Foam Mitigation Study

Bird Lake – Port Augusta

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1. Introduction

Port Augusta Council manages Bird Lake (a salt lake) on the southern approaches to the town. The lake has an input of saltwater from the adjacent ETSA power station. Brine in the lake is maintained at around 150ppt salt to prevent the breeding of chironomid midges. Foam from the lake blows across the main highway and is a traffic hazard. The Council is trialing various interception methods to control the foam, but is also interested in the possibility of preventing its formation in the first place.

Saltwater is more viscous than freshwater due to the increased ionic content of the brine and this means that some foaming is inevitable. However, much foaming in brines is due to the organic matter (proteins and polysaccharides) contained in the brine, and can be minimised. It is a relatively simple matter to determine whether brine has an increased viscosity, using the method developed by Mark Coleman (Actis) and Alex Mitchell (Cheetham Salt). The method is commonly employed in saltfields to provide operators with the ability to control their brine quality and enable the production of better quality crystals.

Previous testing of the brine from Bird Lake has shown it to have an increased viscosity, relative to that of seawater evaporated to the same salinity. In response the Council established a monitoring program to determine the cause of the increased viscosity.

This document summarises the findings of that study, conducted during 1997 and 1998. Delta wish to thank the City of Port Augusta for their permission to place this work on the Internet.

2. Consultant

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3. Bird Lake Foam Mitigation Study

3.1 Summary of monitoring program

A water quality monitoring program was established at Bird Lake in late 1997. The program included bimonthly sampling and some data logging. Parameters included pH, conductivity and specific gravity, turbidity, dissolved oxygen, temperature, floccable organics, oxidised nitrogen, total and dissolved orthophosphates and viscosity. Data logging was conducted for temperature. Plankton were classified and counted to gain a picture of the main species and densities present. Samples were collected at the northern jetty and at the southern discharge as shown below in Figure 1.

Figure 1 - Bird Lake sampling locations

Overall the brine in the brine in the lake is well mixed, with little variation between the sampling locations. This is not surprising, as the lake is shallow (less than half a metre deep) and there frequent breezes. Temperatures at the jetty sometimes peak a little higher than at the discharge point, but overall the two match well.

The water quality data is summarised below in Table 1, using means and medians. Where the data presents a skewed distribution (marked with an asterisk) the median should be used as the more representative figure.

Table 1 – Water quality data

	pH	EC	SG	Turbidity (NTU)*	DO (mg/L)	N(ox) (mg/L) *	Total P (mg/L)	Diss P (mg/L)*	Relative viscosity
Mean	8.5	128	1.09	13	11.7	0.02	0.52	0.42	1.06
median	8.6	129	1.09	6	10.4	0.00	0.51	0.35	1.06
SDev	0.3	9	0.01	15	5.7	0.04	0.21	0.19	0.01
n	17	12	12	16	13	10	12	12	12

3.1.1 pH

The pH range in the lake is within the normal range for seawater derived brines.

3.1.2 electrical conductivity and specific gravity

There was quite a variation in salinity in the lake over the period from October to July. The highest conductivity was in summer, with 143 millisiemens, equivalent to a specific gravity of 1.113 while the lowest salinity occurred in winter (with a conductivity of 113 millisiemens or SG 1.078). This translates to range in the total dissolved solids content in the brine of between 108 g/L and 162 g/L.

3.1.3 turbidity

The brines in the lake were acceptably clear.

3.1.4 dissolved oxygen

The diurnal variation in oxygen readings and the effect of salinity on the quantity of oxygen that could be held in a brine diurnally, were discussed in the sampling manual provided to Council in 1997. Recent research by Sherwood *et al* (1992) has produced a new oxygen saturation curve that is accurate up to the point of sodium chloride saturation and a table derived from it is presented below.

When oxygen levels in brine fall below 30% saturation, the biota of the lake may become stressed. This is unlikely given the shallowness of the lake and its well mixed nature. In fact, the mean and median results of the sampling undertaken over the period indicate that the brine in Bird Lake is normally supersaturated with oxygen.

Table 2 – Sherwood, Stagnitti, Kokkinn and Williams (1992)

Table 2. Predicted values (mg L^{-1}) of C^*_0 for pure NaCl solutions calculated from eqn (1) using coefficients in Table 1.

Concentration (ppt)	Temperature (°C) 0	1	2	3	4	5	6	8	10	12	14	15	16	18	20	25	30	35
0	14.60	14.20	13.82	13.46	13.11	12.79	12.47	11.88	11.34	10.83	10.35	10.13	9.91	9.49	9.10	8.22	7.49	6.92
2	14.40	14.01	13.64	13.28	12.95	12.63	12.32	11.74	11.20	10.70	10.23	10.01	9.79	9.38	9.00	8.13	7.42	6.85
5	14.12	13.74	13.37	13.03	12.70	12.39	12.09	11.52	11.00	10.51	10.05	9.84	9.63	9.22	8.85	8.00	7.30	6.75
10	13.65	13.29	12.94	12.61	12.29	11.99	11.71	11.17	10.66	10.20	9.76	9.55	9.35	8.96	8.60	7.79	7.12	6.59
15	13.20	12.85	12.52	12.20	1.90	11.61	11.34	10.82	10.34	9.89	9.47	9.27	9.08	8.71	8.36	7.58	6.93	6.42
20	12.76	12.43	12.11	11.81	11.52	11.24	10.98	10.48	10.02	9.60	9.19	9.00	8.82	8.46	8.13	7.38	6.75	6.26
25	12.33	12.01	11.71	11.42	11.14	10.88	10.63	10.16	9.72	9.31	8.92	8.74	8.56	8.22	7.90	7.18	6.58	6.11
30	11.92	11.61	11.32	11.05	10.78	10.53	10.29	9.84	9.42	9.02	8.65	8.48	8.31	7.98	7.67	6.98	6.41	5.95
35	11.51	11.22	10.94	10.68	10.43	10.19	9.96	9.53	9.12	8.75	8.39	8.22	8.06	7.75	7.45	6.79	6.24	5.80
40	11.12	10.84	10.58	10.33	10.09	9.86	9.64	9.22	8.84	8.48	8.14	7.98	7.82	7.52	7.24	6.60	6.07	5.65
45	10.74	10.48	10.22	9.98	9.75	9.53	9.32	8.93	8.56	8.21	7.89	7.74	7.59	7.30	7.03	6.42	5.91	5.51
50	10.37	10.12	9.88	9.65	9.43	9.22	9.02	8.64	8.29	7.96	7.65	7.50	7.36	7.08	6.82	6.24	5.75	5.37
55	10.01	9.77	9.54	9.32	9.11	8.91	8.72	8.36	8.02	7.71	7.41	7.27	7.14	6.87	6.62	6.06	5.59	5.23
60	9.67	9.44	9.22	9.01	8.81	8.62	8.43	8.09	7.77	7.47	7.18	7.05	6.92	6.67	6.43	5.89	5.44	5.09
65	9.33	9.11	8.90	8.70	8.51	8.33	8.15	7.82	7.52	7.23	6.96	6.83	6.71	6.46	6.24	5.72	5.29	4.95
70	9.00	8.79	8.59	8.40	8.22	8.05	7.88	7.57	7.28	7.00	6.74	6.62	6.50	6.27	6.05	5.56	5.15	4.82
75	8.69	8.48	8.29	8.11	7.94	7.78	7.62	7.32	7.04	6.78	6.53	6.41	6.30	6.08	5.87	5.40	5.00	4.69
80	8.38	8.19	8.01	7.83	7.67	7.51	7.36	7.07	6.81	6.56	6.32	6.21	6.10	5.89	5.69	5.24	4.86	4.57
90	7.79	7.62	7.45	7.30	7.15	7.00	6.87	6.61	6.37	6.14	5.93	5.82	5.72	5.53	5.35	4.94	4.59	4.32
100	7.24	7.08	6.93	6.79	6.66	6.53	6.40	6.17	5.95	5.75	5.55	5.46	5.37	5.19	5.03	4.65	4.33	4.09
110	6.72	6.58	6.45	6.32	6.20	6.08	5.97	5.76	5.56	5.37	5.19	5.11	5.03	4.87	4.72	4.37	4.09	3.86
120	6.24	6.11	5.99	5.87	5.76	5.66	5.56	5.36	5.19	5.02	4.86	4.78	4.71	4.56	4.42	4.11	3.85	3.65
130	5.78	5.67	5.56	5.46	5.36	5.26	5.17	5.00	4.84	4.68	4.54	4.47	4.40	4.27	4.15	3.86	3.63	3.44
140	5.36	5.26	5.16	5.06	4.97	4.89	4.81	4.65	4.51	4.37	4.24	4.18	4.12	4.00	3.88	3.63	3.41	3.24
150	4.96	4.87	4.78	4.70	4.62	4.54	4.47	4.33	4.20	4.07	3.96	3.90	3.84	3.74	3.64	3.40	3.21	3.06
160	4.59	4.51	4.43	4.35	4.28	4.21	4.15	4.02	3.90	3.79	3.69	3.64	3.59	3.49	3.40	3.19	3.01	2.88
170	4.24	4.17	4.10	4.03	3.97	3.91	3.85	3.74	3.63	3.53	3.44	3.39	3.35	3.26	3.18	2.99	2.83	2.71
180	3.92	3.86	3.79	3.73	3.67	3.62	3.57	3.47	3.37	3.28	3.20	3.16	3.12	3.04	2.97	2.80	2.65	2.55
190	3.62	3.56	3.51	3.45	3.40	3.35	3.30	3.22	3.13	3.05	2.98	2.94	2.91	2.84	2.77	2.62	2.49	2.39
200	3.34	3.29	3.24	3.19	3.14	3.10	3.06	2.98	2.91	2.84	2.77	2.74	2.70	2.64	2.58	2.45	2.33	2.25
220	2.84	2.80	2.76	2.72	2.68	2.65	2.62	2.55	2.50	2.44	2.39	2.36	2.34	2.29	2.24	2.13	2.04	1.98
240	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.18	2.14	2.10	2.05	2.03	2.01	1.98	1.94	1.86	1.78	1.73
260	2.03	2.00	1.98	1.96	1.94	1.92	1.90	1.86	1.83	1.79	1.76	1.75	1.73	1.70	1.67	1.61	1.55	1.51

3.1.5 oxidised nitrogen

Oxidised nitrogen concentrations in the lake were generally within the range specified by ANZECC (1992) in the *Australian Water Quality Guidelines for Fresh and Marine Waters*. Primary production in the lake occurs solely through plankton and periphyton (except in the ETSA polishing pond where seagrasses are growing). The reproductive response time of microscopic algae is very short, so that "blooms" of planktonic chlorophytic species will occur rapidly after a rise in available nitrogen. This bloom will quickly reduce oxidised nitrogen levels in the lake.

While green algal species are limited by the amount of nitrogen available in the brine, cyanobacteria are not. Cyanobacteria are capable of fixing their own nitrogen, and so are limited by the amount of phosphate in the system.

3.1.6 total and dissolved orthophosphates

Phosphate concentrations in the lake exceeded the ANZECC (1992) guidelines by an order of magnitude. The guidelines suggest a concentration of 0.015 mg/L should be the upper limit of phosphates in a coastal/estuarine/lagoonal ecosystem. With both mean and median readings exceeding 0.5 mg/L Bird Lake could be considered polluted with phosphates.

The concentrations of phosphate detected in this study match those obtained by the Australian Water Quality Centre in June 1997 (data provided by Optima Energy) at the Hospital Creek discharge from the power station discharge gate. The discharge is the source water for Bird Lake and it would appear likely that the phosphate is sourced in the flyash of the playa (Figure 2). An analysis of the flyash was conducted for Optima Energy by CSIRO's Lucas Heights Centre for Advanced Analytical Chemistry in 1993.It confirmed that flyash contains about 0.3% phosphorus.

Figure 2 - Flyash playa

As the power station cooling water travels across the flyash playa it would dissolve any soluble phosphates it encountered. The larger the playa, the longer the period the water would remain in contact with the flyash, and the higher the concentration of phosphates.

There has been some suggestion that the high concentrations of phosphates in the lake may be a result of birds and the seagrass in the polishing ponds. The reverse is the more likely, as the availability of phosphates allows massive primary production, which attracts the birds. Should the phosphates in Bird Lake water be sourced from organic sources, there should be a high proportion of undissolved phosphates, that is, phosphates tied up in plankton, the blades of macroalgae and seagrasses and bird bones etc. Instead, the sampling over this period shows that the majority of the phosphates present in the water column at any time are of the dissolved variety – they are not tied up in the biota. This would argue for an external chemical source of the nutrient.

3.1.7 relative viscosity

The brine in the lake has a relative viscosity of 1.06. This means that the lake waters are 6% more viscous than they theoretically should be. Occasional planktonic cells of the cyanobacteria *Synechococcus elebans* were detected in the samples. However, the constancy of the phosphate concentration in the lake encourages benthic mats rather than planktonic populations of this nuisance species (Roux 1997). The presence of the benthic mats was confirmed during the November 1997 site visit.

3.1.8 temperature

Temperature records show that the Lake is well mixed, with little variation between the two sampling points. The maximum may be a little higher at the northern sampling point.

3.1.9 plankton counts

Absolute numbers of planktonic cells in the brine were not high, and varied by season. The warm weather and high nutrient concentrations saw larger numbers of plankton during the summer months. In winter the numbers were lower. However the biomass of the algae did not show such a pronounced trend, as biomass depends on which species are present.

3.2 Site visit

The site was visited during November 1997. Five locations were examined for water quality (the two normal sampling sites, the south-eastern corner of the lake, the shoreline at the gun club, and halfway between the gun club shore and the island). The data are included in *Appendix 1*. The day was hot and windy, resulting in high turbidity values and brine temperatures ranging around 28^{o}C. Dissolved oxygen readings were high due to the wind and to planktonic oxygen production (midday).

3.2.1 Macroinvertebrates and plankton species

Fine mesh (500 micron) plankton net samples of lake brines and dip net samples of sediments examined in November contained the organisms listed in Table 3.

Table 3 – Site visit fine mesh net samples

Sample	Group	Organisms
Brine	Macroinvertebrates	*Artemia fransiscana* (brine shrimp) *Ephydrella* sp (commonly called rat-tailed maggot pupae or brine fly pupae) Nematode worms
	Plankton	*Artemia* nauplii *Artemia* cysts Diatoms (*Cymbella, Diatoma, Tabellaria* and other, pennate, varieties) *Dunaliella salina* (green) Cyanophytes (*Oscillatoria, Lyngbya, Synechococcus, Gleocapsa* and *Rhizoclonium*) Protozoan (*Chilodonella*)
Sediment	Macroinvertebrates	*Artemia fransiscana* *Ephydrella* sp
	Benthic mat	Diatoms (including *Cymbella, Suriella, Diatoma* and *Navicula*) Cyanophytes (*Oscillatoria, Lyngbya, Synechococcus, Microcoleus, Gleocapsa* and *Rhizoclonium*)

Brine shrimp were numerous, as were brine fly larvae. Midge larvae were not obvious in any of the samples, as the salinity was higher than the species (*Tanytarsus barbitarsis*) can tolerate. The large *Artemia* population appeared anomalous considering the lake's low planktonic cell counts, however it appears the species may have adapted its feeding behaviour to utilise benthic food sources.

3.2.2 Benthic mats

A feature immediately observable during the site visit was the almost continuous benthic mat growing across the lake floor (Figure 3).

Figure 3 - Layered benthic mat from the floor of Bird Lake

Benthic microbial mats are a dominant feature of hypersaline/hyperhaline lakes. Microbial mats contain layers of microalga, mainly blue-green algae, diatoms and bacteria. These mats are an essential part of the ecosystem. They utilise nutrients from the brine and form an impermeable mat on the floor of the lake. In some lakes or lagoons the mats grow into balls, and are referred to as stromatolites, as they resemble fossil stromatolites. Considerable study of these and the other benthic mats has been undertaken around the world (Bauld, 1981).

Typically, the different layers of the microbial mats consist of a top layer of diatoms, a lower layer of cyanobacteria and a lowest layer of purple bacteria.

Diatoms found in benthic mats include *Navicula* spp, *Nitzchia* spp, and *Cymbella* spp (see Figure 4, top photograph). The cyanophytes usually include *Phormidium* spp, *Microccoleus* spp, *Aphanothece halophytica* (syn *Synechococcus elebans*), *Spirulina* spp and *Oscillatoria* spp (bottom photograph). The purple layer of bacteria includes *Chromatium* spp and *Beggiatoa* spp.

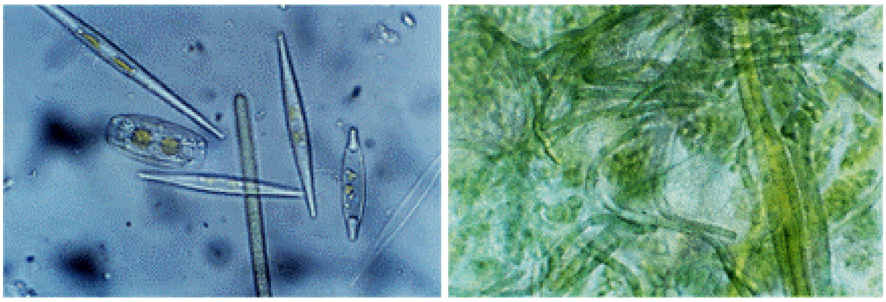

Figure 4 - Some members of the benthic mat community (photos: Exportadora del Sal, 1998)

An unusual feature of Bird Lake is that the *Artemia* population grazes the benthic mats. *Artemia* have been consistently described as obligate filter feeders in the literature. Grazing of benthic mats has been assumed to take place by "accident" when the organisms' constant random swimming knocks pieces from the mats. Recent research in Western Australia (Savage and Knott, 1998) has demonstrated that *Artemia parthenogenetica* will choose to feed from benthic mats in shallow hypersaline lakes and will alter its normal feeding pattern to do so.

The mechanism *Artemia fransiscana* uses to feed from the benthic mat appears to be the same as that used by *Artemia parthenogenetica.* That is, the animals roll over so their ventral surface faces the benthic mat and the phyllopods of the animals continue to beat although all forward motion is ceased. The phyllopods brush the mat, releasing diatoms and cyanobacterial cells to be ingested by the shrimp.

Figure 5 - Artemia feeding on the benthic mat where it coats a rock

In the northern areas of the lake there are some eroded banks edging the water (Figure 6). The fine clay particles are washed into the brine and become incorporated into the benthic mat. Where the mat is growing over the surface of rocks *Artemia* find it easy to attach themselves to feed. Surrounding these rocks is a distinct orange halo (Figure 7) where the clay has been released, either during the “brushing” process of grazing or later from the faecal materials deposited by the shrimp.

Figure 6 - Eroded northern banks

Figure 7 - Clay released from benthic mat surrounds a "grazed" rock

The cyanobacteria found in benthic mats may cause a rise in the viscosity of the brines overlying them. This normally occurs when the cyanobacteria in the mat become nutrient stressed. Roux (1996) found that when nutrient supplies dropped rapidly the cyanobacteria population may shift to its planktonic phase. The extracellular mucilage produced by planktonic cyanobacteria is distributed in the water column, raising the viscosity.

Bird Lake's viscosity is high, even though its planktonic population of *Synechococcus* is low. It is possible that the grazing of the *Artemia* releases sufficient extracellular polysaccharide mucilage from the mat to cause this rise.

The method most commercial salt producers use to control *Synechococcus* mucilage production is to dry out an affected pond followed by input of phosphate reduced water. Using lime can reduce phosphates. Once a pond is clear of cyanobacteria it is important to ensure that phosphate concentrations in the input brine are kept as low as possible. That is because a small population cannot produce a large amount of mucilage. Once a population is large, suddenly starving it of phosphates is likely to increase the problem. With a constant input of phosphorus-rich brines from ETSA Lake, this method is unlikely to succeed.

The *Artemia* in Bird Lake are the food source for many of the protected shorebirds that visit the lake (Figure 8). The shrimp are the route by which phosphates leave the lake. Ideally the shrimp should be able to feed on plankton, rather than on the benthic mat. It is possible that by gradually increasing the availability of oxidised nitrogen and silica, planktonic diatoms may be able to become the dominant algal group in the lake (Ghassemzadeh, 1997). Diatoms do not produce mucilage and are a more valuable food than cyanobacteria for *Artemia*. Any such attempt to change species dominance would need to be undertaken with caution as rapid changes in the availability of nutrients could cause a massive increase in viscosity (and foaming) of the lake waters.

Figure 8 - Shorebirds feeding on Artemia

3.2.3 South-eastern corner of the lake

Where the embankment of the flyash playa abuts the southeastern corner of the lake the lake sediments are very unstable. This is possibly a combination of the permanently waterlogged nature of the somewhat structureless flyash in the playa and embankment, and the locally raised water table head under the lake close to the playa. These unstable sediments do not make a good base for benthic mats. In this location *Synechococcus* is present in numerous floating globular colonies (Figure 9). These globules are abraded by the action of the water and the coarser particles of flyash/coke, releasing mucilage.

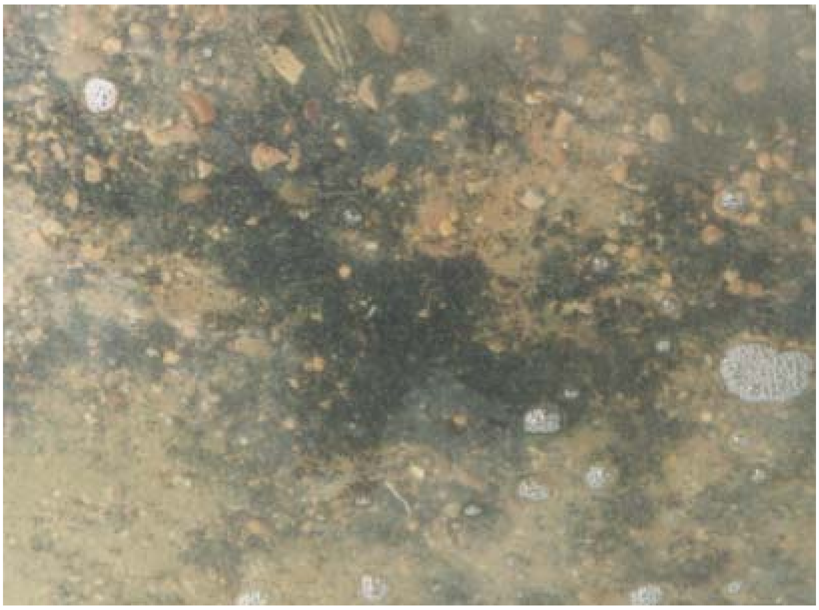

Figure 9 - Floating globular colonies of cyanobacteria

4. Conclusions

- Brines in Bird Lake have a raised viscosity, increasing the severity of foaming
- The viscosity is raised by small quantities of polysaccharides that are dissolved in the brine
- The source of the polysaccharide mucilage is the benthic mat that coats the lake bottom
- The benthic mat is layered, with the middle layer of cyanobacteria being the main source of mucilage
- Cyanobacteria dominate the lake's algal population because of the high concentrations of phosphates in the input waters
- A changed feeding behaviour in the lake's population of Artemia may be causing release of the mucilage into the water column
- Unstable sediments in the southern part of the lake do not provide a firm base for the benthic mat in that area, resulting in increased abrasion of the mats and possibly increased mucilage release

5. Recommendations

- Council and Optima Energy should discuss options for reducing phosphate concentrations in the input waters of Bird Lake
- There may be alternative sources of input water for the lake such as saline groundwater (groundwater frequently has higher concentrations of silica and lower nutrient levels than seawater-derived brines)

- Should a supply of low nutrient water be sourced, the lake could be drained and the remaining brine limed to reduce the available phosphates in the waters prior to refilling with new brines
- Investigations into the feasibility of changing the algal species dominance could be conducted in small enclosures in the lake or nearby ponds
- If revegetation of the "scalded" area west of the lake is envisaged, a drain will be needed that runs along the road edge and that debouches into Hospital Creek

6. References

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