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Memo

To: Bruce Donald, Teck Cominco

From: Paul Erickson

Date: December 14, 2001

Re: **Garrow Lake Dam – Effect of Removal on Lake Stability and Water Quality Response to Comments by DFO**

1. Background

Bruce Fallis of DFO asked whether sequential or progressive mixing of the halocline had been considered. In addition, he was concerned about the loading of contaminants in particular Zn that would be discharged from Garrow Lake subsequent to closure of the mine. These questions are addressed below:

2. Sequential Mixing

There was an error in Figure 4 of our report. This may have resulted in some confusion about what was stated on page 5. The vertical axis in figure 4 should read Duration in days not hours. The text on page 5 of the report which refers to Figure 4 is correct however.

Sequential (year to year or event to event) mixing of the top of the halocline into the surface layer is possible. The present model assumes there is some annual mixing of the top of the halocline but at a low rate. Major wind events over open water will result in higher rates of mixing. As the halocline is mixed into the surface layer however, the surface layer deepens and the energy to further mix the top of the halocline increases. A summary of the wind speeds and duration required to mix the halocline into the surface layer by 1 m increments in a single event or in a series of isolated or individual events is given in Tables 1 and 2 (attached). Actual mixing times to mix more than the top 1 m will be longer since the percentage of wind-derived energy reaching the top of the halocline will be less than the 4 % assumed.

It should be stressed that even if the present halocline with its Zn maximum were to be mixed into the surface layer after draw down of the lake, there would still be a halocline present and the stability of the lake not threatened. The increased salinity of the surface layer (12.9 ppt) would still be far less than in the bottom layer (68 ppt). A "new" halocline would separate the deeper more saline surface water from the bottom layer.

3. Zinc Loading

The following discussion looks at dissolved Zn. Lead concentrations are currently more than a factor of 10 less than the current License limits and, as there is no longer a maximum present in the halocline, no source of excess Pb exists in Garrow Lake that might increase surface layer concentrations.

Concentrations of Zn in the Surface Layer are considered below for three different post-dam scenarios: 1) no mixing of the halocline with the surface layer (greater than already assumed in the model); 2) mixing of the top 1 m of the halocline into the surface layer, and 3) mixing of the top 2 m of the halocline including the Zn maximum into the surface layer. **Predictions are given for the first year of natural drainage after the dam is removed which represents a worst case situation. Zn concentrations are expected to decrease each year after removal of the dam. Model predictions have been updated to include the 2001 SNP data.**

a) No Mixing

Current model predictions are that the surface layer will have Zn concentrations of 0.24 ppm when the dam is removed in 2004. Concentrations are predicted to decrease to less than 0.1 ppm by 2010 (figure 1). The Zn maximum in the halocline is expected to decrease to 0.88 ppm by 2004 and to about 0.33 ppm by 2010 (figure 2).

b) Partial Mixing

If the top metre of the halocline were mixed into the surface layer in the first summer after removal of the dam, the Zn concentration in the surface layer would increase by 0.015 ppm to 0.26 ppm, the surface layer depth would increase to 8.5 m and the mean salinity to 9.4 ppt. In this situation, concentrations would still decrease to 0.1 ppm by 2010.

c) Mixing of the Zn maximum in the halocline into the Surface Layer

Should the top 2 m of the halocline be mixed into the surface layer after removal of the dam, Zn concentrations would increase by 0.07 ppm to 0.31 ppm, the surface layer depth would increase to 9.5 m and the mean surface salinity increase to 12.9 ppt. Natural processes would decrease Zn concentrations to less than 0.1 ppm in nine years.

3.1 Zinc loading in Garrow Creek after dam removal

Although the title of the report referred to outflow water quality, the report gave only predicted concentrations of Zn in the surface layer of the lake. There is a tendency to assume that the concentrations of metals in Garrow Creek will be the same as those in Garrow Lake. This is not the case.

Until Garrow Lake clears of ice, the water at the surface of Garrow Lake is a combination of ice and snow melt. Because of its lower density, melt water floats on top of the brackish water of the surface layer isolating the surface water of Garrow Lake from Garrow Creek. Concentrations of Zn under these conditions reflect melt water concentrations regardless of the Zn concentration in the surface layer.

When the Lake is ice free, the melt water can be mixed by wind into the underlying surface layer producing a well mixed surface layer. However, even under these conditions, the water in Garrow Creek has lower concentrations of Zn than in the surface layer of the lake presumably as a result of dilution with surface run-off. Based on SNP data from 1985 to 1989, Zn concentrations were never more than half of the corresponding concentrations of Zn at the surface of Garrow Lake (note: 1985 to 1989 were the years prior to constructing the dam when surface layer Zn concentrations were increasing as a result of a tailings spill in the winter of 1985).

Calculating a loading of Zn to Garrow Bay must therefore take into account these factors. Estimates of Zn loading relative to original license limits are estimated in Table 3 for the predicted post-mine surface layer Zn concentration and for the Zn concentration that would be present should the upper 2 m of the halocline be mixed into the surface layer as described above. These calculations are for a year where the lake becomes ice free by the beginning of August and assume a dilution factor of 2 in the open water period. Although in the years from 1982 – 1989 more than 70 % of the flow in Garrow Creek occurred while the lake was ice covered, a figure of 60 % has been used in the calculations. The total flow through Garrow Creek has been set at 2.3 Mm^3 which was the maximum flow through Garrow Creek from 1982 – 1989 (less the contribution from tailings input). The calculations therefore present a worst case scenario for total loading in Garrow Creek. The estimates indicate that in the case of predicted post mine concentrations in Garrow Lake, the loading in Garrow Creek would be less than the original licence limit, and about 35 % greater than the original licence limit assuming a worst case scenario of mixing in Garrow Lake and dilution in Garrow Creek.

An actual total Zn loading through Garrow Creek is also given for 1989 based on SNP data from station 262-5. This provides a good reference for the post-mine scenarios as 1989 was a year in which there was natural outflow from Garrow Lake, the lake cleared of ice in August and mean surface layer Zn concentrations (as high as 0.36 ppm) were close to the predicted level of 0.31 ppm should the top 2 m of the halocline be mixed into the surface layer. The total loading in 1989 was about half the calculated worst case post mine loading scenario.

4. Revised Model Predictions

The 2001 SNP data has been used to provide updated predictions of Garrow Lake properties. Figures 1 through 5 give observed values through 2001 and predicted values for:

- Dissolved zinc in the surface layer
- Dissolved zinc in the halocline
- Bottom layer salinity
- Surface layer salinity
- Vertical salinity/depth profile for 2001.

TABLE 1. POST-MINE MIXING OF THE HALOCLINE INTO THE SURFACE LAYER

Layer to be Mixed metres	Mixing Work 10^6 ergs/cm^2	Wind Energy 10^6 ergs/cm^2	Wind Duration hours
7.5 – 8.5	0.45	11.3	2.7
8.5 – 9.5	1.39	34.7	8.1
9.5 – 10.5	1.99	49.7	11.6
10.5 - bottom*	28.36	708.9	166.2

TABLE 2. POST-MINE SINGLE EVENT MIXING

Depth of Mixing metres	Mixing Work 10^6 ergs/cm^2	Wind Energy 10^6 ergs/cm^2	Duration hours
8.5	0.45	11.3	2.7
9.5	1.84	46.0	10.8
10.5	3.83	95.7	22.4
Bottom*	32.19	804.7	188.6

***Note:** The starting point for these calculations is the salinity distribution expected after mill activity ceases, and after draw down has restored the lake to its original level. The surface mixed layer will be 7.5m deep with salinity 8 ppt and temperature 2 ^{0}C; the bottom mixed layer will have salinity 68 ppt and temperature 8 ^{0}C; and the halocline will be 2m thick with salinity increasing linearly between the surface and bottom layers.

Mixing work is that required to mix the indicated layer into the overlying surface mixed layer, and is set to a constant 4 percent of surface wind-derived energy. This is a good approximation for the initial case of surface layer depth of 7.5 m but the percentage will be less as the surface layer gets deeper. However, for the purposes of these calculations 4 % has been used regardless of surface layer depth. Wind duration is calculated for the maximum hourly wind speed recorded at Resolute (29 m/s; 105 km/h). For other wind speeds W the duration should be multiplied by the factor $(29/W)^3$, e.g., for W = 14.5 m/s (52 km/h) listed duration values should be multiplied by 8. **The bottom depth was taken as the mean depth for the lake of 24.5 m.**

Table 3. Annual Discharge of Dissolved Zinc through Garrow Creek

i) Original Water License Limit

Original water licence allowed for average Zn concentrations in Garrow Creek of 0.1 ppm. Assuming the maximum flow of 2.3 Mm^3 recorded in Garrow Creek between 1982 and 1989, the total loading limit for a season was therefore:

$2.3\ Mm^3 \times 0.1\ g/m^3 =$ **230 kg.**

ii) Post-Mine

Present predictions are that the surface layer Zn concentrations will be 0.24 ppm the first year that natural outflow occurs from the lake after dam removal.

Maximum loading in Garrow Creek would be:

Loading while the lake is ice covered + loading when the lake is ice free, or

$(1.38\ Mm^3 \times 0.066\ g/m^3) + (0.92\ Mm^3 \times 0.24/2\ g/m^3) =$ **206 kg**

assuming a flow of 2.3 Mm^3, 40 % of the flow when the lake is ice free and a two fold dilution. The Zn concentration used while the lake is ice covered is the mean Zn concentration in 1987 to the end of July in Garrow Creek – in 1987 there was natural outflow from Garrow Lake and surface layer Zn concentrations were similar (0.23 ppm).

iii) Post-Mine with halocline Zn maximum mixed into the surface layer

Under these worst case conditions the surface layer Zn concentration is predicted to be 0.31 ppm.

The maximum loading in Garrow Creek would be:

$(1.38\ Mm^3 \times 0.12\ g/m^3) + (0.92\ Mm^3 \times 0.31/2\ g/m^3) =$ **308 kg**

Using the same assumptions as in ii) above, with the exception that the Zn concentration while the lake is ice covered is that observed in 1989 when surface layer Zn concentrations were similar (see below).

iv) Actual Zinc loading in 1989

This was the last year that there was natural outflow from Garrow Lake and the lake cleared of ice. Zinc concentrations reached 0.36 ppm in the surface layer (due to a tailings line failure in 1985) similar to the example above. The total flow was 1.5 Mm^3 with 79 % of the flow occurring by July 31. The Zn loading was:

June 19 – July 31:	143 kg
August 1 – September 17:	21 kg
Total	**164 kg**

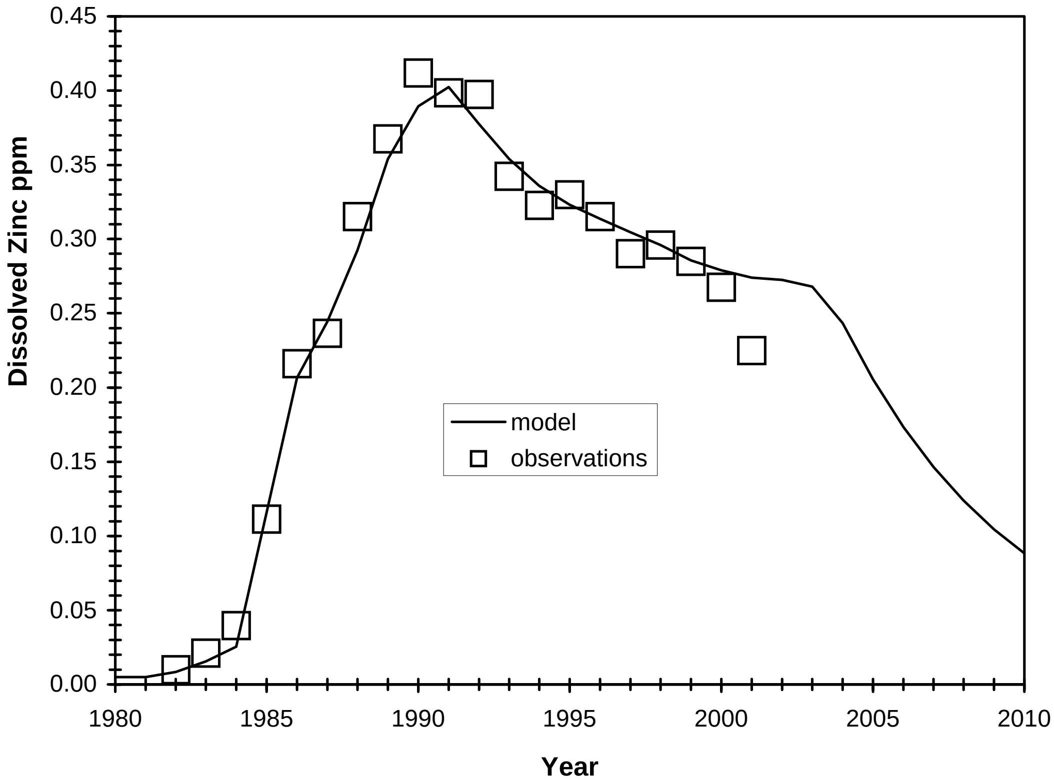

Figure 1. Predicted and Observed Concentrations of Zinc in the Surface Layer of Garrow Lake 1980 - 2010

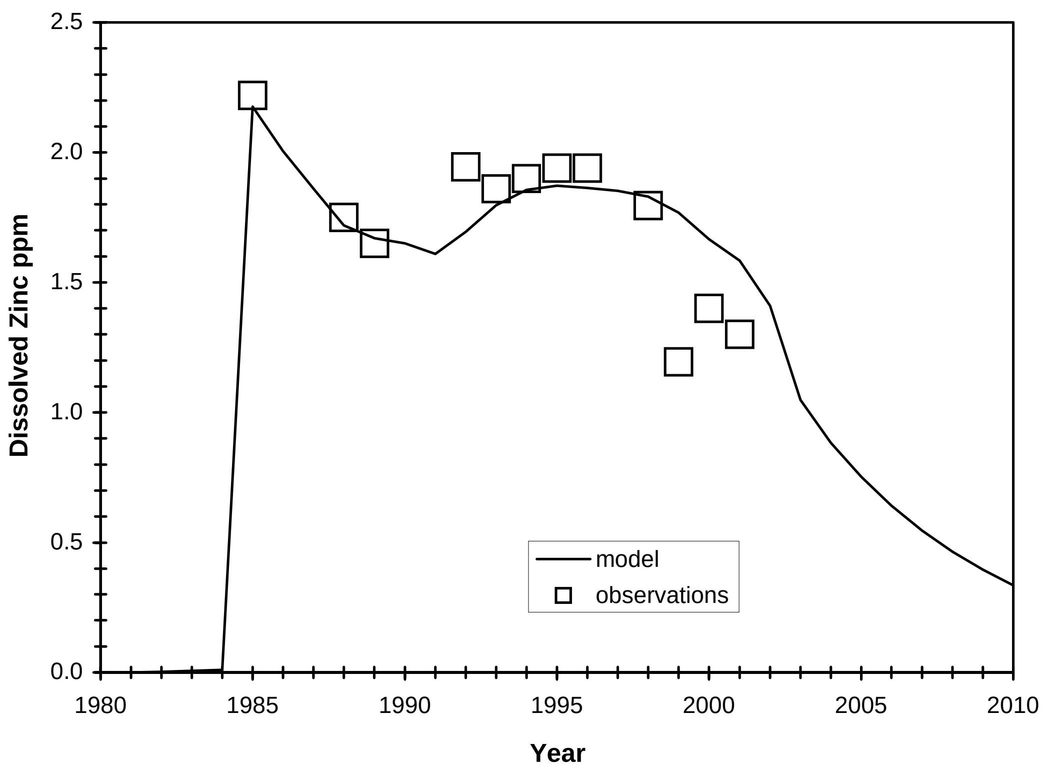

Figure 2. Predicted and Observed Maximum Concentrations of Zinc in the Halocline of Garrow Lake 1980 – 2010

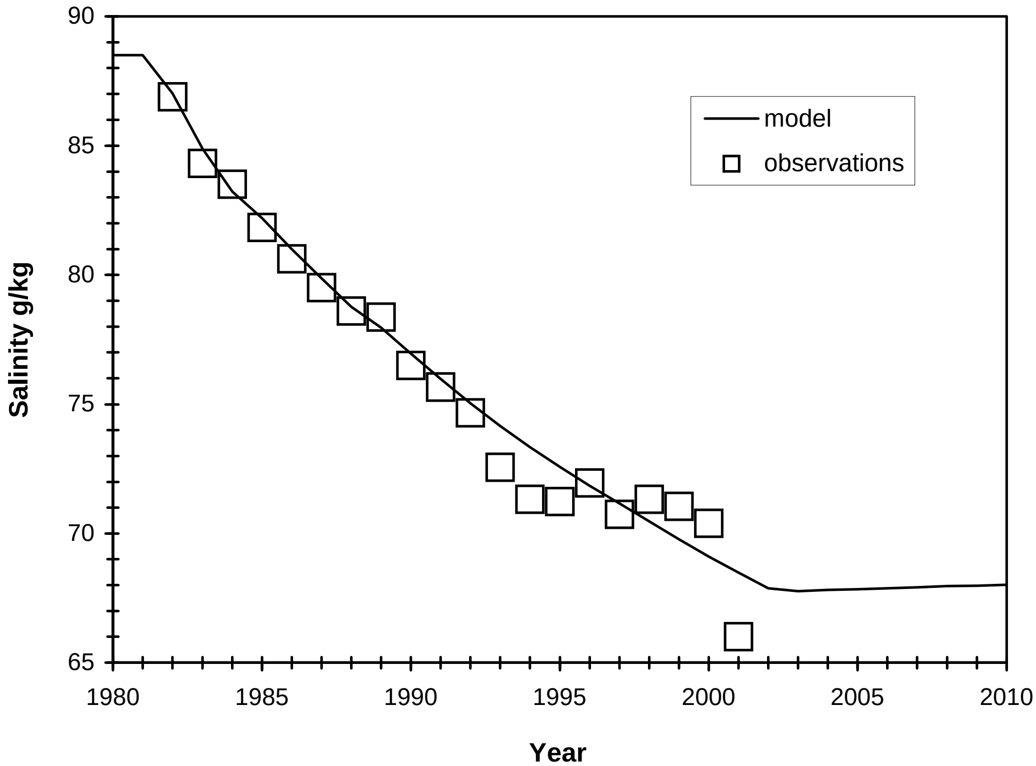

Figure 3. Predicted and Observed Salinity in the Bottom Layer of Garrow Lake 1980 – 2010

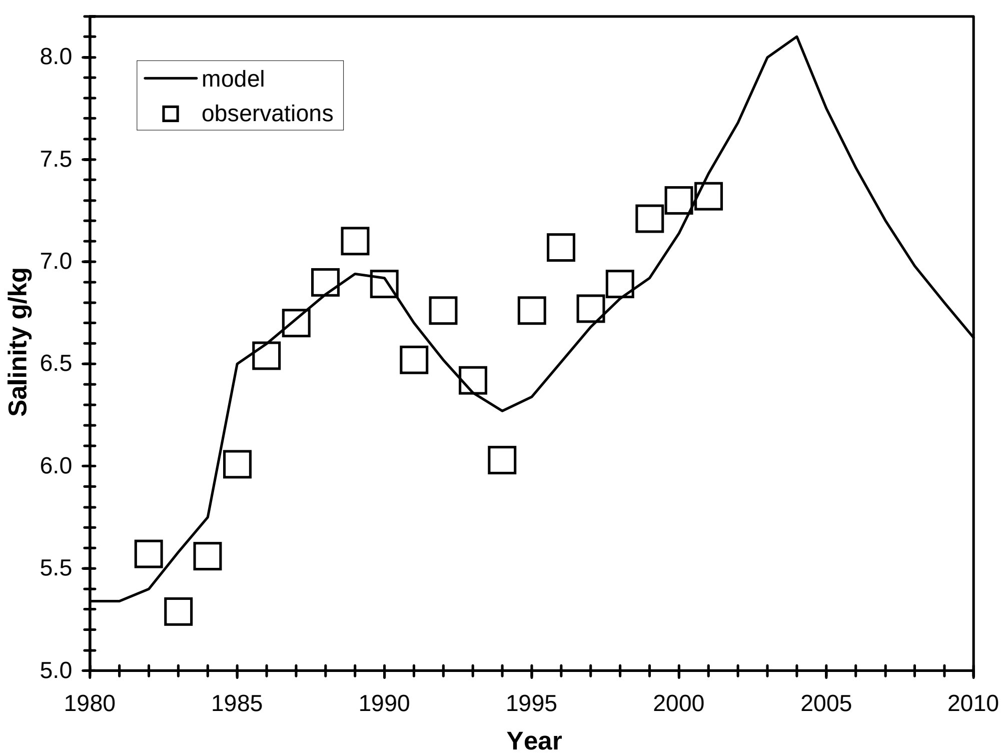

Figure 4. Predicted and Observed Salinity of the Surface Layer of Garrow Lake 1980 – 2010

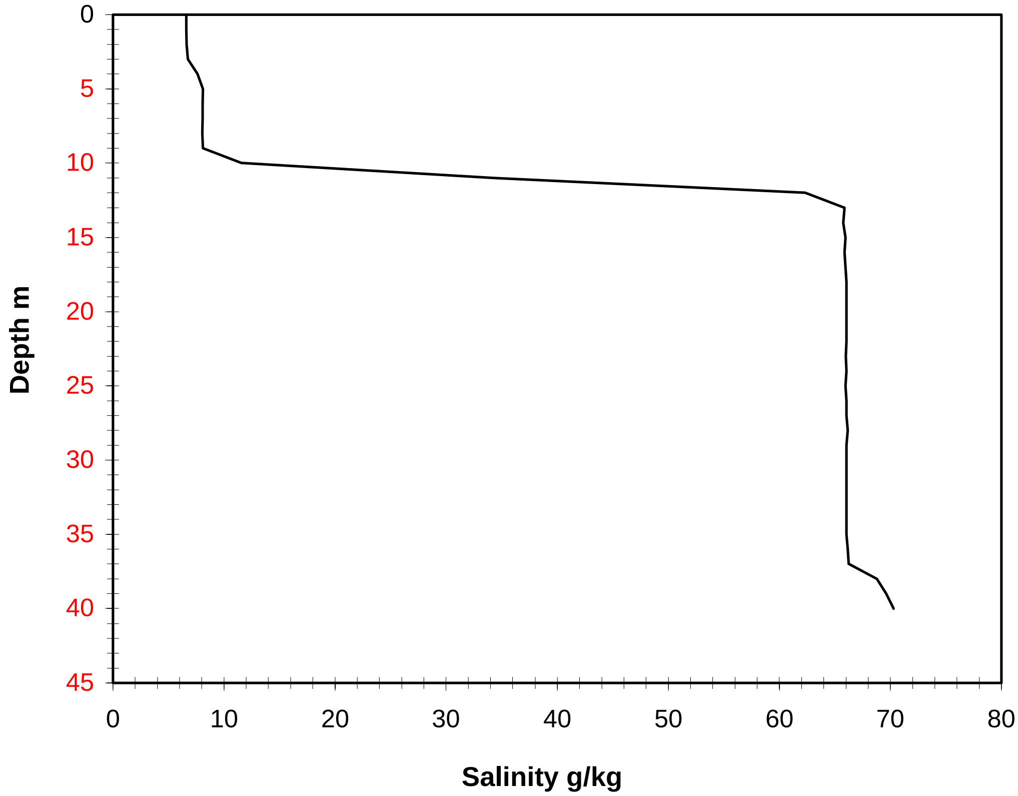

Figure 5. Salinity – Depth Profile, Garrow Lake January 2001