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An evaluation of the effects of enhanced  
thermal loading in Port Hope Harbour,  
Lake Ontario

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A.J. Niimi<sup>1</sup> and P.F. Hamblin<sup>2</sup>

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## ABSTRACT

The heat input into Port Hope Harbour may be increased by nearly two-fold if the proposed expansion of an industrial facility becomes operational. There was some concern about the increased loading on the movement of rainbow trout in the Ganaraska River. Temperature measurements collected between February-September, 1981, were applied to estimate the probable change in temperature at the confluent of the Ganaraska River. It was concluded that surface water temperatures at the confluent could increase up to four Celsius degrees during the spring. During the summer, heat input from the atmosphere was substantially greater than that from the present facility, and that the additional loading could increase water temperatures by one Celsius degree. It was therefore suggested that the proposed increase in heat load into Port Hope Harbour could have some effects on the upstream movement of fish during the spring, and little or no effects on the downstream movement of young fish during the summer and fall. Based on limited scientific evidence, it was concluded that the impact of the proposed project on the rainbow trout fishery in the Ganaraska River would not be a serious factor.

## Introduction

It is proposed to increase the operating capacity of a large plant by replacing an existing facility with a larger one. The heated effluent from the plant complex is presently being discharged into Port Hope Harbour and the proposed modification would almost double this load.

The entrance to Port Hope Harbour includes a 210 m section of the Ganaraska River at its mouth on Lake Ontario (Fig. 1). There is some concern that the proposed increase in heat load could alter the migratory movements of rainbow trout (Salmo gairdneri) in this section of the river. In the early 1970's, the Ontario Ministry of Natural Resources initiated a long-term program that would improve the rainbow trout fishery in the Ganaraska River. Through intensive habitat enhancement and management, the number of adult fish passing through the fishway at Port Hope during the spring spawning run increased from 500 fish in 1974 to 7300 fish in 1981. With continued efforts, it is anticipated that this population will continue to increase. This program has made the Ganaraska River the most important rainbow trout river on Lake Ontario.

There are two periods during the year when water temperature becomes an important factor for trout using this river. Adult fish move upstream during the early spring to spawn and return to the lake shortly thereafter, and young fish move downstream during the summer into the lake. The movement of adult fish upstream peaks during mid-March to mid-April and is strongly influenced by water temperature and probably flow rate. Counts at the fishway indicate the upstream movement is most pronounced on days when water temperatures of 7-9 C in the morning increase to 12-13 C in the early afternoon with increased flow rates. There is some concern that the increased heat loading may influence the upstream migration of the fish in

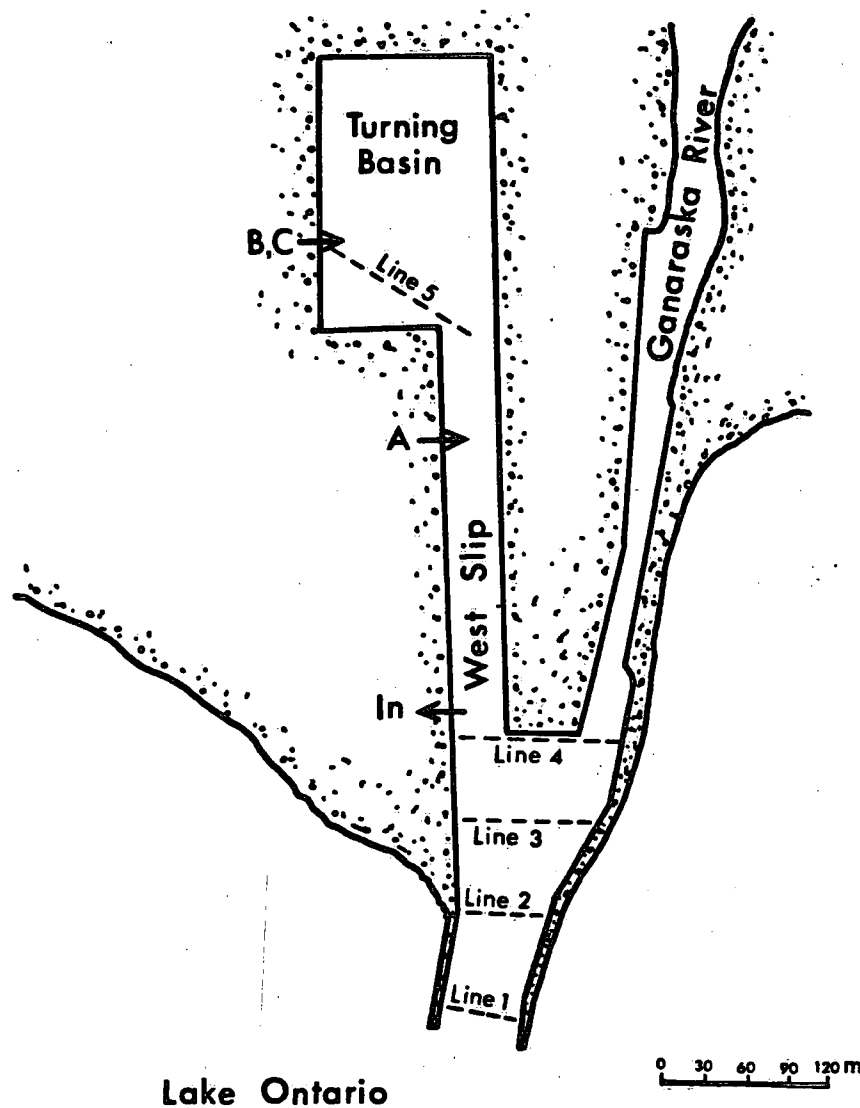


Fig. 1. Port Hope Harbour and Ganaraska River area. Locations of the plant cooling water intake (In), Facility A water return (A), Facility B water return (B), and the proposed Facility C water return (C) are indicated. Lines 1-5 indicate the temperature sampling transects reported in ENL (1982).

the spring, or increase water temperatures in excess of 25 C which could be lethal to the young fish moving downstream.

A series of ten temperature profile measurements were taken between February to September to assess the impact of the heat increment on water temperatures in the harbour and confluence of the Ganaraska River (ENL, 1982). Temperatures were taken at different depths from the surface to bottom along 5 transect lines (Fig. 1).

#### Proposed Plant Modification and Water Discharges

There are two facilities now in operation that account for most of the heated effluent being discharged into the harbour. Facility A discharges 1500 L/min effluent which contains  $0.9 \times 10^4$  Kcal/min into the West Slip, while Facility B discharges 5000 L/min and  $6.1 \times 10^4$  Kcal/min into the Turning Basin at the present time (Fig. 1). Approximately 9000 L/min cooling water is being drawn in near the harbour entrance to meet the plant's present requirements.

The proposed expansion would replace Facility B with Facility C which could discharge 12130 L/min containing  $12.6 \times 10^4$  Kcal/min through the outlet presently used by Facility B (Fig. 1). The modification would increase the heat load into the harbour from  $7.0 \times 10^4$  Kcal/min and 6500 L/min to  $13.5 \times 10^4$  Kcal/min and outflow to 13630 L/min. Estimated cooling water required for the plant complex may approach 17000 L/min.

#### Port Hope Harbour Dimensions

The harbour can be divided into West Slip and Turning Basin portions (Fig. 1). The West Slip is 300 m long, 40 m wide with a mean depth of 2.9 m. The Turning Basin is 197 m long, 126 m wide and 2.4 m in depth. The

entrance of the harbour is located 210 m from the mouth of the Ganaraska River.

### Thermal Loadings

Water temperature profile measurements collected during 1981 indicated a temperature rise between the inner harbour (Line 5) and confluent zone (Line 1). This was strongly dependent on the time of the year and would be influenced by the total incoming heat from the atmosphere (Table 1). The temperature differences based on an average of the surface temperature along Lines 1 and 5 (Table 1) as a function of the ratio of thermal discharge averaged over the surface area of the harbour ( $3.7 \times 10^4 \text{ m}^2$ ) to the total incoming heat input at the time of the year was estimated from the studies of Boyce et al. (1977) along the north shore of Lake Ontario in 1972-73 (Fig. 2). During late March and April, it was estimated that water temperatures at the confluent may increase up to 4 C with the additional heat input into the harbour (Table 1).

During the summer (July), doubling the heat input from the plant complex into the harbour would only change the ratio of thermal discharge to total heat input by 0.3 to 0.5, and could result in a temperature rise of about 1 C (Fig. 3). Hence, despite a doubling of heat input, this amount would account for only a relatively small fraction of the total natural heat input during this period of the year.

### Recirculation

Cooling at the surface could be represented by the linear heat flux condition where the heat transfer coefficient  $K$  can range from  $2.5 \times 10^{-4}$



Table 1

Average surface temperatures (C) at Lines 1 and 5, estimated atmospheric heat input, and ratio of waste heat input to total heat input for 1981 Port Hope Harbour and Ganaraska River temperature surveys (ENL, 1982).

| Survey date   | T <sub>SFC</sub> Line 1 | T <sub>SFC</sub> Line 5 | $\frac{H_{In}}{H_{In} + H_T}$ | H <sub>T</sub> Atmos<br>cal/cm <sup>2</sup> /hr |
|---------------|-------------------------|-------------------------|-------------------------------|---|
| Feb. 24, 1981 | 1.7                     | 8.1                     | 6                             | -8.3  |
| Mar. 11, 1981 | 3.0                     | 4.5                     | 1                             | 0   |
| Mar. 23, 1981 | 3.0                     | 8.4                     | 0.8                           | 2.5   |
| Mar. 29, 1981 | 7.2                     | 9.9                     | 0.8                           | 2.5   |
| Apr. 10, 1981 | 11.6                    | 12.7                    | 0.7                           | 4   |
| Apr. 30, 1981 | 10.8                    | 12.3                    | 0.5                           | 10  |
| June 14, 1981 | 13.8                    | 12.7                    | 0.3                           | 21  |
| July 7, 1981  | 20.1                    | 19.0                    | 0.4                           | 16  |
| Aug. 12, 1981 | 21.3                    | 22.4                    | 0.5                           | 10  |
| Sept. 3, 1981 | 17.7                    | 19.3                    | 0.7                           | 4   |

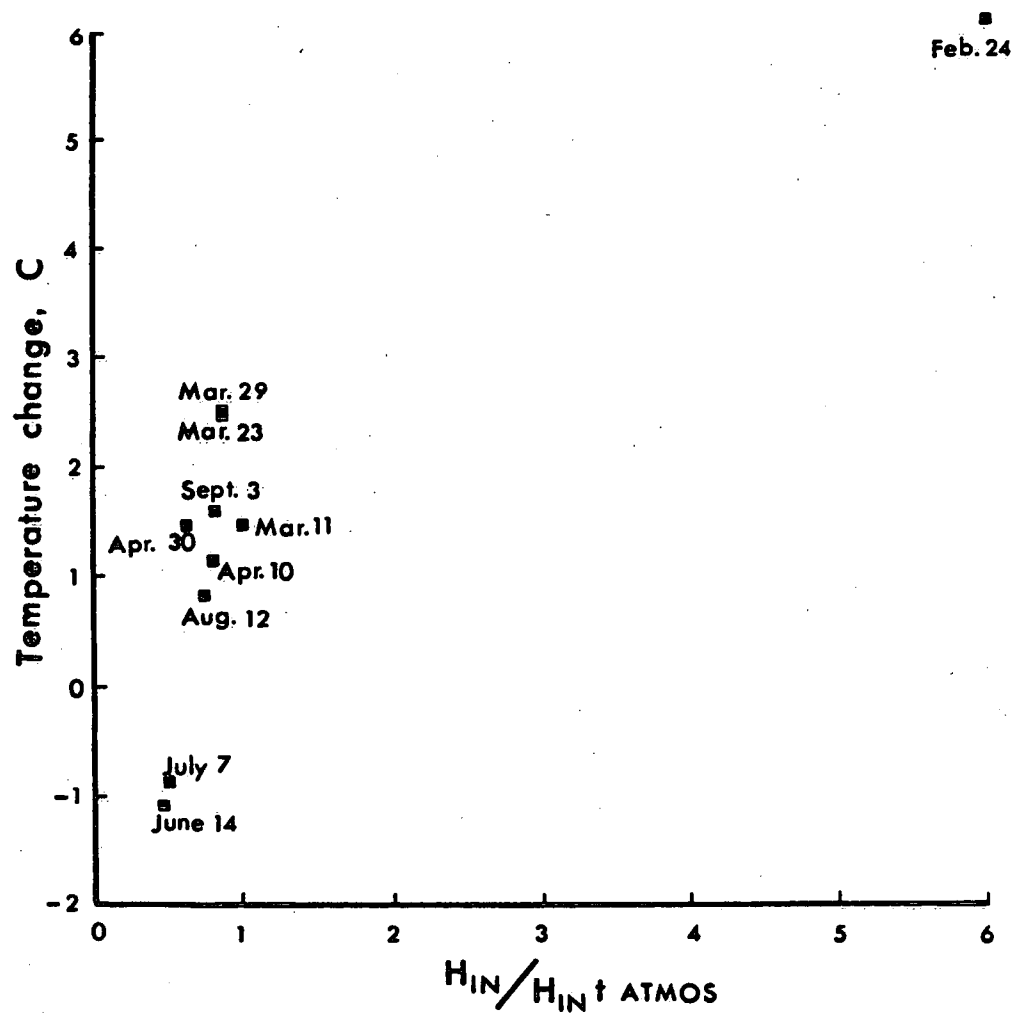


Fig. 2. Surface temperature elevation in the Turning Basin as a function of the ratio of thermal discharge to total heat input.

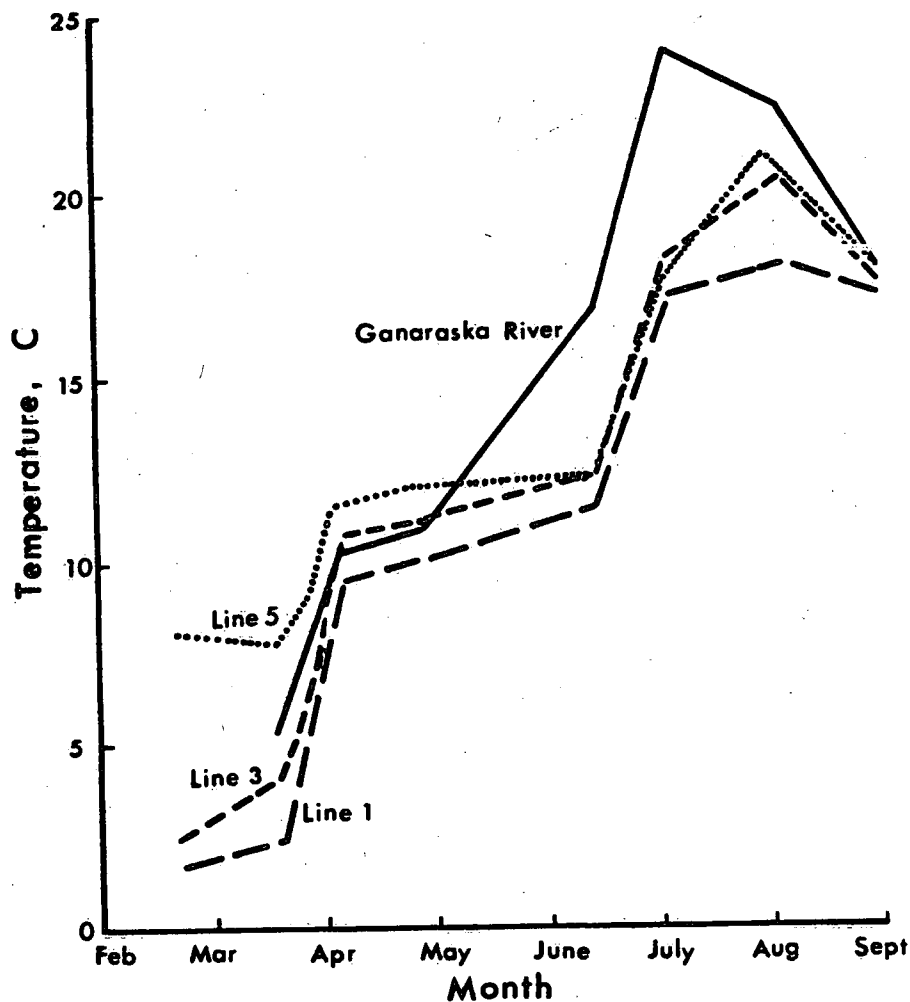


Fig. 3. Temperature profiles near the mouth of the Ganaraska River and Port Hope Harbour between February-September, 1981. Sampling locations for Lines 1, 3, and 5 are shown in Fig. 1, and river temperatures reported in ENL (1982).

to  $5 \times 10^{-3}$  cm/sec for ambient wind speeds of 1 to 5 m/sec (Edinger et al. 1974). Since the outlet of facility A is located within 200 m of the plant intake, there is some concern that the heat effluent could reach the intake area thus reducing the efficiency of the cooling process.

Dispersion is generally the principal process of transporting heat within cooling ponds. In this case, it can be estimated from heat conservation that the horizontal length scale over which heat is transferred to the atmosphere,  $l_1$ , is

$$l_1 = \sqrt{\frac{Dh}{K}}$$

In the present case, the dispersion coefficient,  $D$ , based on the formulation of Fischer et al. (1979) yields an  $l_1$  of 350 m for the augmented outflow rate and for a conservative light wind value of  $K$ . Thus dispersion may be important in transporting heat horizontally and yield a cooling length scale in excess of the distance between the outlet and intake. The average horizontal current,  $V$ , with the augmented flow beyond the outflow from facility A in the West Slip is 2.0 mm/sec. The scale at which advection balances surface cooling is  $L_2$  where

$$L_2 = Vh/K$$

This cooling scale length could range from 120 m under strong winds to 2.4 km under light winds. Thus during light winds and winter conditions there is a possibility of recirculating the heated water into the cooling water intake. The effect of harbour seiches on the cooling length may be estimated by assuming a maximum excursion of the water level of 10 cm from equilibrium in the Turning Basin. The harbour co-oscillation period would

be approximately 400 sec. Thus the maximum flow in the volume of water in the Turning Basin of  $2.5 \times 10^3 \text{ m}^3$  through the cross section of the West Slip ( $120 \text{ m}^2$ ) would be 5 cm/sec. Since the current is much larger than the average outflow in the channel, recirculation effects on the outflow portion of the harbour's seiche would be significant even under high winds.

#### Cooling Pond Classification

It has been shown that the temperature differences along the length of the channel varies during the course of the year (ENL, 1982). For the purposes of pond classification, an average difference of 2 C will be assumed. It should be noted that the pond number (Jirka and Watanabe, 1980) is insensitive to this choice as the non-dimensional parameter varies as the one-fourth ( $\frac{1}{4}$ ) power of temperature difference.

The non-dimensional pond number of 0.1 is based on the augmented outflow of  $0.22 \text{ m}^3/\text{sec}$  (Jirka and Watanabe, 1980). According to their classification the cooling pond should stratify since there is insufficient mixing induced by the outflow to destratify the pond. There is evidence from the thermal profiles taken during winter that the harbour does stratify (ENL, 1982). This has important consequences for the recirculation problem. Recirculation may be prevented or at least reduced by drawing intake cooling water from below the surface heated layer of thickness of 0.2 m according to the theory of Jirka and Watanabe (1980).

#### Probable Effects on Fish Movements

The movement of spawning fish in mid-March to mid-April could be influenced by the additional heat input. Fish congregating near the mouth

of the river could start their spawning run somewhat earlier than expected if water temperature in this portion of the river is higher than that further upstream. The probable impact on the fish movements could be difficult to assess. Water temperatures at the confluent and the river are similar while harbour temperatures are elevated this time of the year at the present heat input (Fig. 3). The additional heat loading could increase water temperatures by several degrees which would present the fish with a larger temperature differential between the confluent and the Ganaraska River proper. One can only surmise that the fish would move back downstream until conditions in the river become more favorable.

Movement of young fish downstream would not likely be affected except during unusually warm years. Temperature measurement conducted during February to September, 1981, indicate water temperatures at the confluent (Lines 1 and 3) are generally lower than that of the river during the summer months (Fig. 3). Annual temperatures of the Ganaraska River at Port Hope generally average 21-23 C during June to August, although temperatures can exceed 25 C (Fig. 4). Some mortality or adverse effects can be expected when salmonids such as rainbow trout are exposed to temperatures exceeding 25 C for prolonged periods. Upper lethal temperatures of 28-33 C have been reported for rainbow trout (Altman and Dittmer, 1966). Lethal temperatures of 26 C for yearling speckled trout (Salvelinus fontinalis) have been reported by Brett (1944), while Fry et al. (1946) reported 28 C was lethal to the same species after 128-291 min. Water temperature determines the time required for death to occur (Fig. 5). The limited information available on salmonids would suggest fish exposed to 25 C could die after 3 hours, while those exposed to 30 C may die within several minutes.

There are young-of-the-year and fish that spend one or more years

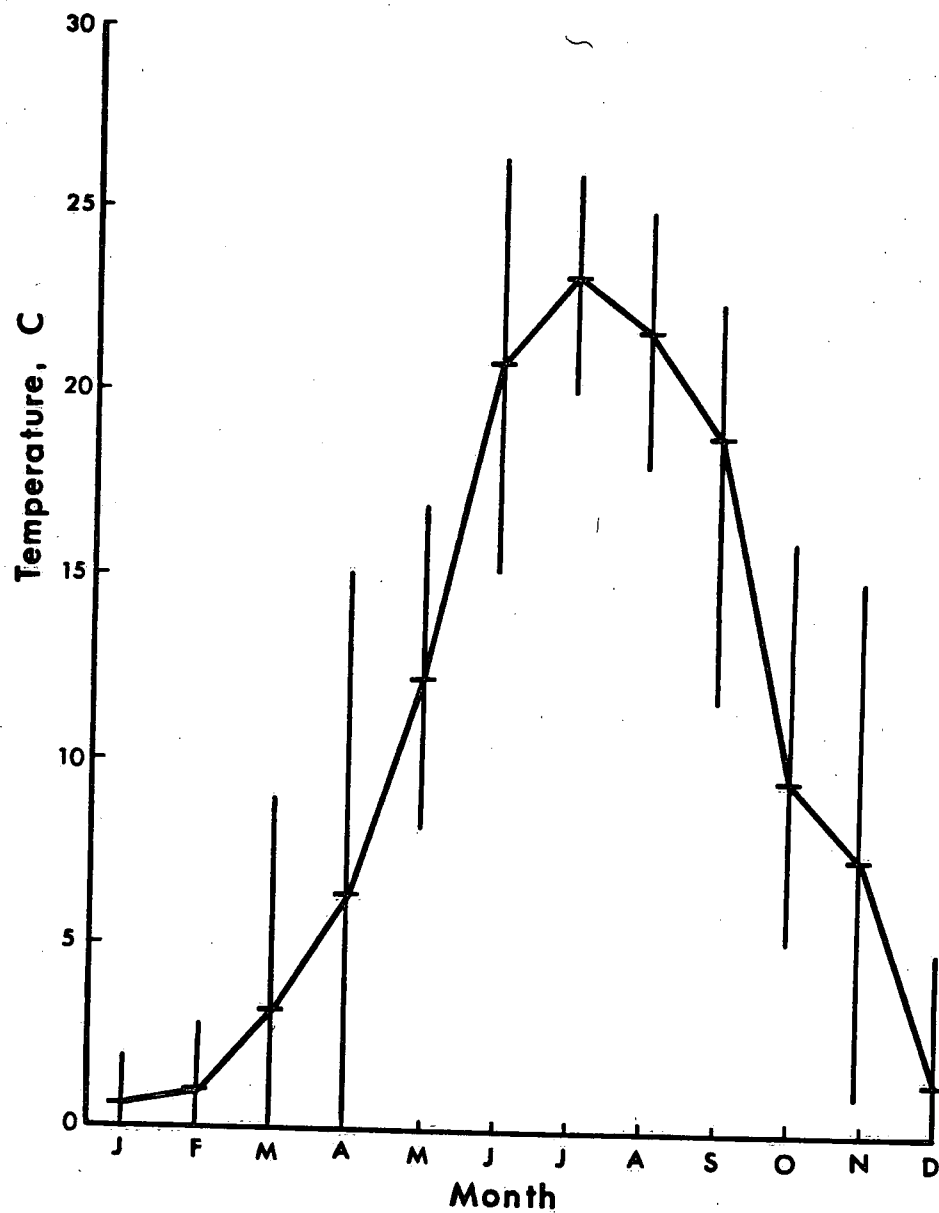


Fig. 4. Average temperature of the Gananaska River at Port Hope between 1970-1979 (Appendix 1). Monthly values show the mean and range.

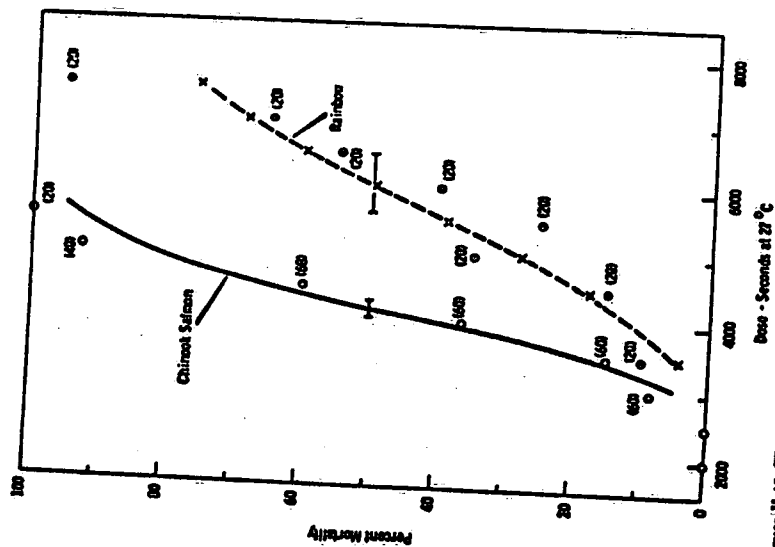


Figure 11-10. The response of chinook salmon and rainbow trout when exposed to 27° C for varying lengths of time.

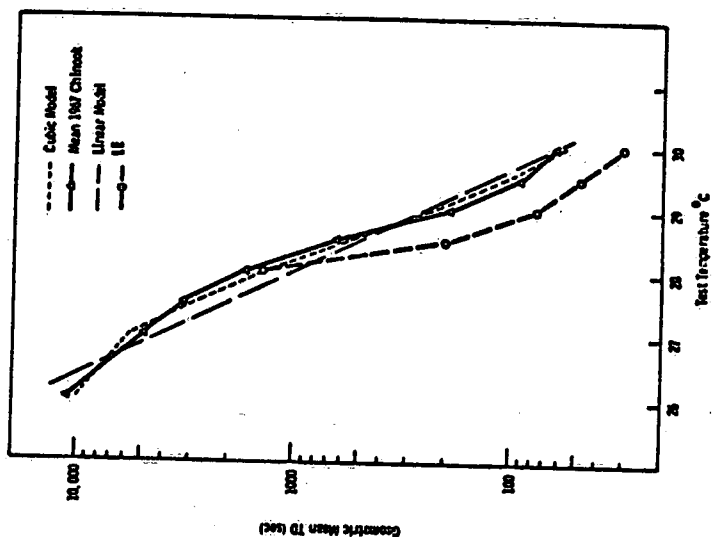


Figure 11-11. The geometric mean median resistance times (GM) for chinook salmon presented as linear, and cubic models and geometric mean median resistance time of the loss of equilibrium (LE).

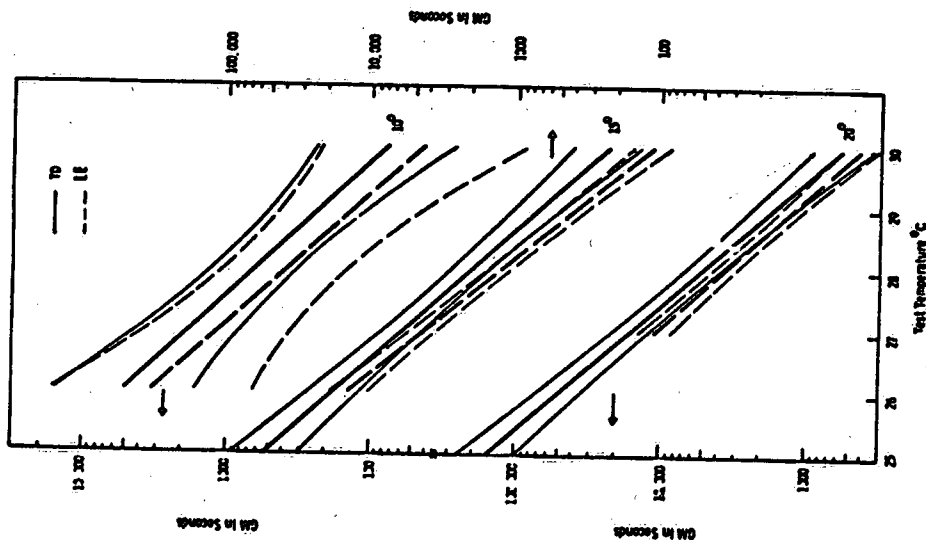


Figure 11-12. The geometric mean median resistance time (GM) and loss of equilibrium (LE) of coho salmon acclimated at 10°, 15° and 20° C.

Fig. 5. Response of salmonids to elevated temperatures (from Dean, 1973).



residence in the streams that move down the Ganaraska River sometime during summer and early fall (D. Wood, Ontario Ministry of Natural Resources, pers. comm.). These fish average 7 cm and 15 cm in length respectively. The heated effluent being discharged would only affect these fish in the 210 meter section at the confluent of the river. Since there are no measurements on fish movements available, one can only estimate the probable time the migrant fish would spend in this section of the river. Assuming the fish moves at a uniform swimming speed through the section without stopping, it is estimated that a 7 cm fish swimming at 1 body length per second would require 50 min, while fish swimming at 5 bl/sec would require 10 min. Similarly, a 15 cm fish swimming at 1 bl/sec would require 23 min, and those at 5 bl/sec would need 5 min to traverse this section. Based on the information available on thermal lethality among salmonids (Fig. 5), the mean annual temperatures of the Ganaraska River at Port Hope (Fig. 4), and the hypothesis that the additional heat load would increase water temperatures at the confluence no more than 1 Celsius degree during the summer, it is suggested that the downstream fish movement would not be appreciably affected. The temperature measurements at different depths along Lines 1 to 4 (Fig. 1) also indicate that there are gradients of 3 to 5 C during the summer months (ENL 1982). A similar examination would also indicate a temperature gradient of 1 to 2 C during March and April. The fish could presumably select the stratum of preferred temperature during their upstream and downstream movements.

#### Conclusions and Recommendations

- (1) During the spring, the heat input from the expanded plant complex

could increase surface water temperatures up to four Celsius degrees in the confluent. During the summer period, the heat input will account for only a small portion of the total natural heat input from the atmosphere and thus would not likely raise temperatures in the confluent zone beyond one Celsius degree.

(2) The movement of spawning rainbow trout into the Ganaraska River in the spring could be affected by the temperature increase. The biological impact of this temperature differential is suggested to be minimal although its effects would be difficult to assess from the limited information available. The movement of young fish downstream during the summer and early fall would not likely be affected by the additional heat input.

(3) Possible recirculation effects have been identified which are the most pronounced during the winter, periods of light winds, and during episodes of harbour seiches. It is recommended that the plant intake be placed at or close to the bottom to avoid recirculation.

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# Appendix 1

Monthly water temperature measurements of the Ganaraska River between 1970-1979. Values were taken at the Peter Street sample point in Port Hope by the Ontario Ministry of the Environment. The values may vary because measurements were taken on different days of the month in different years.

| Year | Jan. | Feb. | Mar. | Apr. | May  | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Reference |
|------|------|------|------|------|------|------|------|------|-------|------|------|------|-----------|
| 1970 | 0.0  | 1.0  | 1.0  | 1.0  | 17.0 | 26.5 | 24.8 | 20.0 | 20.0  | 16.0 | 13.0 | 0.0  | MOE, 1971 |
| 1971 | 0.0  | 0.0  | 1.0  | 0.2  | 8.2  | 15.2 | 22.0 | 23.0 | 22.5  | 15.0 | 15.0 | 0.4  | MOE, 1971 |
| 1972 | 0.5  | 1.0  | 1.0  | 1.5  | 10.0 | 19.8 | 26.0 | -    | 20.2  | -    | 5.1  | 2.0  | MOE, 1972 |
| 1973 | 0.2  | 0.6  | 8.8  | 10.2 | 11.0 | 23.0 | 23.2 | 25.0 | 20.5  | 11.2 | 8.2  | 5.0  | MOE, 1973 |
| 1974 | 0.0  | 2.9  | 1.3  | 15.2 | 11.3 | -    | 21.0 | 18.2 | 11.8  | 6.0  | 11.0 | 2.0  | MOE, 1974 |
| 1975 | 2.0  | 1.2  | -    | 5.2  | 13.0 | 24.8 | 25.5 | 18.0 | 21.2  | 10.0 | 8.0  | -    | MOE, 1975 |
| 1976 | 0.8  | -    | 2.0  | -    | 11.5 | 22.5 | 20.0 | 22.2 | 20.5  | 5.1  | 1.0  | 1.5  | MOE, 1976 |
| 1977 | -    | -    | 9.0  | -    | 17.0 | 19.0 | 22.0 | 25.0 | 17.5  | 9.2  | 5.0  | 0.0  | MOE, 1977 |
| 1978 | 0.0  | 0.0  | -    | 6.5  | 12.0 | 17.0 | 22.5 | 21.9 | 15.0  | 5.5  | 1.0  | 0.5  | MOE, 1978 |
| 1979 | 0.0  | 1.0  | 1.2  | 11.0 | 11.7 | 18.8 | 25.5 | 22.0 | 17.8  | 8.9  | 8.0  | 1.5  | MOE, 1979 |
| Mean | 0.4  | 1.0  | 3.2  | 6.4  | 12.3 | 20.7 | 23.2 | 21.7 | 18.7  | 9.6  | 7.5  | 1.4  |           |
| SD   | 0.7  | 0.9  | 3.6  | 5.4  | 2.8  | 3.7  | 2.1  | 2.6  | 3.2   | 3.9  | 4.7  | 1.6  |           |

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