THE EFFECTS OF SMALL DAMS ON WATER QUALITY

Al Sandilands
Biologist
Forestry and Wildlife Branch
Operations Division
Grand River Conservation Authority

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Introduction

Because of the many mill dams and weirs in the Grand River watershed, we thought it desirable to know what effect these small dams had on water quality. It is well known that they often form a barrier to migrating fish and some aquatic invertebrates but actual chemical and physical differences have not often been determined.

To study the effects of the mill dams, 24 hours were spent at the Queen Street dam in Galt and at the Bissel dam in Elora. Water samples were taken above and below the dam at the same time and analyzed for the various parameters using a Hach DR-EL kit. Members of the survey crew were careful to take all samples from exactly the same spot.

Since temperature was recorded only to the nearest and dissolved oxygen concentrations to the nearest 0.2 mg/L, dissolved oxygen saturations may vary approximately 2 percent.

The effects of small stone dams on oxygen and temperature were recorded from Black Creek, approximately 200 yards below the Luther dam. Two stations were set up as a control. One day later a small rock dam was constructed below the upper station. This dam raised the water level approximately 6 inches at the first station. At this time another station was initiated below the upper dam.

Another dam of the same size was constructed below the bottom station with another station started below the second dam. This experiment was to evaluate this type of structure as a stream improvement device.

Curves of oxygen saturations above and below the. Galt and Elora dams are in Appendix I. Results of the other chemical parameters tested at these two dams are also in the first appendix. A summary of results from the small dams at Luther is in Appendix II.

A. Mill Dams

1. Water Temperature

At both the small dams studied, water below the dam averaged slightly cooler than above over the period of a day.

At the Galt dam, the high water temperature above the dam was 29.0°C while it was only 27.5°C below the dam. The low temperature above and below the dam was 22.0°C.

At the Elora dam, 18.0°C was the highest water temperature measured both above and below the dam. However, the lowest temperature above the dam was 15.0°C while 14.0°C was the minimum recorded below.

The average water temperature below the Galt dam was 0.3°C lower than above while the average below the Elora dam was 0.2°C cooler than above.

The action of the water falling over the dam does cool the temperature slightly due to increased evaporation. This is a desirable feature but it must be kept in mind that it is usually the lake created by the dam that initially raises the water temperature.

2. Dissolved Oxygen

Oxygen is the most important element both in the aquatic and terrestrial ecosystems. The amount of dissolved oxygen present in water determines the species of invertebrates and fish that are capable of living in the water. The absence of oxygen in water promotes growth of anaerobic bacteria which produce hydrogen sulphide and nitrites.

The amount of dissolved oxygen present in running water depends on a variety of other parameters. One of these parameters is water temperature. The higher the temperature of the water, the less oxygen the water is capable of dissolving. In a fairly pure stream, oxygen concentrations are usually at or very near saturation. Thus, in unenriched streams oxygen concentrations follow a daily cycle of being higher at night and lower during the day although the water is saturated in oxygen at all times.

In streams having large amounts of algae present, the daily oxygen cycle is reversed. During the daylight hours aquatic plants photosynthesize their food, converting dissolved carbon dioxide in the water into dissolved oxygen. As a result, daytime oxygen concentrations are often supersaturated. At night, plant photosynthesis ceases so that no oxygen is produced by the plants. The plant respiration often lowers the dissolved oxygen concentration well below the saturation level. Thus, in enriched streams having large amounts of aquatic plants, the daily oxygen cycle is reversed with oxygen concentrations often being super-saturated during the day and undersaturated at night. This daily rhythm is more apparent in a shallow river such as the Speed, than in a deeper river such as the Grand. In deep areas of the Grand, attached algae are usually absent as sunlight cannot reach the bottom due to the turbidity of the water. However, deeper areas are usually slower in flow and often support viable populations of phytoplankton. The phytoplankton exert the same influence on oxygen concentrations as do larger plants, but usually to a lesser degree. Many areas in the Speed River are shallow and almost stagnant so that they support both types of algae with a correspondingly more marked oxygen cycle.

The Galt dam and the Elora dam are similar in that the water behind them is deep, turbid and affected primarily by phytoplankton. Overall results from both dams were very similar but the two showed different oxygen saturation curves above the dam. (See Appendix I).

At the Elora dam, oxygen saturations above the dam were supersaturated in the afternoon. Concentrations dropped slowly at night, reaching a low of 29.4% saturation at 11:00 a.m. Saturations went to a high of 79.5% in the afternoon and then started to drop again. This curve is almost what would be expected except that oxygen saturations should have gone over 100% the second afternoon. However, during the second day, the water was coloured green with algae, which were probably the blue-green algae *Aphanizomenon flos-aquae* or *Oscillatoria*. (Duthie, 1968) These algae coating the water would utilize oxygen because of the biochemical oxygen demand that their lifeless masses would exert. In addition, the only source for re-aeration of a body of water is diffusion through the surface from atmospheric oxygen. The coating of dead algae on the water's surface would reduce re-aeration and prevent light from penetrating so that other algae could photosynthesize.

Below the Elora dam oxygen concentrations and saturations were more constant than above. Dissolved oxygen concentrations ranged from 5.4 to 8.8 mg/L below and 3.0 to 10.4 mg/L above while percent saturations ranged from 52.9 to 89.5 percent below end 29.4 to 108.3 percent above. When the water above the dam was supersaturated with oxygen, the turbulence created by falling over the dam removed any excess oxygen. When oxygen saturations were low above the dam, the turbulence increased oxygen concentrations slightly. When falling over a dam, more surface area of the water is exposed to the air so that re-oxygenation proceeds quicker. Oxygen concentrations below the dam were more constant and averaged slightly higher during the sampling period, but re-aeration was not as great as is often believed.

The oxygen curve above the Galt dam was very odd with oxygen concentrations being generally supersaturated at night and low during the day. The high nocturnal oxygen concentrations cannot readily be explained. The reservoir behind the Gait dam extends for a considerable distance upstream. The water in the reservoir is turbid and near the dam it is fairly deep. The depth and turbidity would allow only phytoplankton to photosynthesize at the dam while submerged vegetation is also present at the shallower upstream end of the reservoir. Oxygen saturations at the dam should then remain fairly constant while saturations would he high during the day and low at night at the upstream end of the reservoir. The effects of plant photosynthesis and respiration at the top of the reservoir may have been sufficient to affect the entire reservoir.

Thus, the oxygen concentrations at the dam would depend on the oxygen cycle above the reservoir and the amount of time it took the water to flow from above the reservoir to the dam. The extremes in oxygen concentrations above the reservoir would be buffered somewhat as the water flowed through the reservoir. Night time lows experienced above the reservoir would increase the next day before reaching the dam due to absorption of oxygen from the atmosphere and phytoplanktonic photosynthesis. Daytime highs would be lowered in the reservoir at night because of phytoplankton respiration. This is merely an attempt to explain the inverted oxygen curve above the Galt dam and needs further studying before this theory is proven or disproven.

However, the action of the water flowing over the dam at Galt produced essentially the same results as at Elora. When the water above the dam was supersaturated in oxygen, flowing over the lam removed the excess oxygen. When the water above the dam was deficient in oxygen, concentrations were usually increased below the dam. Oxygen concentrations above the dam ranged from 5.6 to 10.6 mg/l. and 6.4 to 9.9 mg/L below. The percent oxygen saturation above the dam ranged from 62.8 to 119.1 percent while below the range was 72.7 to 103.3 percent.

Thus, it may be concluded that small dams remove excess oxygen from water and tend to increase the rate of re-aeration in an oxygen deficient stream. However, the increase in oxygen concentrations below dams is slight and oxygen saturations below dams are not constantly 100 percent saturated.

3. pH

The pH is a measure of the concentration of hydroxyl ions in the water and therefore represents the alkalinity or acidity of the water. The pH undergoes a daily cycle which depends primarily upon the oxygen and carbon dioxide concentrations.

Oxygen and carbon dioxide are usually mutually exclusive in water. That is, when oxygen concentrations are high carbon dioxide concentrations are low and vice versa. The presence of carbon dioxide results in the formation of carbonic acid and a correspondingly lower pH. High oxygen concentrations result in no free carbon dioxide and therefore no carbonic acid. High oxygen concentrations go hand in hand with high pH.

In streams where active plant photosynthesis was taking place, one would expect a high daytime pH and a lower pH during the night. In addition, one would expect less daily variation in pH below a small dam as occurs with oxygen.

At the Elora dam, pH below the dam was generally higher at night and lower in the hours from 10:00 a.m. to 4:00 p.m. This time of day is also when the greatest variations occurred between the stations above and below the dam. Contrary to what was expected, the variation in pH below the dam was greater, ranging from 7.05 to 8.80 while the range above was 7.60 to 8.65.

On the two occasions when oxygen concentrations above the dam were supersaturated, the pH readings above and below the dam were exactly the same. When oxygen concentrations were saturated there would be no carbon dioxide present. Although oxygen concentrations below the dam were less on these two occasions, there would be no carbon dioxide present above or below the dam so that the pH should be the same.

During the night, there appeared to be a slight increase in pH below the dam regardless of whether the dissolved oxygen concentration below the dam was higher or lower than above the dam. Carbon dioxide in water is readily lost to the atmosphere so that the action of falling over the dam would remove any carbon dioxide that had been present and thus raise the pH.

The lower pH values recorded below the Elora dam during the day may be related to the occurrence of the blue-green algae which were present. When the cells of many species of blue-green algae are broken, they release dyes or chemicals which drastically affect water quality. Many of these algae produce substances that are toxic. It is probable that many of these cells broke upon falling over the dam and released an acidic chemical which lowered the pH.

At the Galt dam the pH was closer to what was expected with the range below the dam being much less and usually the reading was the same or higher than above the dam. The range in pH above the dam was 6.60 to 8.70 while below it was 8.00 to 8.67. The average pH above was 8.31 and the average below the dam was 8.47.

Under normal circumstances, pH below a dam should be the same as or slightly higher than the pH above a dam. The turbulence of the water falling over the dam removes much of the carbon dioxide present, thus raising the pH. If there is no carbon dioxide present above the dam, pH above and below the dam should be essentially the same. This is an oversimplification as there may be changes in concentrations of many other chemicals that would affect the pH.

4. Iron

Although iron concentrations averaged less below both dams than above, no real pattern was observed. Practically all of this iron recorded can be attributed to industrial and municipal wastes rather than natural. Iron concentrations in a river of this size should be almost zero at the surface at all times. The slightly lower concentrations below the dams may he because some of the iron is trapped behind the dam.

5. Copper

Concentrations of copper above and below the Galt dam were virtually the same.

6. Nitrate Nitrogen

Only eight observations were made so that it is not safe to make many conclusions. Below the dam, nitrate concentrations averaged slightly lower and the high nitrate concentration recorded was 0.5 mg/L lower below the dam. This suggests that the turbulence may remove some nitrate from the water but occasionally concentrations were higher below the dam than above. Neel (1951) also reports that nitrogen and phosphorus concentrations dropped after the stream passed through riffles.

7. Soluble Phosphorus

Results of the tests from the Elora Bissel dam showed that soluble phosphorus concentrations averaged slightly less below the dam than above. However, this difference was so slight that it is almost insignificant.

8. Chloride

No difference was noted in chloride concentrations above and below the dam.

9. Chlorine

Concentrations below the dam were slightly lower than above. Chlorine normally loses its strength quickly in water. The action of falling over the dam just speeds up this process slightly.

Summary of the Effects of Mill Dams

It was found that water was cooled slightly by falling over the dam. However, it is usually the lake behind the dam that increases the water temperature initially.

The dams tended remove excess oxygen from the water and to speed up re-aeration when the water was oxygen deficient. The oxygen saturations below a small dam are more constant than above, but water below a dam is not always saturated with oxygen.

The turbulence created by a small dam usually removes much carbon dioxide from the water. When there is no carbon dioxide present above the dam, the pH below the dam remains the same as above. When carbon dioxide is present above, there is usually an increase in pH below. There are ether compounds and organisms which may be affected by dams which would also alter the pH so that this is an oversimplification of the problem.

No differences were found in copper and chloride concentrations above and below the dams.

Nitrate, soluble phosphorus, iron and chlorine appeared to have slightly lower concentrations below the dams than above. These differences were not greet or significant.

About the only significant improvement that mill dams make on water quality is the decrease in dissolved oxygen fluctuations. However, there was still considerable variation in the oxygen saturations.

Generally speaking, mill dams tend to have somewhat better water quality below them than above. However, the poorer water quality above the dam is often a direct result of the dam itself. The creation of a small impoundment results in higher water temperatures which often encourage algae blooms and growths of submerged aquatic plants in the shallower areas. These plants cause the fluctuations in oxygen concentration that often result in fish kills or stagnant waters. In waters that were previously cool and unenriched, a mill dam would cause deleterious results with the water below the dam, although better in quality than that in the dam, worse than the water flowing into the dam. In streams that are already warm and enriched, the water below the dam might well be of slightly better quality than the inflowing water. To create a mill dam with improving the water quality as the main reason is not valid.

B. Small Stone Dams

After construction of the dams, the average oxygen concentration below each dam was slightly higher than above. (See Appendix II for results.) The average percent oxygen saturation was slightly higher below the first dam and slightly lower below the second dam. At both dams, water temperatures averaged 0.3°C lower below the dam than above.

A comparison of the results from above each of the two dams before and after dam construction shows that dissolved oxygen concentrations an dissolved oxygen saturations increased slightly after construction while water temperatures fell slightly.

It is doubtful if these differences in oxygen concentrations and temperatures would be statistically valid. A difference of only 0.3 ppm of dissolved oxygen and 0.5 to 0.8°C in temperature will not noticeably improve habitat for aquatic life even if the results are statistically valid.

It was noticed that a large number of the smaller minnow species had difficulty in going through or getting over these dams. If the sole purpose of these dams was to improve water quality, it is suggested that the dam only extend approximately three-quarters of the way across the stream. This would result in faster, better aerated water running through the open quarter of the stream and a deep pool or eddy in the other three-quarters below the dam. This would provide a more varied habitat plus cooler, better aerated water.

ACKNOWLEDGEMENTS

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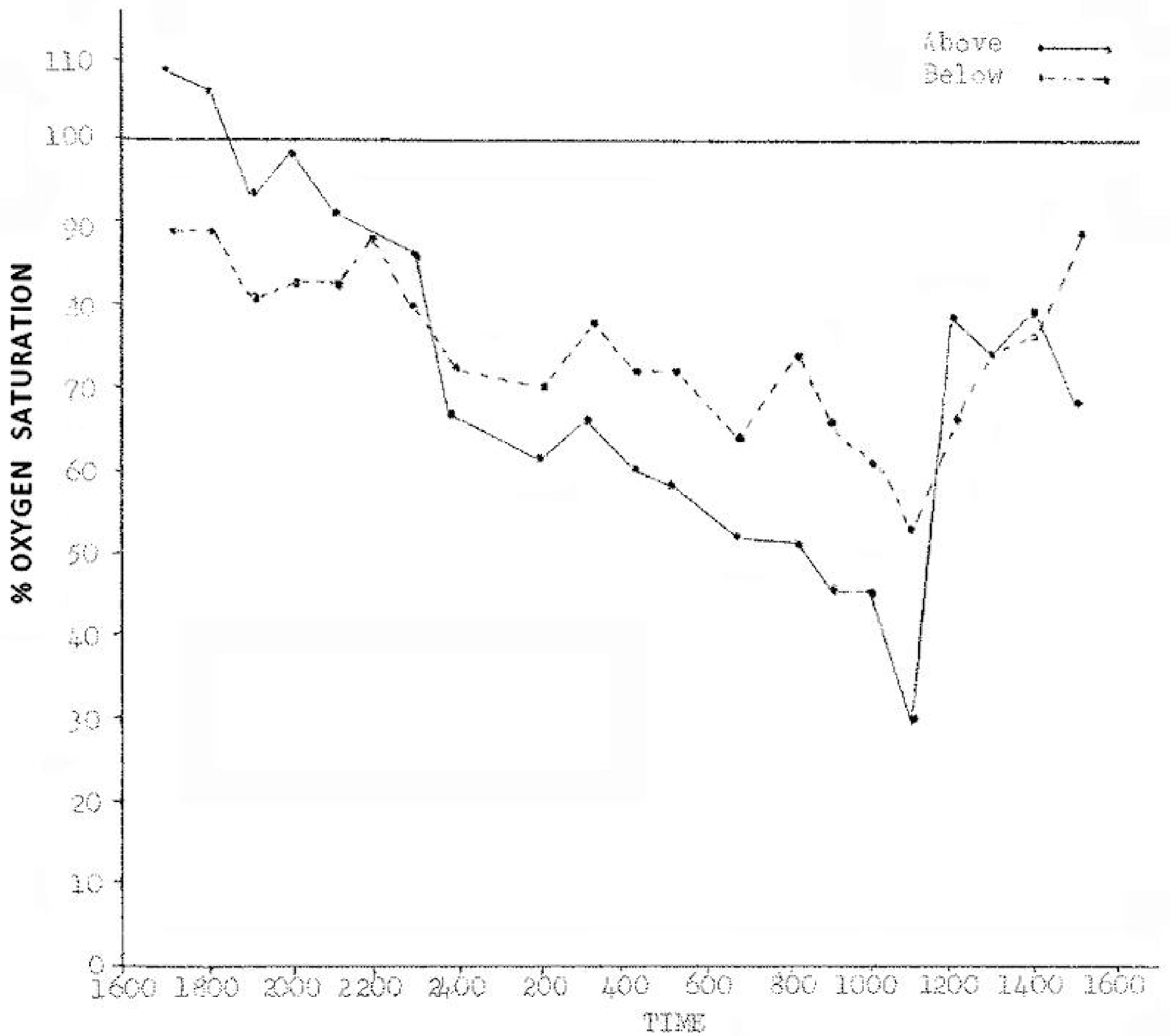
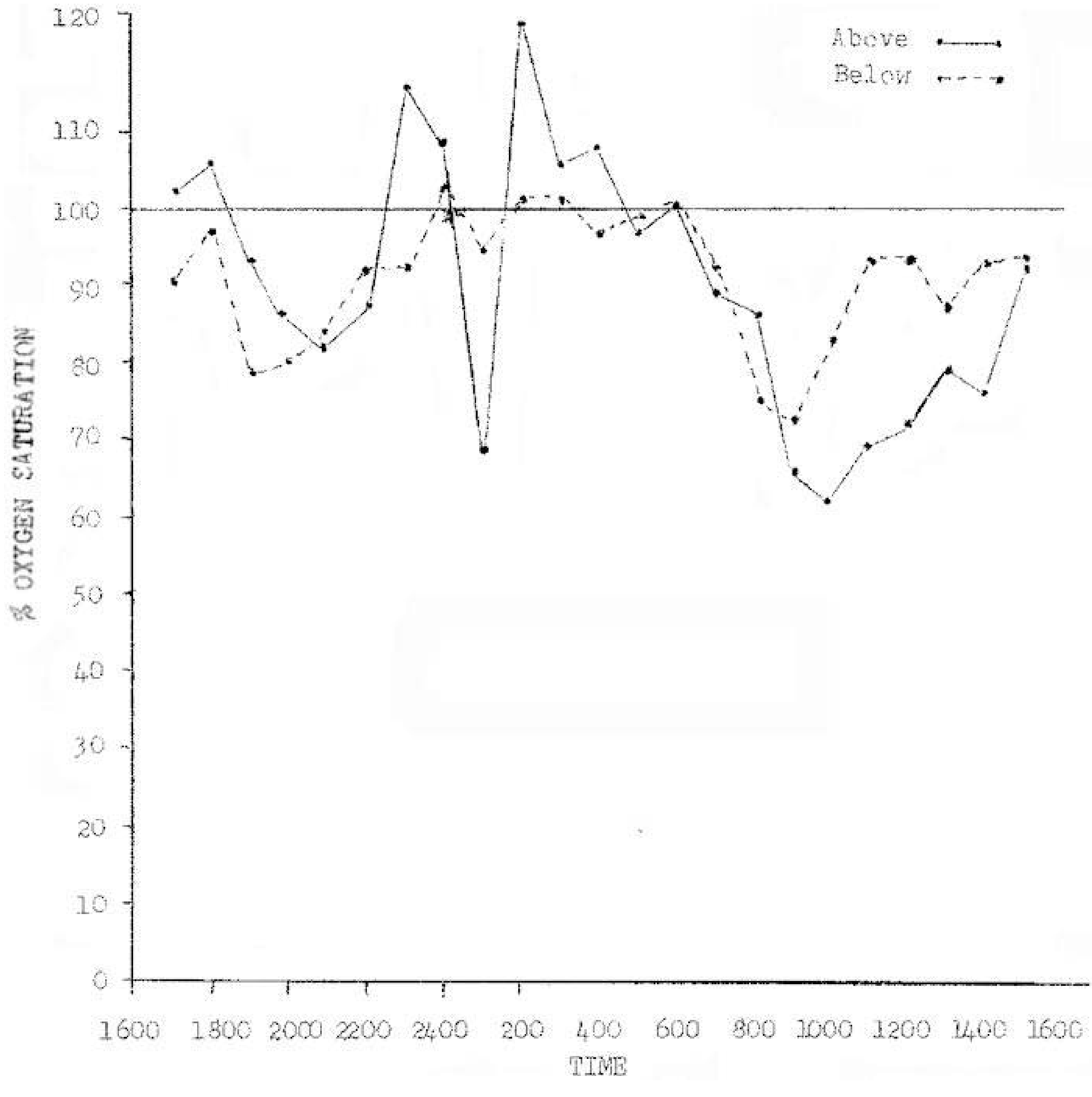
APPENDIX I

GRAPHS AND TABLES
FROM
THE ELORA AND GALT DAMS

Elora Bissel Dam Oxygen Saturations, September 21-22, 1972



Galt Dam Oxygen Saturation, August 31 - September 1, 1972



Elora Bissel Dam, September 21-22, 1972

Location	Time	D.O.	Water Temp.	% Satn.	o-PO_4	Cl^-	Fe	pH
Above	17:00	10.4	18.0	103.3	0.005	5	0.00	8.65
Below		8.6	18.0	89.5	0.15	10	0.05	8.65
Above	18:00	10.2	18.0	106.2	0.10	5	0.00	8.60
Below		8.6	18.0	89.5	0.10	5	0.00	8.60
Above	19:00	9.0	13.0	93.7	0.08	5	0.00	8.40
Below		7.8	16.0	81.2	0.05	7.5	0.00	8.50
Above	20:00	9.6	17.0	97.9	0.07	5	0.00	8.3
Below		8.2	17.0	83.6	0.04	7.5	0.00	8.4
Above	21:00	9.0	17.0	91.8	0.15	5	0.00	8.2
Below		8.2	17.0	83.6	0.06	10	0.00	8.4
Above	22:00	8.8	16.0	88.0	0.15	7.5	0.00	8.2
Below		8.8	16.0	88.0	0.06	10	0.00	8.3
Above	23:00	8.6	16.0	86.0	0.10	7.5	0.00	8.1
Below		8.0	16.0	80.0	0.07	7.5	0.00	8.4
Above	00:40	6.8	15.0	66.6	0.00	15	0.1	8.45
Below		7.4	15.0	72.5	0.00	15	0.0	8.6
Above	2:00	6.2	16.0	62.0	0.00	0	0.0	6.5
Below		7.0	15.0	70.0	0.00	10	0.0	8.6
Above	3:10	6.6	16.0	66.0	0.00			
Below		7.8	16.0	78.0				
Above	4:15	6.0	15.0	60.0	0.00	10	0.0	8.50
Below		7.2	16.0	72.0	0.02	10	0.0	8.55
Above	5:05	6.0	15.0	58.8	0.00	10	0.0	8.4
Below		7.4	15.0	72.5	0.00	10	0.0	8.5
Above	6:45	5.4	15.0	52.9	0.00	10	0.0	8.4
Below		6.6	12.0	63.4	0.00	12.5	0.05	8.5
Above	8:15	5.2	15.0	50.9	0.10	10	0.09	8.5
Below		7.6	15.0	74.5	0.10	10	0.00	8.35
Above	9:00	4.6	15.0	45.6	0.10	10	0.01	8.4
Below		6.8	14.0	65.3	0.05	10	0.05	8.8
Above	10:00	4.6	15.0	45.0	0.10	7.5	0.05	8.3
Below		6.2	15.0	60.7	0.05	7.5	0.08	7.8

Elora Bissel Dam, September 21-22, 1972.

Location	Time	D.O.	Water Temp.	% Satn.	$o\text{-}PO_4$	Cl^-	Fe	pH
Above	11:00	3.0	15.0	29.4	0.03	10	0.00	8.2
Below		5.4	15.0	52.9	0.03	10	0.00	7.05
Above	12:00	7.6	17.0	77.5	0.05	7.5	0.10	8.5
Below		6.4	17.0	65.3	0.08	10	0.05	8.2
Above	13:00	7.4	16.0	74.0	0.04	10	0.11	7.6
Below		7.4	16.0	74.0	0.06	10	0.00	7.3
Above	14:00	7.8	17.0	79.5	0.05	7.5	0.03	8.2
Below		7.6	16.0	76.0	0.04	10	0.00	7.6
Above	15:00	6.6	17.0	67.3	0.08	7.5	0.01	8.0
Below		8.8	16.0	88.0	0.05	10	0.02	8.2
		Range	Range	Range	Range	Range	Range	Range
Above		3.0 - 10.4	15.0 - 18.0	29.4 - 108.3	0.00 - 0.15	0 - 15	0 - 0.11	7.6 - 8.45
Below		5.4 - 8.8	14.0 - 18.0	52.9 - 89.5	0.00 - 0.15	5 - 15	0 - 0.08	7.05 - 8.80
		Av.	Av.	Av.	Av.	Av.	Av.	Av.
Above		7.1	16.2	71.8	0.055	7.75	0.025	8.32
Below		7.5	16.0	75.2	0.050	8.63	0.016	8.27

Galt Dam, August 31 - September 1, 1972.

Location	Time	D.O.	Water Temp. (°C)	% Satn.	Iron	Copper	Nitrate	pH	Chlorine
Above	16:00	10.4			0.05		0.37	8.40	
Below		6.4			0.05		1.00	8.55	
Above	17:00	8.0	29.0	102.6	0.00		1.5	8.61	
Below		7.2	27.5	90.0	0.00		0.99	8.63	
Above	18:00	8.2	29.6	105.1	6.00		0.88	8.69	
Below		7.8	27.5	97.6	0.00		0.90	8.35	
Above	18:55	8.0	24.0	93.0	0.01		0.95	8.57	
Below		6.8	23.0	78.2	0.00		0.89	8.60	
Above	19:45	7.4	23.5	86.7	0.00	0.05	0.76	8.65	
Below		7.0	22.5	79.5	0.00	0.05	0.70	8.40	
Above	20:45	7.2	23.0	82.8	0.18	0.05	0.87	8.65	
Below		7.4	22.0	83.1	0.00	0.05	0.87	8.65	
Above	22:00	7.6	23.0	87.4	0.05	0.05	0.59	8.70	
Below		8.0	23.0	92.0	0.00	0.05	0.65	8.60	
Above	23:00	10.2	23.0	116.0	0.15	0.10	0.50	8.70	
Below		8.0	23.0	92.0	0.05	0.08	0.60	8.67	
Above	24:00	9.4	23.0	108.0					
Below		9.0	23.0	103.3					
Above	1:00	6.0	23.0	69.0					
Below		8.2	23.0	94.3					
Above	2:00	10.6	22.0	119.1					
Below		9.0	22.0	101.1					
Above	3:00	9.4	22.0	105.1					
Below		9.0	22.0	101.1					
Above	4:00	9.6	22.3	107.9					
Below		8.6	22.0	96.6					
Above	5:00	8.6	22.0	96.6					
Below		8.8	22.0	98.8					
Above	6:00	9.0	22.0	101.1					
Below		9.0	22.0	101.1					
Above	7:00	8.0	22.0	89.9					
Below		8.2	22.0	92.1					

Galt Dam August 31 - September 1, 1972.

Location	Time	D.O.	Water Temp.°C	% Satn.	Iron	Copper	Nitrate	pH	chlorine
Above	8:10	7.6	22.9	86.4	0.10	0.12		8.53	0.015
Below		6.6	22.5	75.0	0.08	0.15		8.57	0.010
Above	9:05	5.8	22.5	63.9	0.05	0.03		7.45	0.010
Below		6.4	22.5	72.7	0.08	0.095		8.45	0.045
Above	10:00	5.6	23.0	62.8	0.05	0.05		8.40	0.055
Below		7.4	23.0	83.1	0.04	0.03		8.46	0.015
Above	11:00	6.0	23.5	69.8	0.36	0.05		6.60	0.045
Below		8.0	23.5	93.0	0.075	0.08		8.40	0.015
Above	12:00	6.2	24.0	72.1	0.03	0.05		8.10	0.085
Below		8.0	23.5	93.0	0.075	0.05		8.48	0.075
Above	13:00	6.8	24.0	79.1	0.03	0.12		8.10	0.085
Below		7.6	23.5	87.4	0.35	0.12		8.30	0.070
Above	14:00	6.6	24.0	76.6	0.10	0.05		8.42	0.070
Below		8.0	23.5	93.0	0.09	0.11		8.42	0.060
Above	15:00	7.8	25.0	92.9	0.05	0.09		8.39	0.052
Below		8.0	24.0	93.0	0.03	0.03		8.00	0.041
Above	<u>Range</u>	5.6 - 10.6	22.0 - 29.0	62.8 - 119.1	0.00 - 0.36	0.03 - 0.12	0.50 - 1.50	6.60 - 8.70	0.010 - 0.085
Below		6.4 - 9.0	22.6 - 27.5	72.7 - 103.3	0.00 - 0.33	0.03 - 0.15	0.60 - 1.00	8.00 - 8.67	0.010 - 0.075
Above	<u>Aver.</u>	7.91	23.5	90.3	0.08	0.068	0.865	8.31	0.052
Below		7.85	23.2	90.9	0.06	0.079	0.825	8.47	0.041

APPENDIX II

SUMMARY OF RESULTS FROM BLACK CREEK

BLACK CREEK - LUTHER

	Station BC1		Station BC2	
	Above	Below	Above	Below
Range of Dissolved Oxygen (mg/L)	5.2 - 8.8	3.2 - 9.2	5.6 - 9.8	6.6 - 8.4
Average Dissolved Oxygen (mg/L)	7.13	7.21	7.24	7.43
Range of Oxygen Saturations (%)	57.7 - 104.7	35.5 - 109.5	62.9 - 116.6	70.2 - 96.5
Average Oxygen Saturations (%)	78.76	79.37	80.38	79.21
Average Water Temperature (°C)	20.9	20.6	21.0	20.7
No. of Observations	111	66	109	29

	Above Station BC1		Above Station BC2	
	Before Dam	After Dam	Before Dam	After Dam
Range of Dissolved Oxygen (mg/L)	5.2 - 8.2	6.2 - 8.8	5.6 - 9.8	6.6 - 8.2
Average Dissolved Oxygen (mg/L)	6.92	7.28	7.16	7.44
Range of Oxygen Saturations (%)	57.7 - 93.1	67.3 - 109.5	62.9 - 116.6	71.7 - 94.2
Average of Oxygen Saturations (%)	77.16	83.56	78.79	82.08
Average Water Temperature (°C)	21.4	20.6	21.2	20.7
No. of Observations	45	66	80	29