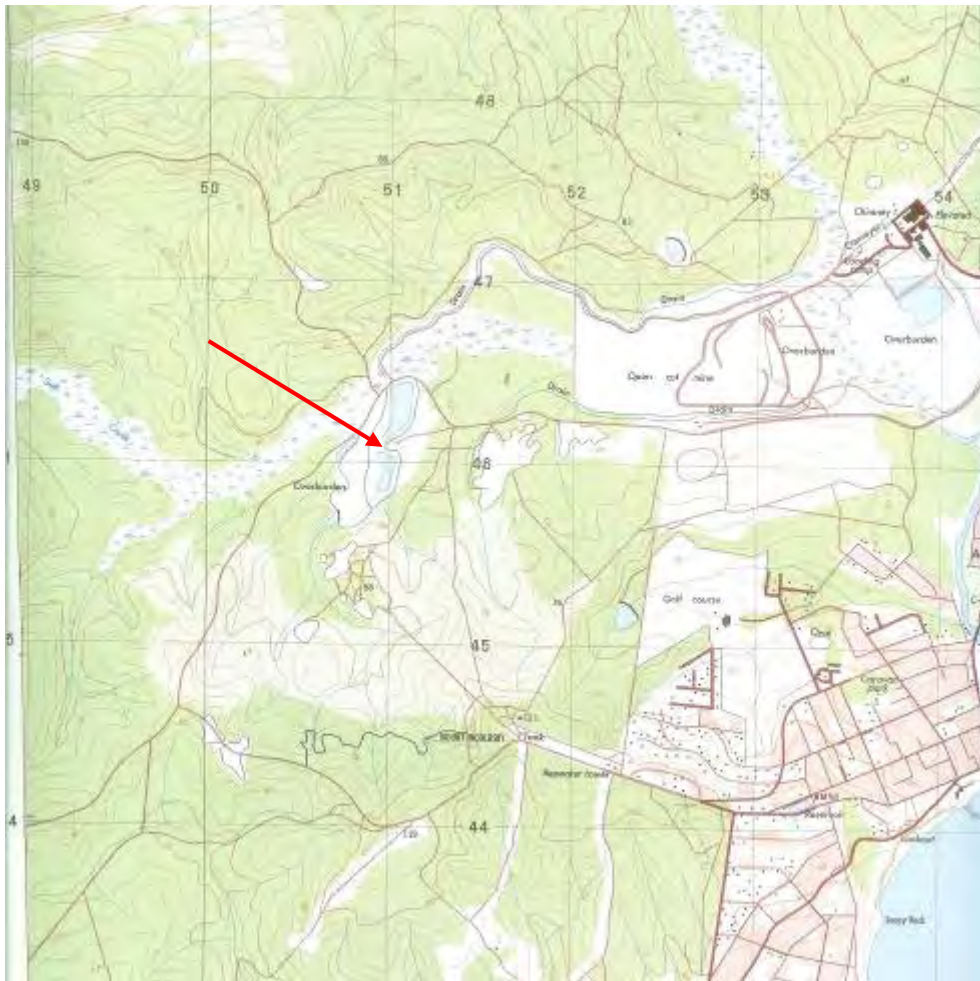
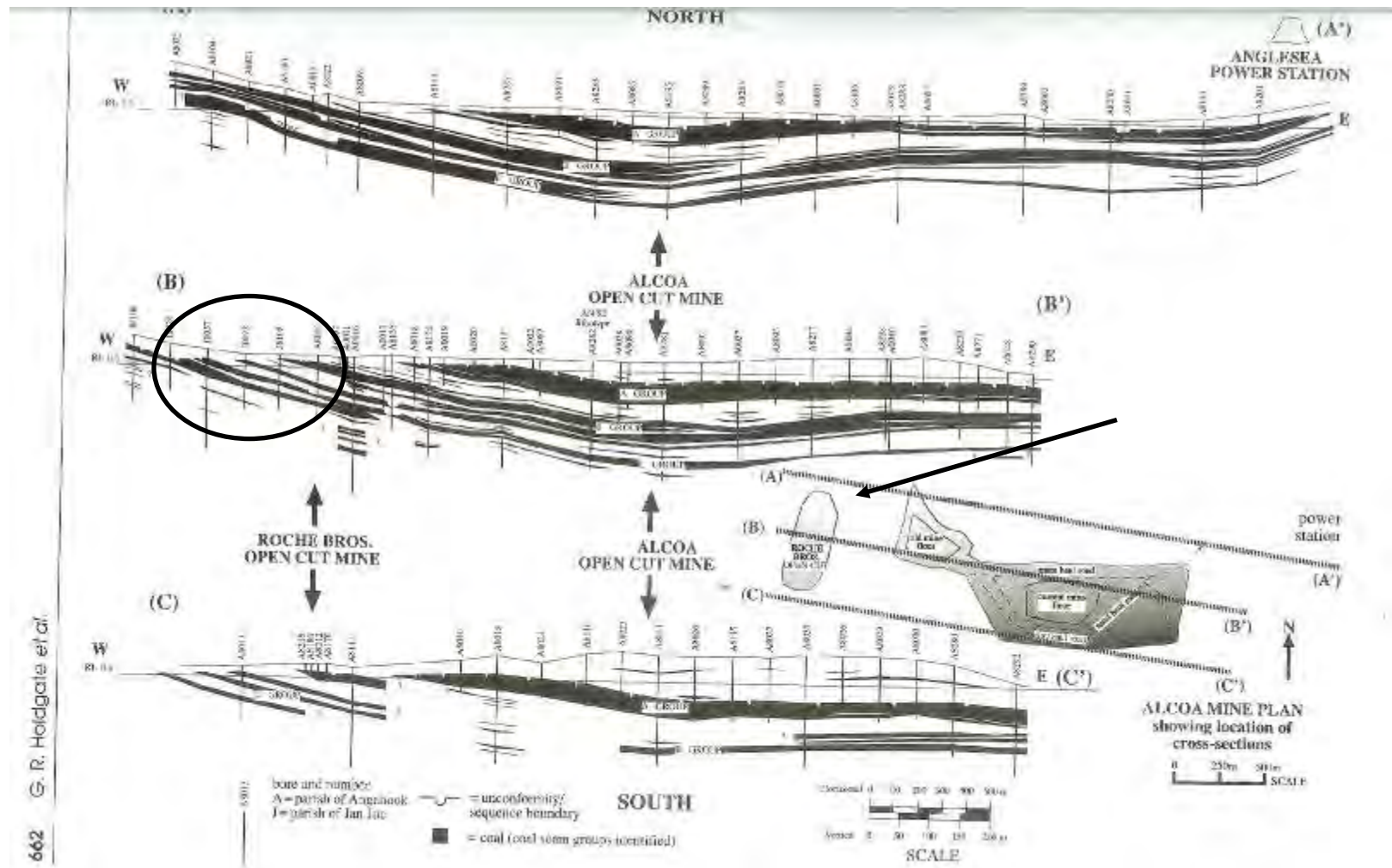


Figure 78. The Anglesea 1977 topographic map (1:25,000) showing the old Roche coal mine west of Alcoa's current mine.



Details of backfilling of the old Roche mine are limited but it is described in Heritage Victoria (2008). *“Backfilling of the old Roche Brothers open cut was used to minimise external dumps at ground surface and to facilitate rehabilitation of the old open cut. In general, backfilling had power station ash placed in the bottom of the worked out mining areas, superimposed with the sand and clay overburden. Final landscaping used sandy topsoil and its buried seeds recovered from stockpile.”*

Given that the old Roche mine has been backfilled, pathways for continuing exposure and oxidation of pyritic materials will have been significantly reduced. The extent to which this past coal mine operation may affect present acid drainage is uncertain, and must be taken into context with the catchment wide acid drainage.

The open pit mine may have initiated some acid generation both in the swamps (from general disturbance caused by excavation and drainage), and in the coal seams from exposure. Acid generation, once started, can continue for many years and an example of this in the region is the old Wensleydale Coal Mine (now lake) studied by Tutt (2008) which is still acidic (pH 5) after 40 years. The open pit may have also have created a lens or “hole” in local aquifers, the effects of which are unknown. As seen in the topographic map, both pits became water bodies and depending on the stratigraphy, may have opened a path or leakage route between previously more isolated aquifer units. The backfilling process will have “plugged” the void to some degree, but if substantial sand was used to fill the mine void its influence is still unknown. As previously mentioned in section 6.2.2, Barwon Water investigations have reported the perched water table characteristics of the swamps and their general good health. Furthermore they make the observation that the swamps are still in good health after 40 years of Alcoa groundwater extraction from the upper EVF. Conceptually, if a leak is present in the Salt Creek swamp’s perched water table, perhaps over time the leak may have a measurable effect, and this may explain why Salt Creek flows are more irregular than Marshy Creek (i.e; the Salt Creek marsh “sponge” is drained more than Marshy Creek’s due to the increased connectivity between its marsh perched water table and other aquifers of the upper EVF). However, as discussed previously, the Salt Creek Catchment extends over the 3 sub units of the EVF and the geological difference may be a greater explanation to the difference in flows observed in Salt Creek and Marshy Creek.

Water quality data (Hermon 2001 and EPA 2000 event data) indicates differences between the Salt Creek and Marshy Creek systems. This has led to the hypothesis that the previous Roche coal mine and filling the void with ash (which is high in aluminium and sulphates) may be having an effect on acid generation. Sampling at the location called Bald Hills/ No 2 Road (also the end of the Salt Creek marshes before flow is directed into the diversion channel) generally returns higher sulphate and aluminium results, when compared to other sites in the catchment, including from further up the Salt Creek catchment, at SF3 and SF4 (see Figure 29).

However, the general process of acid drainage from the greater catchment’s geology is also indicated by water quality data, and taken into context. Alcoa monitoring at the time of the 2000 estuary acidification event also measured low pH (3.4), high sulphate and aluminium levels (340 and 36 mg/L) in Salt Creek well upstream (4 - 5 km) of the Roche mine (see section 6.2.1.). EPA testing from the 2000 (27/9/00) event for Distillery Creek, the adjacent catchment to the west of Salt Creek (same geological setting) recorded a pH of 3.66, and sulphate and aluminium concentration of 580 mg/L and 58 mg/L respectively.

Possible influences of the old Roche mine on water flow paths and also as a possible source of aluminium and sulphate, as measured at the Bald Hill/No 2 Rd sampling point is shown in Figure 80.

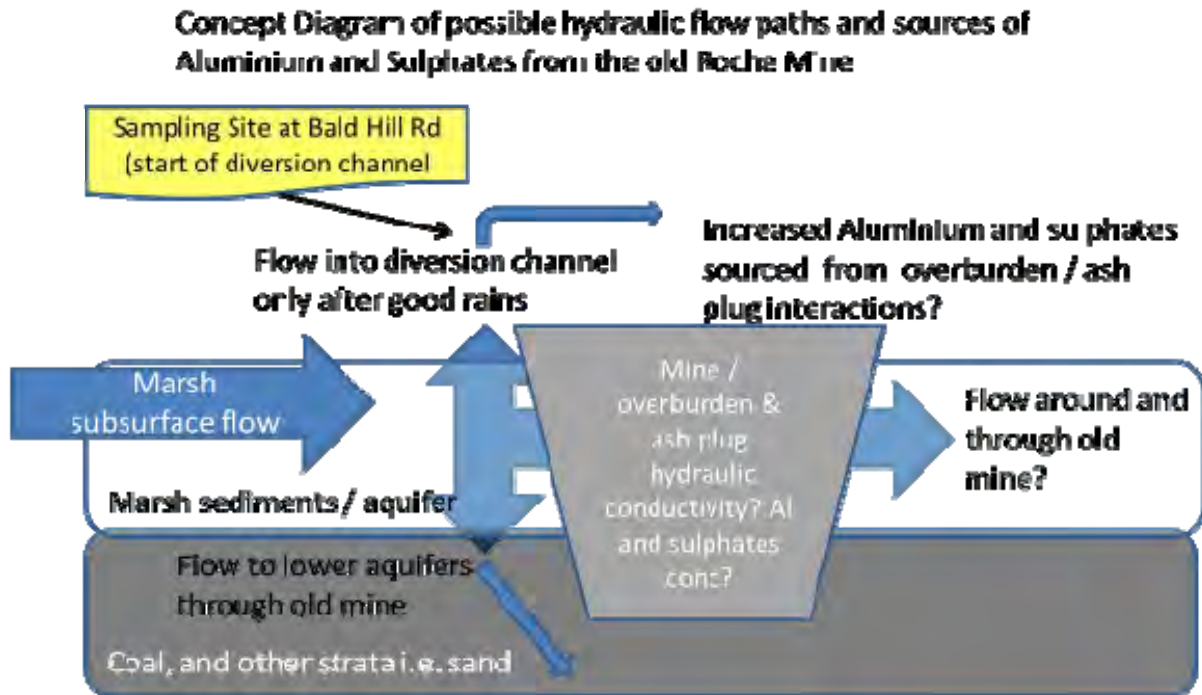


Figure 80. Concept diagram of possible hydraulic flow paths and sources of aluminium and sulphate from the old Roche coal mine.

As outlined in Figure 80 and in the description provided of the backfilling of the old mine, and taking into account the complexities of the local geology, possible flow paths of water in the Salt Creek sub catchment post-mining have likely been altered. Although the old mine has been filled and revegetation is progressing, uncertainties exist regarding how and how much this feature may have altered the local aquifers, caused acid generation (during its operation) and be a possible source of aluminium and sulphates (detected at an adjacent sampling point by Hermon 2002).

Without further information and data it is difficult to draw conclusive explanations about possible effects of the old mine. Reference can be made to nearby old Wensleydale coal mine, now a lake which has not been backfilled but has clearly altered the local environment.

Conclusions

The Roche coal mine was filled with ash and may be a source of aluminium (and other trace metals) leaching from ash used to fill the mine. However, relative to catchment wide acid drainage and metal sources, its contribution is likely to be small and unlikely to be a major source.

Key Points

The Roche open cut coal mine was located at the lower end of the Salt Creek catchment. Details of the mining operation are limited but production of coal occurred in the late 1950s and early 1960s.

Previous coal mining operations may have increased localised acid generation by draw down of water tables, and the excavation and exposure of pyritic materials..

Given the mine has been a backfilled, pathways for continuing exposure and oxidation of pyritic materials will have been significantly reduced.

The mine may have affected local hydrogeological conditions.

The open pit mine may have initiated some acid generation in the swamps (from general disturbance caused by excavation and drainage) and in the coal seams from exposure. Once acid generation has started it can continue for many years.

If a leak is present in the swamp's perched water table, over time the leak may have a measurable effect and this may explain why Salt Creek flows are more irregular than Marshy Creek.

Water quality data indicates differences in the Salt Creek and Marshy Creek system, which has led to the hypothesis that the previous coal mine and filling with ash (high in aluminium and sulphates) may be having an effect.

Knowledge Gaps

The effects of the mine on hydraulic connectivity between aquifer units.

The effects of the old coal mine and backfill including ash on localised acid generation and contribution to aluminium and sulphates in Salt Creek.

6.4.3 Coogoorah Park

Coogoorah Park (Figure 81) is described in the Anglesea estuary management plan as “a series of channels created to let water from the river extinguish peat fires post the 1983 Ash Wednesday bushfires” (Surf Coast Shire 2004).



Figure 81. Anglesea estuary aerial photo – Coogoorah Park indicated by red oval (Source Anglesea EMP 2004).

Coogoorah Park is best described as a coastal peat swamp, and as such, has a similar process of acid generation as discussed in section 4.2.2.

Given the park's history, size and location, and the fact that it apparently does not dry out due to ongoing Alcoa inputs, it is unlikely that the park is a significant source of acid in the system. However, no soil test or local water table measurements have been identified as part of the review to more accurately confirm the condition of the park sediments.

Conclusions

Given the scale and location of the park in the river/estuary system, it is unlikely the park is a significant contributor to estuary acidification.

Key Points

Coogoorah Park is described in the Anglesea estuary management plan as “a series of channels created to let water from the river extinguish peat fires post the 1983 Ash Wednesday bushfires.

The park can be described as a coastal peat swamp and is therefore likely to have acid generating potential.

Given the history, size, location, and the fact that the park does not “dry out” it is unlikely that Coogoorah Park is a significant source of acid in the system.

Knowledge Gaps

The sulphide profiles of Coogoorah Park soils, local water tables and soil moisture profiles as an indicator to acid sulphate soil potential.

6.4.4 Anglesea Landfill

The Anglesea landfill has been in operation for decades. Exact operational details are unknown but leachate is completely contained onsite. It is currently operated under an EPA license, including regular environmental monitoring of leachate leakage. Its location is shown in Figure 82.

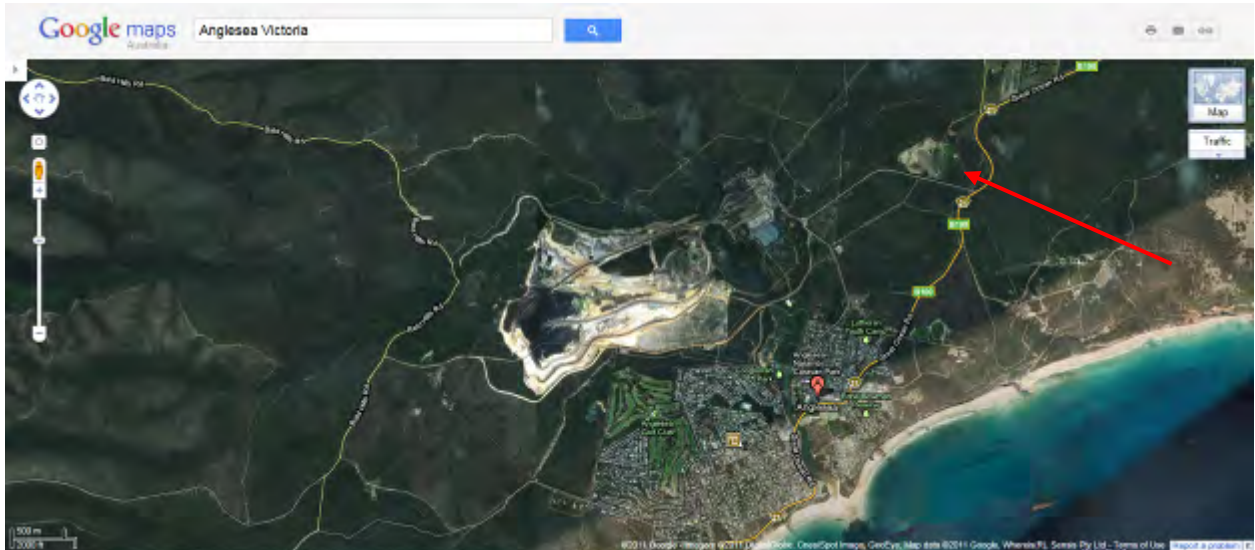


Figure 82. Image showing location of Anglesea landfill (red arrow), relative to the power station, coal mine and township (Google Maps).

As part of our site visits the manager of the landfill site communicated that the leachate treatment system is designed to completely contain leachate on site and regular environmental monitoring is undertaken of leachate leakage is undertaken.

A 2010 groundwater report by Coffey Environmental (sections of the report provided to the review by the EPA) states that "...concentrations of ammonia and arsenic preclude one or more beneficial uses within the vicinity of the site and are potentially associated with landfill activities. However, it is unlikely the beneficial uses will be negatively impacted given the following:

- Current use of the site as a landfill
- Distance to the Anglesea River
- Distance and depth of the aquifer used for the Barwon Water extractive bore field; and
- The cost involved for private bore installation when groundwater is at depths such as those observed on the site."

A 2007 report by Hyder noted some indicators of leachate plume in the immediate vicinity of the landfill and that further review of the landfill is underway in a detailed hydrogeological report. The report also noted the proximity of the landfill to Alcoa's operation, and the effect that groundwater extraction may have on explaining the steep hydraulic gradients observed.

Conclusion

The landfill is not a significant source of acid or trace metals to the Anglesea River.

Key Points

The Anglesea landfill has been in operation for decades.

Leachate treatment system is designed to completely contain leachate on site and regular environmental monitoring of leachate leakage is undertaken.

Environmental monitoring and reports acknowledge some effect of the landfill on groundwater in the immediate vicinity.

Knowledge gaps

Extent of leachate plume and risk of plume interacting with surface waters / reaching the river.

Possible surface water runoff from site (possibly contaminated) due to rain.

7 Remediation options

Considerable work has been undertaken on the management and treatment of acid water either from acid sulphate soils or from acid mine drainage. The knowledge the mining industry has built up on the subject may be a logical start for further investigations on “remediation of poor water quality originating from the catchment”.

In the 2010-2011 event, ideas such as opening the estuary to introduce more sea water in were presented by some community members, and subsequently CCMA contracted a computer modelling of the idea to test its possible effectiveness (Water Technology 2010).

As discussed, it would appear that acid events are, and will continue to be natural and ongoing, and it is highly likely that “severe” events that have social impacts, such as fish kills and recreation restrictions, will occur in the future.

Options for possible solutions to the problem including the primary problem of water with low pH are outline in Table 7. Historically, it seems that the estuary does ‘recover’ over time without intervention (i.e; fish deaths in 2000 and 2010) but the time for recovery may be considered an issue by community members.

Table 7. Options for Anglesea acidic flows.

Option	Details	Comment
Do nothing	Periodic severe estuary acidification resulting in fish deaths, and associated social and financial impact for the community.	Improved response plans, including importantly community education and awareness. Issue: needs to be socially acceptable.
Refuge constructed	- Provision of pools/branches in the estuary that are semi-isolated from severe acid flushes. (i.e; the rate of water quality change is less rapid, providing for higher survival rates, and therefore quicker recovery rates	Recently developed model to be used to identify current and possible zones for refuge. Issues: practicality and cost.
Refuge constructed with increased buffering capacity	- As above, with the addition of alkaline rock (i.e; limestone) beaching and/or porous berms. The flow into and out of refuge may be through or over a constructed limestone berm (with fish passage either through or over). Concept to draw upon	As above and further investigate concept. Issues: practicality and cost.

	passive treatment systems.	
Buffer estuary (such as pumping sea water or opening estuary)	Increased estuary volume may provide a buffer to “acid events”, as sea water is naturally highly buffered. Option may include deepening or broadening the estuary.	Use existing model to run scenarios. Issues: practicality, cost and ecological modifications.
Buffer estuary	Installation of alkaline beaching / berms throughout estuary (see passive treatment systems)	Localised buffering around rocks only Issues: practicality, cost and ecological modifications
Treat – flow	Numerous options.	Calculate or model, recent flow volumes and reassess. Issues: Likely to be impractical or unfeasible, due to large volumes of water likely in a severe event. Cost and ecological modifications.
Store – release	Similar to a flood mitigation dam, a storage could be constructed to store large acid flows, which then could be regulated and released over time reducing the severity of the “acid event”.	Investigate further – significant earthwork ongoing as part of mining operation, that could incorporate a dam of sorts. Issues: Likely impractical and or unfeasible, due to large volumes of water likely in a severe event. Cost and ecological modifications.
Store – treat and release	As above with a treatment system, natural or conventional chemical, to treat the release prior to it entering the estuary. (see treatment section)	As above
Store, dilute / buffer / treat release	As above with investigations into using other water sources such as the Alcoa ash ponds water to dilute / buffer / treat the acid flow. The storage could also incorporate natural acid treatment systems such as wetlands and bioremediation via organic sediment stratum.	As above
Other – treatment of Salt Creek sub-	Investigate options for incorporate a treatment	Issues: practicality, cost and ecological modifications.

catchment using existing diversion drain	component into existing diversion drain, such as open or closed limestone drains. Expansion of the drain or diversion through a constructed wetland may also be investigated.	
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Conclusion

As shown in Table 11, there are a number of options for acidity management in the Anglesea estuary, but each option would need further investigation before any real comparison or recommendation could be made on what is most appropriate, effective or realistic when evaluated according to triple bottom line assessments. Also, all options have short and long term ecological consequences that may be worse than letting nature take its course.

A comprehensive discussion of options listed above is outside the scope of this report. However, each option would need to be considered in depth. For example although treatment of water at its source, with lime to raise the pH may appear to be an attractive option, the freshwater ecology of the tributaries and river may be changed irreversibly as the ecosystems in these waterways are adapted to periods of low pH.

It is recommended that investigating remediation options would involve assessing each option in terms of viability, appropriateness, cost effectiveness and any potential social, economic and environmental impacts.

If remediation of acid and trace metal inputs (at the source or in transit) is not feasible then estuary management options such as opening of the estuary to allow fish to escape need to be considered. However, this also will require a thorough understanding of the hydrology and ecology of the estuary and social and environmental consequences

8 Summary

Summaries are provided in sub sections following.

8.1 Summary of conclusions

4 Acid: history, sources, generation and transport

4.1 Acidification history – Anglesea River

Anglesea River, its tributaries and the estuary experience frequent acidic water quality (pH 3-4) or acid flows which have been documented since 1972 when regular monitoring began.

4.2.1 Geology – coal and pyrites

The catchment has the necessary geology and acid generating capacity above the water table and above creek and stream levels to explain the low pH of stream waters.

The acid generation potential of coal and pyritic strata within the catchment, and connectivity between potential acid producing strata and waterways, needs investigating to fully understand acid generation within the catchment.

4.2.2 Tea Tree Marshes (swamps)

The extent of sulphide contents and drying out must be known before the marshes' acid contribution in the catchment can be determined. How any drying may have occurred (ie; climate variation, historical or current mining operations or groundwater extraction) is difficult evaluate without relevant data.

4.2.3 Potential artificial sources of acidification: Deposition of SO₂ from smoke stacks

The acidification resulting from SO₂ released by the Anglesea power station seems low and represents a small proportion of the total acidification compared to the natural processes occurring in the catchment.

4.3.1 Acid Transport and fish death events

Rainfall intensity and timing is the key determinant of whether or not an acid flush occurs.

An acid flush is likely after an extended period of low rainfall or drought.

Quantification of infiltration and recharge rates in the Anglesea catchment, and flows in tributaries and the Anglesea River, should provide an insight into the acid flush mechanism.

5 Dissolved Metals

Four sources are likely to be contributing trace metals to the estuary; natural sources, the old Roche mine, activities associated with coal mining and power generation activities (ash pond effluent and coal burning) and storm water runoff from the Anglesea township.

Natural sources are contributing the most aluminium, especially during periods of high flow. However, at periods of low flow the ash pond discharge is probably the source of aluminium

(and other trace metals).

The relatively small amounts of trace metals deposited over the catchment from emissions from coal burning will become bound to vegetation, clays and organic rich soils, which makes this an insignificant source to the estuary.

Flow and specific trace metal concentrations data isn't synchronized or comprehensive enough to accurately estimate the contribution of trace metals by each source.

Boron concentrations regularly exceed the ANZECC/ARMCANZ (2000) trigger levels for protection of moderately disturbed freshwater ecosystems. Both natural sources and ash pond effluent contribute boron to the Anglesea River. Boron concentrations are naturally high in seawater and should not constitute a problem in estuary to marine life.

At low flows, flocculation occurs in the zone where the Salt and Marshy Creeks and ash pond effluent mix, as well as in the upper parts of the estuary.

During high flows, some (if not all) this flocculated material would be expected to be re-solubilised during flood events as the pH and salinity drop.

During high flow, if a layer of fresh water exists over the more saline estuarine water, flocculation will occur where the freshwater meets the seawater. Flocculation will occur as far as the layer of freshwater extends into the estuary. Also, if fish are in the low pH water, flocculation may well occur on the gills of fish.

6 Specific items of concern that may influence acid generation

6.1 Fire

Fire can cause changes in evaporation and transpiration rates and alter soil properties. This can then affect run-off and infiltration. Water infiltration is the key to acid generation and transportation.

Further investigation is required using available data on climate, rainfall, water flow and water quality for up to 10 years after the fire to fully understand the influence of fire and implications of any fire management plan using controlled burns.

6.2.1 Pumping by Alcoa

Alcoa pumping probably had little effect on acid drainage from the greater catchment because pyritic material exposed in the cone of groundwater depression is unlikely to contribute acid into surface water systems. However more information should be collected on the potential drying out of surrounding marshes and the wider catchment area.

6.2.2 Pumping by Barwon Water

Bore field extraction may alter groundwater levels in the EVF and therefore interactions with surface water, altering water tables and creating effects such as drying out of swamps and acid generation in acid-sulphate soils.

The current groundwater model is not well calibrated enough to predict impacts and therefore not considered a reliable model. Further investigation and updating the model is necessary.

6.3 Licensed Discharges

The pH of Alcoa in the range of pH 7-8 is not the source of low pH water in the Anglesea estuary.

Alcoa discharge contributes trace metals to the Anglesea River (Al, Fe, Zn).

6.4.1 Resource Extraction – gravel and sand mines

Gravel mining has major potential to promote acid generation and transport given the extent of gravel mining, significantly higher recharge rates, proximity of the mines to gullies and watercourses, and relative height compared to surface water courses.

6.4.2 Previous Coal Mining

The Roche coal mine was filled with ash and may be a source of aluminium (and other trace metals) leaching from ash used to fill the mine. However, relative to catchment wide acid drainage and metal sources, its contribution is likely to be small and unlikely to be a major source.

6.4.3 Coogoorah Park

Given the scale and location of the park in the river/estuary system, it is unlikely the park is a significant contributor to estuary acidification.

6.4.4 Anglesea Landfill

The landfill is not a significant source of acid or trace metals to the Anglesea River.

8.2 Summary of key points

3 Context

The Anglesea River, its tributaries and the estuary, experience periods where water quality is acidic (i.e. has low pH). Some of these acid periods result in fish deaths. Deaths were documented in 2000, 2007 and spring 2010 to autumn 2011.

After a fish death event in the Anglesea River estuary on 13 September 2010, EPA investigations found estuary waters were pH 4 and similar, or lower, pH measurements were recorded in the rivers and streams upstream in the catchment.

Fish deaths in the Anglesea River estuary were probably caused by a combination of pH stress, aluminium toxicity and suffocation as a result of gills being smothered by precipitated aluminium compounds.

4 Acid: history, sources, generation and transport

4.1 Acidification history – Anglesea River

Water quality data dating back to 1972 indicated numerous estuary acidifications to pH 4.

Monitoring from October 2010 to February 2011 by Frank Parsons (2011) shows similar results to the historical measurement of pH in Salt and Marshy Creek tributaries and in the Anglesea

River above the Alcoa discharge.

4.2.1 Geology – coal and pyrites

In the Anglesea catchment potential natural sources of acid are tea tree marshes (swamps), mineral coal deposits and pyritic strata, including marcasite (a form of iron sulphide) bands.

Substantial coal deposits extend throughout the Marshy and Salt Creek catchments under the valley swamps and in the hills.

Coal was mined in the lower reaches of Salt Creek west of the current mine in the late 1950s early 1960s. This indicates that coal reserves are located in the current valley floor, and that disturbance of the swamp and coal occurred at this site. This makes it highly likely that acid generation occurred in the lower reaches of Salt Creek.

Coal is known to be acid generating and other pyritic strata, including bands of pyrite, have been recorded.

The known presence of coal and lignitic strata associated with the Eastern View Formation, and the known sulphur content of coal deposits and possibly other strata (marcasite bands), means it is likely that the catchment has significant acid generating capacity.

4.2.2 Tea tree marshes (swamps)

Marshes are likely to have acid sulphate (pyritic) materials present in their sediments and are therefore a potential source of acid.

If marshes are disturbed by a lowering of the water table they dry out and can become acid generating.

The marshes only cover a small percentage of the total catchment area (approximately 2%) and are unlikely to be a major source of acid.

The marshes in the catchment appear to be perched, so the significant cone of groundwater depression around the mine and power station appears not to have “drained” the marshes over the last 40 years of Alcoa’s operation.

A larger decrease in chloride/sulphate ratios through Salt Creek marshes compared to Marshy Creek’s marshes, plus more intermittent flows from the Salt Creek catchment, may indicate some drying out of acid sulphate marsh sediments.

4.2.3 Potential artificial sources of acidification: Deposition of SO₂ from smoke stacks

Anglesea coal has relatively high sulphur content. This means that emissions from burning coal could contribute to acidity due to acid rain.

Once SO₂ is in the atmosphere it can undergo processes and reactions including gravitational settling, adsorption into larger particles, and reaction with atmospheric water and rain (sulphuric acid generation – acid rain).

Emissions modelling by Alcoa (atmospheric dispersion at Anglesea) indicates that of the 37Kt of sulphur emitted each year, about 1.7-3.9Kt may deposit in the Marshy Creek catchment while the bulk of emissions are blown out of the catchment.

Wind roses for nearby Aireys Inlet show westerly prevailing wind patterns, with coastal influences of afternoon sea breezes.

The Anglesea River catchment generally extends north and west from the power station site so stack emissions would mainly be deposited outside the catchment.

Measured sulphur concentrations from sites in the catchment show some deposition (wet or dry) from stack emissions.

Evidence of chloride/sulphate ratios lower than seawater in streams and tributaries indicate sulphate enrichment. However, greater sulphate concentrations in Salt Creek rather than Marshy Creek (which is in the plume area) indicate that higher sulphate concentrations may be from pyrite oxidation.

There is evidence of artesian water contributing sulphate to Marshy Creek, which has elevated sulphate concentrations.

The measurable effects of sulphur deposition on vegetation and soil are within the scale of natural variation, and adverse effects indicating substantial acid rain have not been identified.

Given Anglesea's background geological conditions, it is hard to substantiate or quantify the effects of sulphur emissions.

4.2 Acid transport and fish death events

Transportation of 'acid' from its geological sources to water courses is by infiltration of water (typically rain) into the strata, and its subsequent discharge to surface waters. Similarly, if marshes in the Anglesea catchment had 'dried out', the same hydrological process of rewetting, oxidation and transport of acid downstream would apply.

The annual hydrologic cycle appears to be the key mechanism for generating and transporting acid in the Anglesea catchment (i.e; drying out of coal/pyrite and sediment).

The type of rainfall is also important in determining whether an acid flush occurs. In other words, rain that infiltrates and transports acid to surface water systems via groundwater.

The years of the fish kills (2000 and 2010) experienced higher rains than the preceding years.

Small and steady rain of 5mm per day in the week before estuary acidification (fish deaths 13 September 2010) may have been optimal for infiltration and are likely to have created a slow flush of acidic waters from the vadose zone (underground flow) and surface water aquifers to the streams and creeks, and ultimately into the estuary.

Pope (2006) documented that the first significant flows in two years from the Salt Creek catchment occurred at the time of the acid event in 2000, with water of low pH and high sulphate concentrations.

Alcoa monitoring indicated Salt Creek had not flowed for 32 months before the 2010 acid event.

A seasonal water balance model by Tutt (2008) showed why the acid event of 2000 was severe. It explained that the flush of acid from the catchments is made worse when an extended dry period is followed by soaking rains through autumn to spring.

5 Dissolved Metals

There is evidence of high iron, manganese and aluminium concentrations in streams and

tributaries.

Data from samples taken in the 2000 flood/fish kill event show that tributaries in the upper catchment have very little aluminium and sulphate concentrations, but once the water hits the valley the aluminium and sulphate concentrations in Salt Creek become notably higher.

It is important to note that a similar pattern of high acidity and high aluminium, sulphate, manganese, and zinc concentrations were recorded in Distillery Creek, a tributary of Painkalac Creek which is located south west of the Anglesea catchment

There is evidence of elevated iron, manganese and zinc concentrations leaving marshes, therefore marsh sediments are a potential source of iron, manganese and aluminium.

There is evidence of elevated aluminium and zinc concentrations in streams after the first substantial flow, probably as a result of wetting and drying of sulphidic soils.

Alcoa's long term data indicates that while the very high aluminium concentrations recorded in 2000 have not occurred since 1979, there have been lesser events where elevated metal concentrations have occurred. Data from the 2010 fish death event indicates higher aluminium concentrations than those recorded in the 2000 fish death event.

There is evidence that No2 ash pond effluent provides a source of dissolved salts through conductivity measurements.

Recent data on ash pond effluent (5 May 2011) shows that of the 23 trace metals measured, aluminium, nickel and zinc marginally exceeded ANZECC/ARMCANZ (2000) trigger levels for toxicity to aquatic organisms in moderately disturbed systems. Boron measured at 3.2 mg/l vastly exceeded the guideline value of 0.37 mg/l.

However, data supplied for Marshy Creek taken at the same time showed higher concentrations of aluminium, nickel and zinc. Marshy Creek also indicated that chromium concentrations were higher than guideline values.

Boron in Marshy Creek was lower (0.14 mg/l) than the guidelines. Salt Creek was not flowing at the time of sampling.

Data indicates that during periods of high flow when fish deaths are likely to occur, the contribution of aluminium from discharges from the ash pond are relatively small (< 0.06%).

There is photographic evidence of flocculation at SP3 when acidic tributary waters (pH 3-4) contact water discharged by Alcoa of pH 7-9 value, although verification of the location of this photographic evidence is required.

There is evidence that floccs contain elevated trace metal concentrations. These floccs were found upstream of Alcoa's operation.

There is evidence that after a major rainfall, pH at SP3 drops and there is a dramatic increase in aluminium, iron and manganese, probably from dissolution of floccs. There are likely upstream sources in this case as well.

The September 2010 data suggests that aluminium in the mixing zone could be being dissolved by the differences in aluminium concentrations recorded at SP3 compared with the sum of the inputs.

There is evidence of trace metal contributions from activities downstream of power generation

activities.

There is evidence that trace metal concentrations at SP3 sometimes exceed the ANZECC/ARMCANZ (2000) trigger levels for protection of moderately disturbed freshwater ecosystems.

Boron concentrations regularly exceed the ANZECC/ARMCANZ (2000) guidelines with both natural sources and ash pond effluent contributing boron to the Anglesea River.

There is evidence of high concentrations of aluminium and iron flocculating on seagrasses from elevated zinc, copper and lead concentrations measured over short periods on *Z.muelleri*.

There is little evidence of sediments containing elevated trace metals being deposited.

Alcoa emits trace metals into the air during coal burning, with 4-10% deposited in the Anglesea catchment. This amounts to approximately 200kg per year.

6 Specific items of concern that may influence acid generation

6.1 Fire

Fire can affect the hydrological cycle in a number of ways, including changing evaporation and transpiration rates (also referred to as evapo-transpiration), and altering soil properties. This can then affect run-off and infiltration.

Fire can cause short and long term effects on the hydrology of a catchment depending on the extent of changes to evapo-transpiration (from changes to vegetation), and infiltration and run-off due to changes in soil properties.

After fire there is usually a short term increase in infiltration and run-off, then longer term reduction in infiltration and run-off as the forest regrows and evapo-transpiration increases.

Significant fires over a substantial area in the Anglesea catchment, such as the 1983 Ash Wednesday fires, would have influenced or altered the hydrological conditions at Anglesea.

In an acid-generating scenario, water infiltrating with higher oxygen concentrations (possibly due to the loss of organics and microbial fauna in the topsoil consuming the oxygen) could further increase the rate of acid generation.

6.2.1 Pumping by Alcoa

Alcoa's extraction regime has not changed substantially in recent years, remaining at approximately 3000ML/yr.

A 'cone of groundwater depression' exists around the mine and power station site.

The coal mine and power station operation have not 'drained' the marshes in the catchment. The marshes are in good health and seem to have their own perched water table operating.

The mine pit is substantially below river and sea levels, and aquifer hydraulic flow paths were directed to Alcoa extraction bores. Therefore, any acidity generated in the cone of groundwater depression is unlikely to contribute to the acidity of surface water.

The cone of depression, or the open cut mine itself, may have 'disturbed' seams or pockets of perched water (other than the swamps) because the Salt Creek sub catchment shows signs of possible disturbance compared to Marshy Creek. However, this may be the result of the

creeks' differing catchment geology and longer term drying out caused by historical mining.

6.2.2 Pumping by Barwon Water

Barwon Water began operating the Anglesea Bore field in October 2009.

Numerical modelling identified potentially base flow dependant surface water features in the upper reaches of the Anglesea River and Salt Creek in the LEVF outcrop area. These features may be affected by draw-down associated with extraction of water.

Bore field extraction will alter groundwater levels in the EVF and therefore interactions with surface water. Altering water tables can cause swamps to dry out and the possibility of ASS also drying out. Marshes may dry out more often than under natural conditions and this may generate acidity.

Assessments to date have not significantly addressed the bore field project's potential impacts as a result of exposure or disturbance of pyritic strata from the draw-down.

The Technical Audit Panel Review (November 2008) stated it "... does not believe that the current groundwater model is sufficiently well calibrated for prediction of impacts to be considered reliable."

6.3 Licensed Discharges

Alcoa has the only EPA licensed discharge in the Anglesea catchment.

The discharge is to the Anglesea River downstream of the power station / mine site. The discharge is approximately 4ML/d and is made up of cooling tower water, storm water and ash dam water.

Alcoa's discharge has a significant influence on the dynamics of the Anglesea River estuary, in terms of hydraulics, flows and quality.

The pH of Alcoa in the range of pH 7-8 is not the source of low pH water in the Anglesea estuary.

Alcoa discharge contributes trace metals to the Anglesea River (Al, Fe, Zn).

On approximately four occasions between 2008 and 2010, bore development water from the lower EVF from Barwon Waters' bore project was discharged into Alcoa's ash ponds in accordance with terms and conditions agreed by Barwon Water, Alcoa and the EPA.

6.4.1 Resource Extraction – gravel and sand mines

Most land in the Anglesea catchment falls under Alcoa mine lease (7,221 Ha), 90% of which is a reserve with similar status as a National Park and managed in conjunction with Parks Victoria (Alcoa EIP 2008).

Other land uses include township, mining (quarries), other parks in the Great Otway National Park and agriculture.

In 2002, the breakdown of catchment land use was calculated as minimal use 61%, nature conservation 22.8%, forestry 7.1%, dry land agriculture 4.4%, built environment 4.2% and the remaining 0.5% unclassified.

Gravel and sand resources are mined at many locations in the catchment (266 ha), including

the upper EVF adjacent and bordering the rivers catchment and licensed to extract 250 ML per year.

Quarrying can disturb acid sulphate soils and rock.

Existing gravel mining areas have significantly higher recharge rates than adjacent land.

Given the proximity of the quarries to the Anglesea catchment recharge could be significant.

Given the area's relative height to surface water courses and the Anglesea River means 'recharge' may connect or interact with surface waters.

Assuming pyritic material is present in the geology around the quarries, there is potential for acid generation and transport.

6.4.2 Previous Coal Mining

The Roche open cut coal mine was located at the lower end of the Salt Creek catchment. Details of the mining operation are limited but production of coal occurred in the late 1950s and early 1960s.

Previous coal mining operations may have increased localised acid generation by draw down of water tables, and the excavation and exposure of pyritic materials..

Given the mine has been a backfilled, pathways for continuing exposure and oxidation of pyritic materials will have been significantly reduced.

The mine may have affected local hydrogeological conditions.

The open pit mine may have initiated some acid generation in the swamps (from general disturbance caused by excavation and drainage) and in the coal seams from exposure. Once acid generation has started it can continue for many years.

If a leak is present in the swamp's perched water table, over time the leak may have a measurable effect and this may explain why Salt Creek flows are more irregular than Marshy Creek.

Water quality data indicates differences in the Salt Creek and Marshy Creek system, which has led to the hypothesis that the previous coal mine and filling with ash (high in aluminium and sulphates) may be having an effect.

6.4.3 Coogoorah Park

Coogoorah Park is described in the Anglesea estuary management plan as "a series of channels created to let water from the river extinguish peat fires post the 1983 Ash Wednesday bushfires.

The park can be described as a coastal peat swamp and is therefore likely to have acid generating potential.

Given the history, size, location, and the fact that the park does not "dry out" it is unlikely that Coogoorah Park is a significant source of acid in the system.

6.4.4 Anglesea Landfill

The Anglesea landfill has been in operation for decades.

Leachate treatment system is designed to completely contain leachate on site and regular environmental monitoring of leachate leakage is undertaken.

Environmental monitoring and reports acknowledge some effect of the landfill on groundwater in the immediate vicinity.

8.3 Summary of knowledge gaps

4 Acid sources

4.1.1 Geology – coal and pyrites

The extent of coal and pyritic strata throughout the Anglesea catchment.

The sulphide content and acid generation potential of coal and pyritic strata (such as that listed at site AL622 in the upper the catchment) are unknown.

The connectivity between potential acid producing strata and waterways.

4.1.2 Tea tree marshes (swamps)

The sulphur content of the marsh sediments is unknown and this information is key in determining the contributing effect of the marshes to potential acid generation in the Anglesea catchment.

The extent of the 'drying out' of the marshes is unknown.

4.2.4 Deposition on Sulphur dioxide

Proportional contribution of sulphur emissions to acid drainage in the Anglesea catchment.

Apportioning the contribution of sulphate to streams and tributaries from natural sources and plume deposits.

4.3 Acid transport and fish death events

Measurements of infiltration and recharge rates for the Anglesea catchment.

Flow data in the catchment (including the river) and sub catchment of both creeks.

Lack of sulphate measurements in water quality monitoring programs as an indicator of acidity source.

5 Dissolved metals

The relative contributions of specific trace metal loads from the natural flow of the Anglesea River, ash pond discharges and storm water inflows.

The fate and remobilization of trace metals in river-estuarine zone downstream of where the ash pond effluent enters the Anglesea River.

The risk of the Anglesea River freshwater ecosystems to high concentrations of boron.

6 Specific items of concern that may influence acid generation

6.1 Fire

An understanding of infiltration (water and oxygen) and recharge after fire and effects on infiltration and stream pH.

6.2.1 Pumping by Alcoa

Connections between Salt Creek marshes, other possible perched water tables and the current mine void and the cone of groundwater depression, and therefore the effects on water tables and the potential drying out of pyritic material and acid generation.

6.2.2 Pumping by Barwon Water

Alteration of groundwater levels in the EVF and effects including swamps drying out.

Effects associated with exposure / disturbance of pyritic strata due to groundwater extraction.

6.3 Licensed Discharges

Data on the relative proportions of water sources (i.e; stream flow versus discharge) over time.

6.4.1 Resource Extraction – gravel and sand mines

Effects of groundwater extraction and quarrying on generation of acids and trace metals export.

6.4.2 Previous Coal Mining

The effects of the mine on hydraulic connectivity between aquifer units.

The effects of the old coal mine and backfill including ash on localised acid generation and contribution to aluminium and sulphates in Salt Creek.

6.4.3 Coogoorah Park

The sulphide profiles of Coogoorah Park soils, local water tables and soil moisture profiles as an indicator to acid sulphate soil potential.

6.4.4 Anglesea Landfill

Extent of leachate plume and risk of plume interacting with surface waters / reaching the river.

Possible surface water runoff from site (possibly contaminated) due to rain.