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THERMAL EFFECTS OF BRANDON GENERATING STATION ON THE ASSINIBOINE RIVER

by

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ABSTRACT

The thermal effects of the Brandon Generating Station on the Assiniboine River were investigated from October 23, 1973 to August 9, 1974. Physical, chemical and biological sampling and analysis were performed throughout the study period. The biological sampling performed revealed development of macro-invertebrates during late February and early March, when the organisms are normally in a dormant state. The reach of the Assiniboine affected by the thermal discharge was repopulated with macro-invertebrates by July. The physical and chemical data did not reveal any detrimental effects on the Assiniboine River for the flow conditions of the river and the degree of generating station operation experiences during the study period.

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CHAPTER I

SUMMARY

This study involved the investigation of a short reach of the Assiniboine River affected by the thermal discharge of the Brandon Generating Station. The investigation was carried out to determine what effects the thermal discharge was having on the river.

The study was divided into two study periods, the first extending from October 23, 1973 to March 15, 1974 and the second extending from May 8, 1974 to August 9, 1974. Physical, chemical and biological data were collected during the two study periods for analysis. Two automatic recorders were employed to monitor the water temperature at three locations of the reach of river investigated. Water quality analysis were performed at frequent intervals to determine the dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, pH and solids concentrations of the river water. Aquatic macro-invertebrates were chosen as indicator organisms to assess the effect of the thermal discharge on the aquatic life of the river.

The results of the analyses performed are presented in the section RESULTS AND OBSERVATIONS and the analysis of these results is presented in the section DISCUSSION.

CHAPTER II

CONCLUSIONS

1. The thermal discharge prevents the formation of ice cover as far as five miles downstream of the Brandon Generating Station during the winter months. This allows for reaeration of the river water, increasing the dissolved oxygen concentration.

2. The thermal discharge does not effect the water quality of the Assiniboine River as to be detrimental to any water users downstream.

3. The changes and rates of change of water temperature frequently exceed recommended water quality standards as a result of the thermal discharge. The biological data indicates that there does not appear to be any detrimental effect resulting from this artificially imposed thermal regime for the flow conditions of the river and the degree of generating station operation experienced during the study period.

4. The increased biological activity below the thermal discharge during the winter months may be beneficial to the aquatic ecosystem. The aquatic macro-invertebrates which were found present during the winter months may provide food for other aquatic organisms.

5. The reach of river in which the benthic organisms mature out of season as a result of the altered thermal regine is repopulated in the spring. This repopulation is most likely the result of drift

fauna or the immigration of adult aerial stages.

6. During periods of high flow (3,000 cubic feet per second or greater) in the Assiniboine River, the thermal discharge results in pronounced channelized flow conditions. The heated effluent had returned to ambient water temperature within 1.5 miles of the thermal discharge under these flow conditions.

CHAPTER III

RECOMMENDATIONS

Further study is required in order that the waste heat discharge from the Brandon Generating Station can be expressed in quantitative terms that can be related to such standard parameters as biochemical oxygen demand (BOD).

BOD progressions of up to twenty days in length will be required to determine what phase of reaction (carbonaceous or nitrogenous) the BOD is undergoing. This information will be needed to express the waste heat discharge in quantitative terms.

Study of the aquatic macro-invertebrates throughout the winter months is required. Such a study will provide data showing the periods during which these organisms are developing, out of season. Summer study during low flow conditions is also required.

CHAPTER IV

INTRODUCTION

4.1 Statement of Problem

Spent cooling water from the fossil fuel, steam electric generating station located at Brandon, Manitoba is discharged into the Assiniboine River. The generating station is operated to supply the peaking power demands of the Manitoba electrical system. Rapid fluctuations in the temperature of the river result from this peaking operation due to the continuous changes in the quantity and temperature of spent cooling water. Water quality and aquatic life can be affected by elevated temperatures resulting from thermal discharge. Thermal shock of the organisms inhabiting the river may result from rapid fluctuations of the temperature of the water.

4.2 Study Objectives

The objectives of the study were to determine the effect of the altered thermal characteristics of the section of river studied on the aquatic community and the water quality. These objectives were achieved through the correlation of physical, chemical and biological data collected during the course of the study.

CHAPTER V

LITERATURE REVIEW

5.1 Introduction

River, lake, estuary and coastal marine environments all have unique ecosystems. This literature review is limited to the effect of thermal discharge on fresh water rivers.

Heat transfer, power generation and industrial processing are the major uses of water in industry. United States surveys have found that water used for heat transfer comprises 90% of all industrial water use(1)*. A large portion of this water is used for cooling purposes in the generation of electrical energy. The increasing demand for electrical power will increase the quantity of water used for cooling purposes.

5.2 Physical Effects of Thermal Discharge

5.2.1 Dissipation of Heat From a River

Temperature profiles measured along rivers have been reported in various studies. These studies have all shown a definite temperature profile pattern(2). The pattern consists of a temperature peak adjacent to the point of thermal discharge,

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* The numbers in parentheses in the text indicate references that are listed in the List of References section.

followed by a logarithmic shaped temperature decay curve. The temperature of rivers, downstream of thermal discharge, depends principally on turbulent mixing in the river and heat exchange between the water and its surroundings, primarily the atmosphere. Heat exchange with the atmosphere is governed by the mechanisms of conduction, convection, evaporation and aeration. Conduction, convection and evaporation increase with increasing water temperature while aeration decreases with increasing water temperature[3,4]. The heat is passed to the atmosphere from the water surface until a state of equilibrium is established. The heat transfer process is driven by the elevated water surface temperature. A number of studies have been carried out on rivers receiving a thermal discharge. A great many of these studies considered 40 to 150 mile reaches of river below the points of the thermal discharge. Significant cumulative temperature rises due to the heat discharges were not found to occur in the reaches of rivers considered.

5.2.2 River Temperature Profile Evaluation

The evaluation of temperature profiles of a river, caused by a thermal discharge, should include the separation of temperature variations due to changes in power production and changes in solar radiation and other meteorological conditions[5]. The time of occurence of peak daily temperature varies along a river regime depending upon the distance downstream from the plant as well as the time of day. Water bodies exhibit fluctuations in response to the heat load from a thermal discharge and diurnal fluctuations in response to varying meteorological conditions.

5.2.3 Direct Effects of Temperature

An increase in water temperature can be directly detrimental if the water is to be used for further cooling processes or if it is required as a palatable water supply. McKee and Wolf[6] report that a water temperature of 10°C is satisfactory for drinking purposes whereas a water temperature of 15°C is objectionable from an aesthetic view-point.

The efficiency of various water treatment processes are affected by variations in water temperature[7]. The effectiveness of filtration increases with temperature as does that of flocculation and chlorination. The effect of variations in temperature on ion exchange differs depending on the type of resin used[6]. Increasing sedimentation rates occur with increasing temperature[6,8]. This phenomena could result in the build up of sludge or silt banks in a river receiving thermal discharge.

The discharge of heated waters to a cold water river may be considered beneficial if the river is to be used for recreational bathing. The prevention of ice cover throughout the winter period may also be considered beneficial in providing for reaeration and year round navigation[8].

5.2.4 Effect of Temperature on Physical Properties of Water

Temperature affects nearly all physical properties of concern in water quality management, including vapor pressure, viscosity, density, surface energy, gas soluability, and gas diffusitivity. These effects are summarized in Table 5.1.

5.2.4.1 Gas Solubility, Gas Diffusitivity and Reaeration

Gas solubility in water, particularly that of oxygen, is probably the most important of the physical properties[7]. Most biological life is dependent on the availability of oxygen for life. The effect of decreased oxygen solubility with increased temperature may be partially offset by the effect of temperature on reaeration. The effect on reaeration is of importance in determining the waste assimilative capacity of a stream above and below a point of thermal discharge[7,8]. Streeter's reaeration coefficient, k_2, can be seen to increase monotonically with temperature, as shown in equation 5.1.

$$k_{2(T^oC)} = k_{2(20^oC)}\theta^{(T^o(-20^oC))} \quad (5.1)$$

where θ = the temperature coefficient.

It has been suggested that the increased aeration rate with increased temperature is a result of the increase in gas diffusitivity through water[8]. This concept is supported as shown by equation 5.2[9].

$$k_2 = \frac{(D_L U)^{\frac{1}{2}}}{H^{3/2}} \quad (5.2)$$

where D_L = diffusitivity coefficient per day;

U = velocity of flow; and

H = depth of flow.

The effect of temperature on reaeration is variable and depends upon

Temperature (^{o}Celcius)	Vapor Pressure (mm. Hg)	Viscosity (centipoise)	Density (gm/ml)	Surface Energy (dynes/cm)	Oxygen Solubility* Concentration (mg/l)	Oxygen Diffusitivity (cm^2/sec)
0	4.579	1.787	0.99984	75.6	14.6	
5	6.543	1.519	0.99997	74.9	12.8	
10	9.209	1.307	0.99970	74.2	11.3	15.7
15	12.788	1.139	0.99910	73.5	10.2	18.3
20	17.535	1.002	0.99820	72.8	9.2	20.9
25	23.756	0.890	0.99704	72.0	8.4	23.7
30	31.824	0.798	0.99565	71.2	7.6	27.4
35	42.175	0.719	0.99406			
40	55.324	0.653	0.99224	69.6	6.6	

* Chloride Concentration = 0 mg/l

TABLE 5.1 - Physical Properties of Water as Related to Temperature[8]

the surface turbulence of the water. The turbulence is affected by the surface energy and the viscosity of the water, which vary with temperature[8].

5.2.4.2 Effect of Density Differences

Heated water discharge to a stream can induce a stratified flow condition due to density differences and inhibition of mixing in the initial thermal discharge[4,10]. The capacity of the water to hold oxygen is reduced by such a condition by inhibiting oxygen replacement to the lower layers of the water through mixing. Organics discharged to the lower layers are not benefited by that portion of the stream flow in the upper layer. This results in less available oxygen, less dilution and an overall reduction in waste assimilative capacity[7,11]. The volume of water affected by the heat will be reduced by discharging in such a manner as to cause a heated layer above the main flow. The aquatic environment from a few feet below the surface to the bottom will be left undisturbed[12]. A stratified flow condition of this type will increase the driving force to equilibrium between the stream and atmospheric temperature by increasing the rate of evaporation and conduction.

5.2.4.3 Effect of Viscosity Differences

Viscosity has been found to vary only with temperature under ordinary conditions of pressure[13]. The higher the temperature, the less is the resistance to relative motion of the fluid, and better mixing occurs. The discharge of hot water into a cooler water body can induce channeling of the heated water due to differences in viscosity[2]. Warmer water flowing by adjacent cooler water yields an overall channeling effect. Krenkel[11] studied the channeling effect resulting from the confluence of two Polish rivers, one being considerably warmer than the other. He found that the channeling effect continued for over ten kilometers.

5.2.4.4 Changes in Dissolved Oxygen During Passage Through the Condensers

Numerous studies have been carried out to determine the changes in dissolved oxygen as a result of passage of water through the condensers of steam electric generating stations. Markowsky[14], in a study of twelve steam electric power stations in England, found very little change in the dissolved oxygen between the influent and the effluent of the condensers. Effer[15] studied a steam electric power station in Ontario and found no changes in dissolved oxygen greater than 0.1 milligrams per liter. A similar study on the cooling water of the Martins Creek Steam Electric Station on the Delaware River near Easton, Pennsylvania consistantly showed decreases in the dissolved oxygen concentration[8]. The dissolved oxygen was however seldom reduced to a critical level for aquatic life.

5.3 Chemical Effects of Thermal Discharge

5.3.1 Changes in Water Quality Through the Use of Cooling Towers

The use of cooling towers for cooling of heated waters prior to their discharge can have a variety of effects on the water quality. Concentration of dissolved salts, such as sulphates and chlorides, can occur as a result of loss of water through evaporation. The concentration factor is usually between 1.15 and 1.3[10].

The pH and hardness of the cooling water can also be altered. Cooling towers scrub dissolved carbon dioxide from the water, resulting in a rise in pH. The loss of loosely bound carbon dioxide from the bicarbonate ion results in a lowering of the pH and a change in the hardness by shifting the equilibrium of equation 5.3 to the right[10].

$$Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + CO_2 + H_2O \qquad 5.3$$

5.3.2 Chemical Reactions

Increased temperature has a profound effect on chemical reactions. The rates of most chemical and biochemical reactions increase with increasing temperature. Biochemical reactions follow Van't Hoff's rule of a doubling of reaction rate for every 10°C rise in temperature, within limited temperature ranges[16]. Temperature affects not only the rate, but also the extent to which reactions take place.

The equilibrium of chemical reactions shifts with changes in temperature[16]. This is demonstrated by equation 5.4.

$$\frac{d\ln K}{dT} = \frac{\Delta H^o}{RT^2} \qquad 5.4$$

where K = equilibrium constant;

T = absolute temperature in degrees Kelvin;

ΔH^{o} = activation energy, calories per mole;

R = universal gas constant, 1.99 calories per degree mole.

This equation illustrates that for exothermic reactions the equilibrium constant decreases with increasing temperature, while for endothermic reactions it increases.

An increase in temperature will also increase the rate of anaerobic biochemical reactions taking place in the bottom sludges of a river[(10)]. This increase in reaction will result in an increase in the release of anaerobic decomposition end products to the water.

Changes in the temperature of a receiving water will bring about accompanying changes in the ionic strength, conductivity, dissociation, solubility and corrosiveness of the water[(8)].

5.3.3 Waste Assimilation

5.3.3.1 Stratification

Stratification, as induced by thermal discharge, has considerable influence on the waste assimilative capacity of a river. It inhibits mixing between the upper and lower layers of water, hampering oxygen replacement, reducing the oxygen capacity of the rivers and the full dilution capacity of the river[(7)]. These factors, when considered with the increasing rate of oxygen uptake with increasing temperature, result in a reduction in the waste assimilative capacity[8]. The overall effect is a higher rate of waste assimilation and possible complete depletion of oxygen in the river.

Waste assimilation is also affected if the heated water is discharged in such a manner as to cause complete mixing with the receiving water. The increase in river water temperature is accompanied by an increase in microbial activity, an increase in the rate of biochemical oxygen demand (BOD), and a reduction in the dissolved oxygen capacity. A reduction in the waste assimilative capacity of the river may occur[8].

A shorter reach of river is affected by oxygen consuming wastes under both stratified and completely mixed flow conditions, if and only if complete de-oxygenation does not occur[10]. The higher water temperature is accompanied by a higher rate of biodegradation if sufficient oxygen is present for aerobic degradation.

5.3.3.2 Waste Heat As a Pollutant

Waste heat is as much a pollutant as municipal and industrial discharges[11]. Waste heat may cause a reduction in dissolved oxygen of the receiving water.

An increase in water temperature is accompanied by an increase in the de-oxygenation rate and an increase in the reaeration rate. These two rate changes do not balance one another, however, as with increasing temperature there is a reduction in the dissolved oxygen potential of the water. The de-oxygenation rate increases more rapidly than the reaeration rate[8]. The effect of these changes on waste assimilation was demonstrated by a study on the Coosa River in Georgia[7,8,11]. It was concluded from this study that a rise in the temperature of the river water from 25°C to 30°C was equivalent to 18.6 milligrams per liter of organic BOD loading.

5.4 Biological Effects of Thermal Discharge

5.4.1 Introduction

Thermal discharge can cause changes in the aquatic environment. These changes may have immediate significance or may occur slowly over a period of prolonged exposure. Thermal discharge can reduce spawning and hatching of eggs, disturb the life cycle of the aquatic organisms, increase sensitivity to toxic chemicals and cause death[17].

Skelford's law of tolerance states that for an organism to survive, all conditions must be favourable. The distribution of a species is restricted if any one factor becomes unfavourable and approaches the limit of tolerance for the species[10].

5.4.2 Tolerance of Aquatic Organisms to Thermal Discharge

Water bodies are subject to seasonal fluctuations in temperature. These fluctuations are of ecological significance as they provide the different temperature ranges required by aquatic organisms at their different stages of development[10].

Many field observations of seasonal algae successions suggest that they are temperature induced[10]. Sewage fungus in polluted rivers is commonly associated with winter conditions and low temperatures. At higher temperatures, the stretch of a river affected by sewage fungus is shortened because of the higher rates of metabolism. Even in shorter stretches of a river the fungus is less profuse than in colder weather. This is presumably due to higher rates of metabolism, utilizing a higher proportion of the available nutrient material[10]. Natural seasonal fluctuations permit a series of different species to become successively established throughout the year.

All species of aquatic organisms have tolerance ranges or zones. Those with a wide tolerance range are termed eurythermal and those with a narrow tolerance range are termed stenothermal[10]. Outside the zone of tolerance there is a zone of resistance, in which organisms can exist only at the expense of such functions as growth, migration and maturation.

The thermal tolerance of organisms is usually determined under ideal laboratory conditions. The organisms are usually allowed a period of acclimation to higher temperatures and the results of thermal tolerance levels are reported as the median tolerance level for a specific time duration[7]. The organisms are subjected to less than ideal conditions in the field and often to rapid fluctuations in temperature resulting from thermal discharge.

The effect of a thermal modification brought about by thermal discharge then becomes difficult to predict from laboratory tolerance levels[7,18].

5.4.3 The Effects of Thermal Stress

The effects of thermal stress from thermal generating stations occurs in three specific areas[18]. Organisms of entrainment are affected by the sharp temperature rise in the condensors. Sharp temperature differences occur between the discharge plume and the river at the point of discharge. Thermal stress also occurs downstream of the discharge where diffusion of the thermal plume and the river is complete. The effects are most detrimental in geographic areas where production of indigenous fish is marginal[18].

Thermal stress results in three levels of biological response to aquatic organisms[19]. The first response is one which occurs when the thermal discharge results in no abnormal change to the biota. Increased thermal discharge results in a zone of graded response where increasing stress results in increasing response. A threshold is finally reached, beyond which increased stress elicits no further response. All aquatic life has succumbed.

Aquatic organisms have no regulatory mechanism to respond to thermal stress. They can withstand the effects of heat only within narrow limits[19]. Increased temperature can delay migration of anadromous fish, induce stress, contribute to disease and favour some species of fish over others[18].

Gradual changes in the natural thermal environment of a