Effects of Thermal Pollution

Ontario

Ministry of the Environment

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EFFECTS OF THERMAL DISCHARGES FROM THE NUCLEAR POWER INDUSTRY

INTRODUCTION

In these times, environmental "problems" appear rapidly with the subsequent demand for quick responsive action. Prior to the 1960's, generally speaking there was little concern for water pollution other than those bacteriological aspects which related to public health. The past decade has seen dramatic changes in this situation and now most people have become aware through the media of the environmental dangers associated with unwise use and excessive loss of 'hard' detergents, phosphate fertilizers, mercury, polychlorinated biphenyls (PCBs), chlorinated aromatic pesticides, radionuclides, and now HEAT.

THE POTENTIAL THERMAL PROBLEM

The use of water for cooling purposes is a common practice in many industrial operations, and particularly important in the generation of electricity from fossil-fuel or nuclear power stations. The state of the art in predicting the effects of waste heat on the aquatic environment is largely unknown and only in the initial developmental stages. It is well known that many adverse physical, chemical and biological effects on water quality and aquatic life can occur from heated discharges, hence the term thermal pollution.

The present controversy on thermal pollution has arisen because of the phenomenal growth of the electrical power generation industry, particularly so in the United States. In that country, many power stations have been built on relatively small lakes and rivers, and in a number of cases there have been significant ecological changes observed in the aquatic environment.[1] Concern for the aquatic environment has caused construction and operating permits to be withheld pending further technical studies and public hearings on a number of proposed thermal plants.

In Ontario, the demand for electric power is doubling approximately every ten years and, since the Province's economic hydro-electric resources are almost totally harnessed, Ontario Hydro is building large thermal stations on the shores of the Great Lakes utilizing once-through cooling systems with discharge of waste heat to the receiving waters. At the present time, existing electrical output from all thermal stations is approximately 8,000 megawatts (MWe), with 9,000 MWe under construction. If the present rate of load growth continues through the remainder of the 1970's and 1980's, a further 30,000 MWe will be required in service by 1990. The volumes of cooling water used are enormous; for example, the 3,000 MWe nuclear station at Bruce is designed to use in excess of 2 million gallons of cooling water per minute. The conversion efficiencies of the CANDU stations are such that approximately seventy per-cent of the energy generated is dissipated to the receiving waters as heat. (Figure 1)[2]

Since temperature is considered to be the primary control of life on earth and is therefore important in a body of water, and since it can determine the species that will live and reproduce, ecologists are deeply concerned with the threat to fish and other aquatic life forms which can occur in the future because of increases in power demands and consequently heat losses to receiving waters.

[1] *Parker, F.L., and Krenkel, P.A., Thermal Pollution: Status of the Art, 1969. Report No. 3, Prepared for the Federal Water Pollution Control Administration.*

[2] *Ontario Hydro, Environmental Design Manual 1972. A Report Submitted to the Ministry of the Environment by Ontario Hydro.*

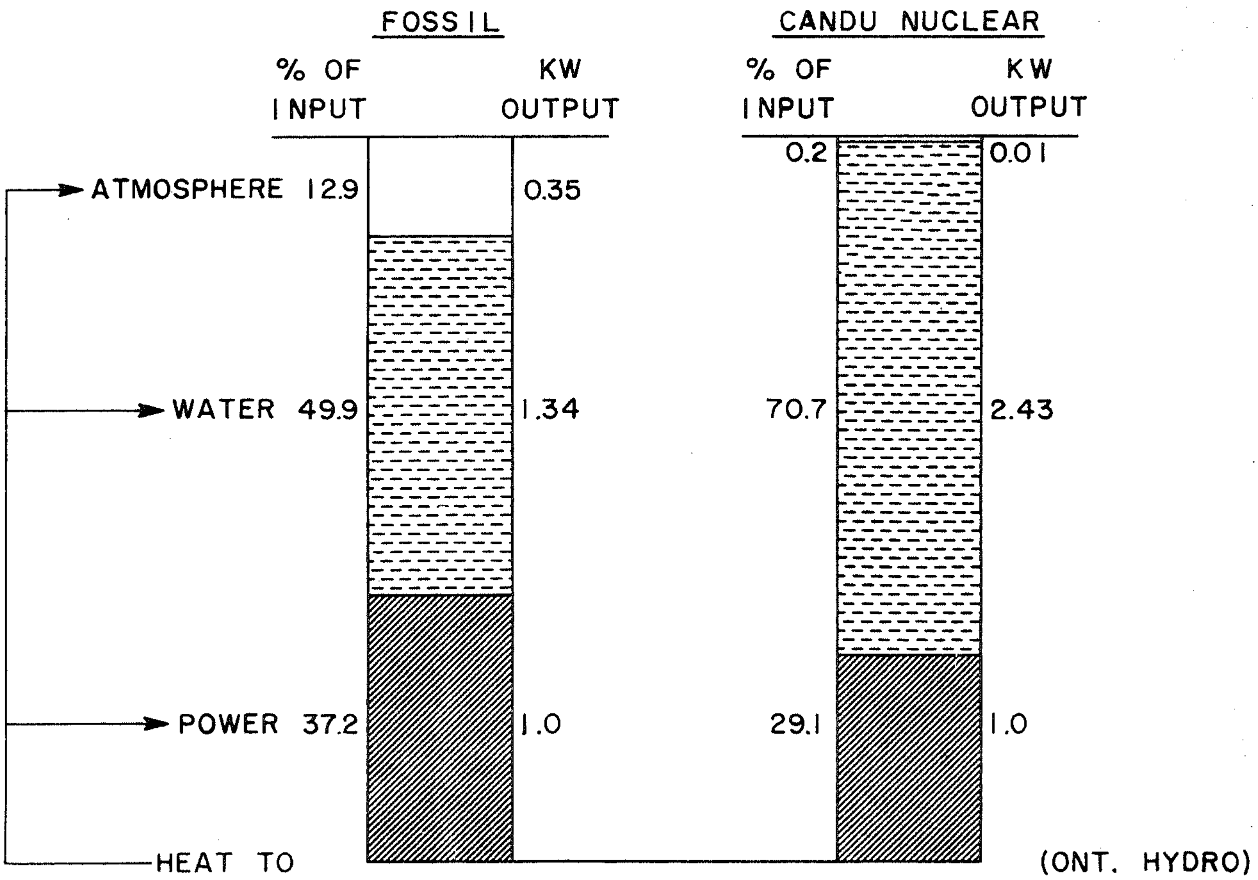

FIGURE 1 - FOSSIL AND NUCLEAR PERCENTAGE HEAT DISTRIBUTION

It may be appropriate to quote from the 1966 Symposium on Water Quality Criteria to Protect Aquatic Life where biothermal experts Mihursky and Kennedy[3] stated that:

"Lessons from past environmental changes indicate environmental repair is difficult to economically or politically justify once the damage has occurred. The task concerning temperature considerations is to indicate exactly the ecological alterations to be expected under temperature regimes and to exactly determine the temperature requirements of the species involved. Undoubtedly, at the present level of understanding in this complex problem, it is imperative that a conservative point of view be maintained when establishing regulations."

HEAT INPUTS TO THE GREAT LAKES

To those using the Great Lakes for cooling purposes, a knowledge of man-made heat inputs relative to the heat gained naturally through solar input, condensation and conduction is of some importance. Ontario Hydro and other power companies have contributed data to a federally-sponsored study of present and future levels of discharged heat and the effects of these discharges on overall lake surface temperature.[4,5] During the years 1970-2000,

3
Mihursky, J.A., and Kennedy, V.S., 1967, Water Quality Criteria to Protect Aquatic Life. American Fisheries Society, Special Publication No. 4.

4
H. G. Acres Ltd., Niagara Falls, Thermal Inputs to the Great Lakes, 1968-2000. Report for the Canada Centre for Inland Waters.

5
Effects of Thermal Inputs to Lake Ontario, 1968-2000, Ibid.

thermal inputs from existing and planned generating stations, steel mills and municipal waste treatment plants on the United States and Canadian sides of the Great Lakes are expected to increase elvenfold from 9.89×10^{10} Btu per hour to 11.4×10^{11} Btu per hour. For example, the heat input to Lake Ontario in the year 2000 has been calculated to be equivalent to 6 percent of the natural heat content variation of the lake. H. G. Acres in their report made the basic assumption that if this heat input were to be equally distributed across the entire lake surface, the maximum increase in lake surface temperature would be 0.56°F. While this is an interesting academic exercise, in that it serves to illustrate the magnitude of the effect of the heat input over the entire lake, the results are meaningless since for all practical purposes, the assumption is invalid. This is because thermal discharges are restricted to near-shore areas where temperature increases would be considerably higher.

Despite the foregoing, power utilities like to compare their heat losses from existing and future plants with the heat input from the sun to water bodies. In this vein, Ontario Hydro has calculated that its own planned capacity by 1990 will put heat into Lakes Ontario, Erie and Huron equivalent to 0.3 percent of the average annual solar input to these lakes. A further calculation shows that the annual solar input to Lake Ontario is equivalent to 670 stations the size of the Pickering Nuclear Station (2,000 MWe). Therefore, an average sized power plant on Lake Ontario would discharge to the lake over a whole year the heat equivalent to that received by the lake in about half a day of sunshine.[6] Again, I would like to emphasize that this approach does nothing more than compare on a theoretical basis, and in an apparently favourable light to the utilities, the relative contribution of heat inputs to the lakes from the two sources.

[6] *Storr, J.F., "Does Thermal Pollution or Nuclear Contamination Pose an Ecological Threat to Lake Ontario?" Statement to Sub-Committee on the Ecological Problems of the Great Lakes, Oswego, N.Y., September 11, 1969.*

On Lake Erie, an IJC study showed that the total waste heat input in 1969 was 15×10^9 Btu per hour (equivalent to 4,400 MW) or 0.13 percent of the solar input of 11.2×10^{12} Btu per hour for the period April-August.[7] Based on a heat exchange coefficient for the Great Lakes of 30 MW/mi^2°F [8], an approximate area of 10,000 square miles for Lake Erie and a surface temperature rise of 1°F, Lake Erie's assimilative capacity is approximately 3×10^5 MW or approximately 1/20 the current rate of fuel energy release in the world. This heat rejection, if it came totally from nuclear plants, would be equivalent to generating capacity of about 130,000 MWe.

However, as stated previously, only the near-shore areas of the Great Lakes fall within the influence of the thermal discharges. If, for example, we assume that an average 1°F temperature rise was acceptable and occurred within a distance of 5 miles of the shoreline (and not over the entire lake surface), the lakes' capacity to assimilate heat would more nearly approximate 15,000 MW per 100 miles of shoreline. This is equivalent to a nuclear electric generation capacity of about 6,500 MWe per 100 miles of shoreline. Thus for Lake Erie, this would be approximately 14,000 MWe for the Ontario shoreline. Doubling for US generation gives 28,000 MWe and this can be compared with the 130,000 MWe quoted above. Obviously, in-shore temperature rises will be significantly higher than 1°F if 130,000 MWe are installed.

7 *International Lake Erie Water Pollution Board and the International Lake Ontario-St. Lawrence River Water Pollution Board. Volume 2 - Lake Erie. Report to the International Joint Commission on the Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River, 1969.*

8 *Brady, D.K., The Dissipation of Heat from Thermal Discharges. 2nd Thermal Pollution Seminar, Institute of Environmental Science, Chicago, October 1970.*

Similar figures can be calculated for Lake Ontario, showing approximately 14,000 MWe being capable of raising the near-shore waters (out to a distance of 5 miles) an average of $1^{o}F$ on the Canadian side. At the same time, it is interesting to note that Ontario Hydro would probably like to build on Lake Ontario approximately 24,000 MWe by the year 1990.

These various calculations are of interest in assessing concerns expressed over influences from thermal discharges. The IJC has stated that the effect of waste heat input on the Great Lakes as a whole is not considered to be significant at this time.[9] However, it is recognized that although man-made inputs in the next 30 years may be considered of small significance in the Great Lakes if dissipated over the whole surface, this does not occur in actual practice. Thermal discharges and their effects are generally restricted to near-shore areas which support the more active and sensitive aquatic communities.

THERMAL EFFECTS

(1) Physical

One of the basic considerations in the evaluation of the effects of discharging large quantities of heated water into a cooler water body is determining what happens to the heat after it enters the aquatic environment. Basically, three physical processes operate to determine the resulting pattern of temperature increase within the receiving water and the three-dimensional spacial area over which the temperature increase will be observable. These may loosely be termed "mixing", "stratification", and "atmospheric transfer". These processes are inter-related and are subject to a variety of determining influences.

[9] *IJC Report. Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River, 1970.*

"Mixing" implies the diffusion or spreading out of the heat within the receiving water, such that temperature effects on the environment tend to become more evenly distributed throughout the water body, with smaller temperature increases in any particular location than would have existed had mixing not occurred. Where there is a significant movement in the receiving water body, such as currents and flows in a river and wave actions in larger lakes, a significant amount of mixing tends to occur. However, where such physical mixing forces are weak or absent, mixing is significantly slowed and thermal stratification becomes an important factor.

"Stratification" is the process by which heavy dense liquids settle and lighter less dense liquids rise to the surface. The density of water increases as the temperature decreases, at least within the range considered here. Consequently, the heated effluents have a natural tendency to stratify and rise to the surface where maximum heat loss can occur. The warmer the effluent relative to the receiving water, the more pronounced will be the stratification tendency. The observed temperature change will be greater with stratification than with mixing, but the affected cross-sectional area will be smaller.

It is important to note that natural water bodies tend toward an equilibrium temperature that depends primarily on atmospheric conditions at any given time. Thus, they do not permanently retain the heat from a power plant's discharge, but only hold it temporarily as physical processes operate to restore the original equilibrium. Thus, any rise in temperature imposed on a water body above its natural temperature will be temporary, and the excess heat will eventually flow to the atmosphere by processes of evaporation, convection, and radiation. These processes are very sensitive to atmospheric conditions such as relative humidity and wind and especially to the temperature difference between the air and surface water. In general, however, the warmer the surface water the more rapid will be the heat loss to the atmosphere. Thus, thermal stratification tends to increase the rate of heat transfer and hasten the process of restoring equilibrium to ambient water temperatures.[10]

Before anything can logically be said about the ecological and social significance of thermal discharges, it is first necessary to know what physical temperature effects the added heat will produce on the receiving water body, both with respect to the spacial pattern of temperature changes and the degree of temperature increase at various points within the three-dimensional spacial area of the affected water body. This is of primary significance for projecting and interpreting possible ecological effects on living organisms and for evaluating the effects of heated waters on those social activities directly sensitive to water temperatures per se. For example, migratory fish will not pass through water after it reaches a certain temperature limit. However, under stratified conditions, the surface temperature may be above the limit while a sub-surface passage within the allowable temperature range remains open -- hence the need for defining the extent of thermal plumes under a variety of meteorological and station operating conditions.

Temperature affects nearly every physical property of concern in water quality management including density, viscosity, vapour pressure, surface tension, gas solubility, and gas diffusion. The solubility of oxygen is probably the most important of these parameters, inasmuch as dissolved oxygen in water is necessary to sustain many forms of aquatic life. Table I gives the change in oxygen solubility with

[10] *Cheney, P.B., and Smith, F.A., "A Systems Analysis of Aquatic Thermal Pollution and its Implications", Vol. 1, Summary Report, January 1969. Prepared for the National Coal Policy Conference, Inc.*

change in temperature. Obviously, the lower solubility induced by higher temperatures, if combined with an organic load and an increased bacterial metabolism, could lead to such low levels of oxygen that fish could not survive.

TABLE I

OXYGEN SOLUBILITY IN WATER AS A FUNCTION OF TEMPERATURE

Temperature °C	Oxygen Solubility mg/l
0	14.6
5	12.8
10	11.3
15	10.2
20	9.2
25	8.4
30	7.6
35	7.1
40	6.6

As higher temperatures speed up the metabolic activities of fish and other aquatic animals, thereby increasing the oxygen requirements of the animals, the same elevated heat level reduces the amount of oxygen which a given volume of water can dissolve. In other words, increased demand occurs at a time of reduced supply.

However, it has been shown that the oxygen content of water discharged from condensers is changed very little from that of the influent and is even increased in some cases. In the light of much evidence in the literature, the fears expressed concerning lethal reductions in the dissolved oxygen of streams and lakes caused by heated effluents seem unjustified if the oxygen content is normally adequate and the water is not heavily polluted.

Because many properties of water vary with temperature, changes in filtration, flocculation and ion exchange rates will occur in treatment processes which are used to produce potable water. However, increased temperatures may pose a problem in that water with temperatures of 70°F or higher can be objectionable for drinking purposes.[11]

Temperature changes affect biochemical purification processes in the receiving water. Also, temperature effects on micro-organisms are significant to the biological processes of waste stabilization because of induced changes in growth rates and changes in death rates. In general, the higher the temperature, the more active a micro-organism becomes, unless the temperature or a secondary effect becomes a limiting factor.

11 *McKee, J.E., and Wolf, H.W., Water Quality Criteria, the Resources Agency of California State Water Quality Control Board, Publication No. 3-A, Second Edition, 1963.*

Temperature has a profound effect on the rate of oxidation. In receiving waters, a multitude of different organisms are active in waste assimilation, all with their own characteristics and temperature tolerances. The distribution of organisms may change drastically with shifts in temperature or types of waste, each species having a different rate of metabolism. However, there is an upper temperature limit for biochemical stabilization of organic waste because the rate of protein denaturation increases at temperatures above 86°F. The protein portion of the enzyme is inactivated and the reactions apparently begin to slow down at temperatures above 86°F. The decrease in reaction rate at high temperatures could therefore be caused by thermal inactivation of enzymes.

One final physical effect of temperature that all scientists are familiar with is the general rule of thumb that an increase in temperature will usually have a profound effect on chemical reactions, the rate of reaction being approximately doubled for each 18°F (10°C) rise in temperature.

(2) <u>Biological</u>

The effects of temperature upon aquatic organisms have always been of great interest to biologists and much research has been carried out in this area since the late 1880's. Unfortunately, the sheer mass of detailed information leaves the reader with a feeling of hopeless frustration. Strickland[12] reflected this mood of frustration when

[12] *Strickland, J.B., "The Effects of Heated Discharges on Marine Zooplankton". Biological Aspects of Thermal Pollution 1969, Edited by Krenkel and Parker, Vanderbilt University Press.*

he commented, "Really, the business is in such a state that we can never be certain. We don't really know to what extent the entire food chain and its indirections and feedbacks are affecting any particular part of it. The more we get to know about it, the more complicated and inter-acting it becomes."

The response of aquatic organisms to elevated water temperatures has been studied in the laboratory and in situ by experts in many scientific disciplines. Some well documented responses of primary significance are listed below:

(i) A Shift in Population Structure of the Ecosystem

The structure of aquatic communities, often called the "food web" (Figure 2) is the result of the relationship between organisms and the environment as well as among the organisms themselves. Most forms of stress cause a decrease in the complexity of the aquatic community.

Bottom fauna studies provide a useful index of changes in water quality due to thermal and other influences. Many species are very sensitive to specific types of pollutants and are quickly eliminated. The relative immobility of these organisms compared with fish and plankton make them suitable for monitoring transient as well as long term influences. In the food web, they occupy a middle position between the simpler organisms on which they feed and the higher aquatic life such as fish which use them for food. Thus, conditions which may influence the upper and lower levels of the food web may be reflected in changes in the bottom fauna population and composition. Any stresses caused by temperature changes will tend to reduce the number of species by elimination of those which are thermally

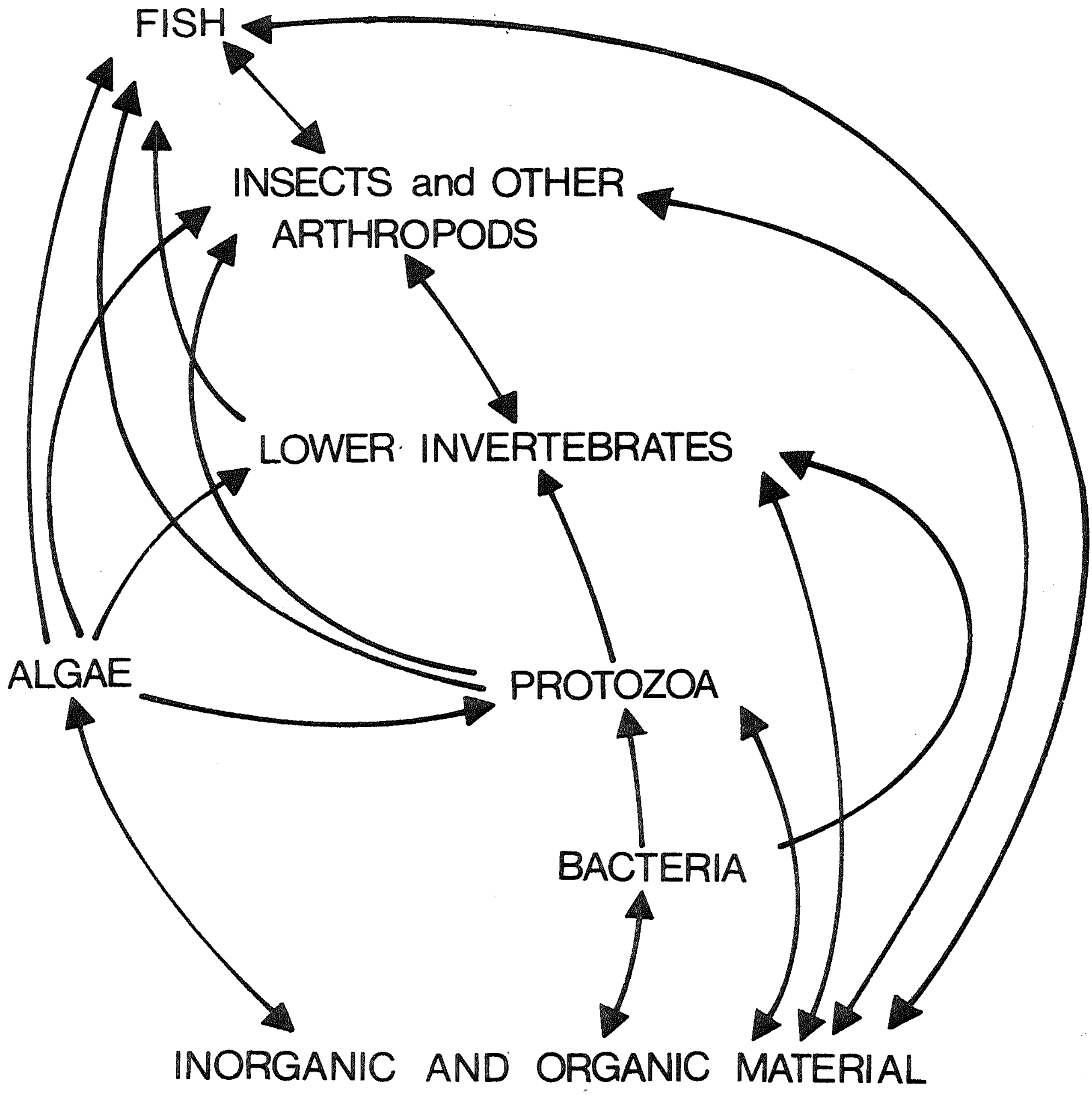

Figure 2 Simplified Aquatic Food Web

intolerant. The upper tolerance limit of many benthic organisms is reached about 90°F.[13]

The effect of temperature on population structure can best be illustrated with a mixed algae population which is subjected to a gradual increase in temperature. Figure 3 demonstrates the shift in predominance from diatoms at 68°F to blue-green algae, the species often found in abundance under conditions of organic or chemical pollution, in the range of 95 to 102°F.[14]

Some of the blue-green forms may become dominant in organically enriched waters at lower temperatures, and are responsible for many taste and odour problems in water. They are not considered to be a valuable food source for fish[15], so a shift to predominantly blue-green algae would therefore be one index of thermal pollution. A shift in dominance from a diatom to a green algae population has been observed in an Ontario Hydro thermal discharge into Lake Ontario where maximum discharged temperatures approached 85°F.[16] An extremely small percentage of the total algae population consisted of blue-green forms at this temperature.

13 *Trembley, F.J., Research Project on Effects of Condenser Discharge Water on Aquatic Life. Progress Report 1956-59. Inst. Research, Lehigh University, 1960.*

14 *Cairns, J., Jr., 1956a, "Effects of Increased Temperatures on Aquatic Organisms".*

15 *Cairns, J., "The Response of Fresh Water Protozoan Communities to Heated Waste Waters", Chesapeake Science, 1969, Vol. 10, pg. 177-185.*

16 *Effer, W.R., "The Effects of Thermal Discharge from Lakeview GS on the Growth Patterns of Algae". Ontario Hydro Research Report 70-161-K, 1970.*

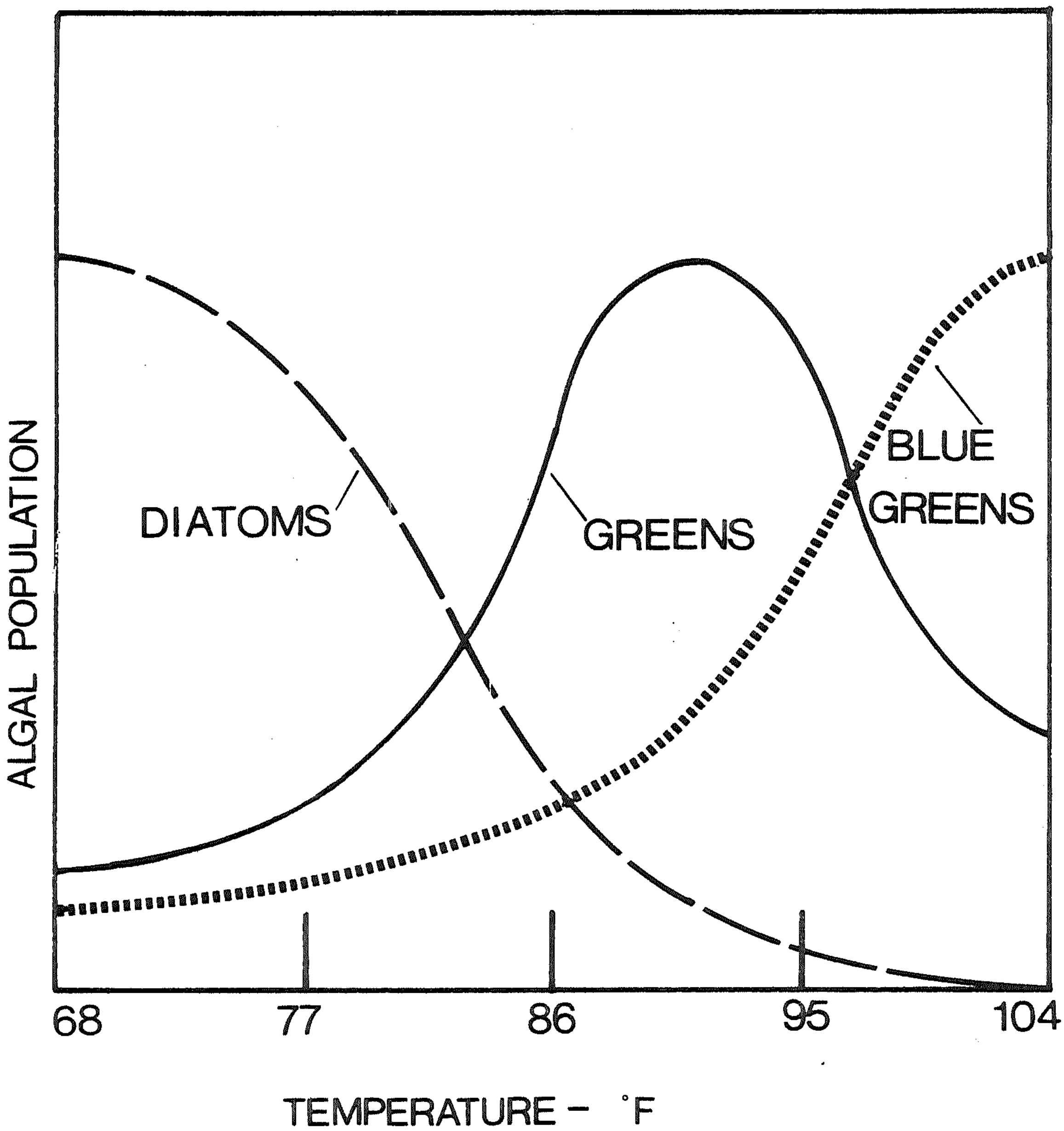

Figure 3 Algae population shifts with change in temperature.

The growth of filamentous algae such as Cladophora is commonly believed to be enhanced by increased temperatures and could therefore be a problem in shallow areas influenced by a thermal discharge. Such increased growth would tend to occur within a given temperature range when other factors such as light intensity, day length, nutrients and water movement are not limiting growth. No increases in growth rates were measured during on-site studies at thermal generating stations in the United States[17,18,19]. Effer has obtained similar results at an Ontario Hydro station on Lake Ontario where it was observed that at the higher temperatures of the discharge, both the growth and decay phases of Cladophora occurred about four weeks earlier than at the intake temperature, but the total growth in heated and unheated water was similar.

(ii) <u>Death Beyond Certain Temperatures</u>

Extremes of temperature which can be endured by fishes have been studied since the 1940's with considerably more emphasis on upper lethal temperatures than on lower ones. The lethal temperature has been found to be a function of many factors including diet, activity, age, general health and weather to name a few. This large number of variables makes it difficult to determine a useful value for the lethal temperature under laboratory conditions since the lethal temperature changes somewhat with variations in each of those variables.

17 *Beer, L.P., and W.O. Pipes, "A Practical Approach: Environmental Effects of Condenser Water Discharge in Southwest Lake Michigan. Commonwealth Edison Report, 1969.*

18 *Trembley, F.J., Research Project on Effects of Condenser Discharge Water on Aquatic Life. Progress Report 1956-59. Inst. Research, Lehigh University, 1960.*

19 *Storr, J.F., "Ecological Effects of Cooling Water Discharge". Report for Rochester Gas & Electric Corp. 1972.*

The effect of acclimatization (thermal history) and exposure time on upper lethal limits for speckled trout is shown in Figure 4.

The extremes of temperature which can be tolerated indefinitely by a species and their dependence on acclimatization temperature is interesting. For many fishes, the difference between the 50 percent and the 5 percent lethal levels is small, indicating that a large increase in mortality can result from a small change in temperature near the tolerance limits.[20]

It should be noted that organisms can also be quite sensitive to sudden changes in temperature from cooler water and fish kills have been caused by the release of cold, oxygen-devoid waters from the hypolimnion of stratified reservoirs.[21]

Actually, in the literature there is a surprising scarcity of fish kills in which the lethal agent is incontestably heat addition.

In considering lethal effects on aquatic organisms, some mention should be made of plankton entrainment. Many plankton studies are concerned with the effects of heat and mechanical shock when the organisms are entrained in condenser cooling water. In a fresh water environment, a high proportion of the organisms have stages in the life cycle associated with the benthos and therefore entrainment damage may not be significant. Studies on fresh water bodies have found that adverse effects depend on many variables. One study[19] showed that mechanical shock had a greater influence on overall mortality than the thermal rise. At a

[20] *Brett, J.R., 1958, "Implications and Assessments of Environmental Stress". The Investigations of Fish Power Problems. H. R. MacMillan Lectures in Fisheries, Vancouver, B.C.*

[21] *Jones, S.L., Personal Communication, 1966.*

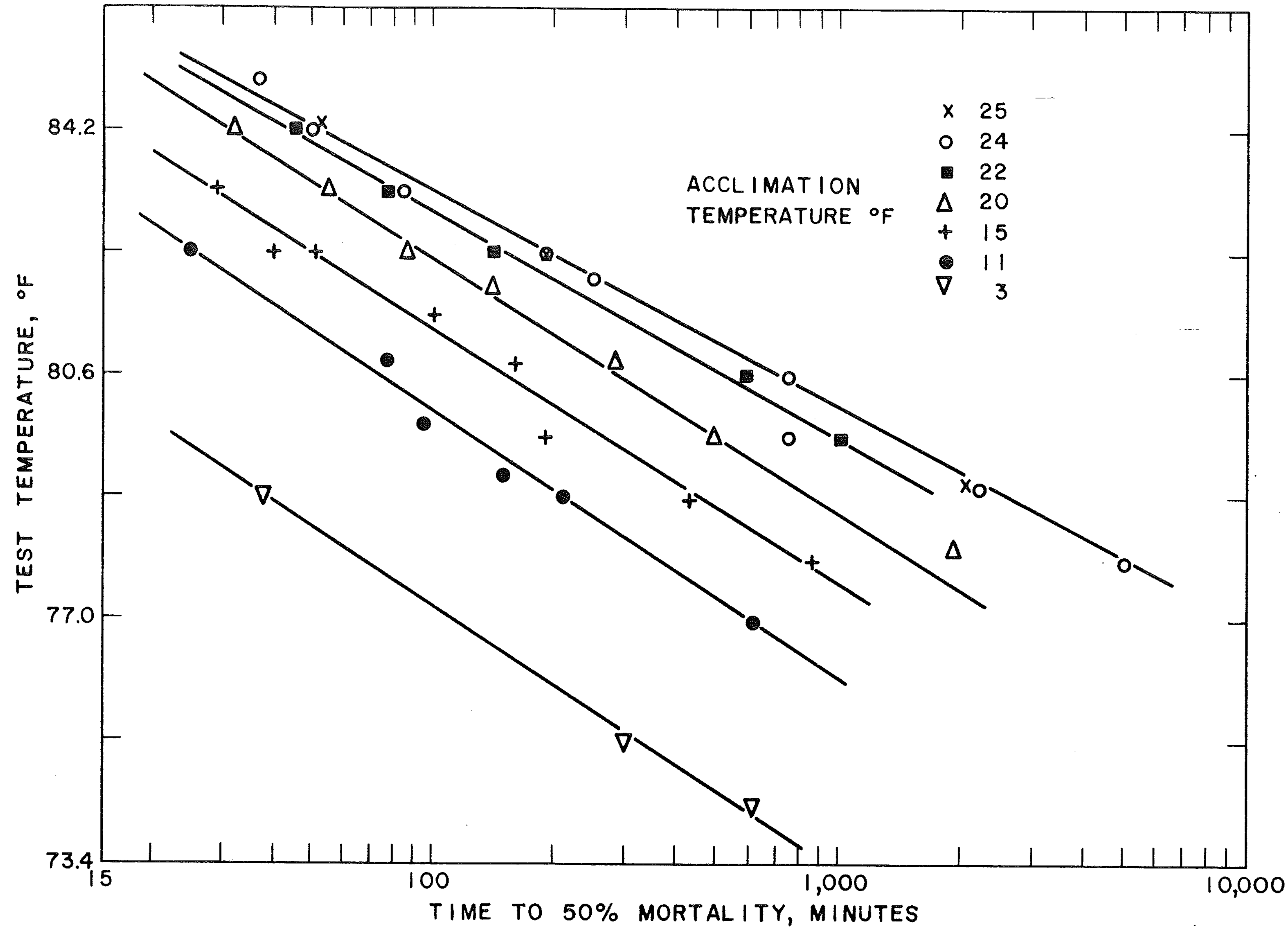

FIGURE 4 - EFFECT OF ACCLIMATIZATION TEMPERATURE ON UPPER LETHAL LIMIT OF SPECKLED TROUT

Lake Ontario site, primary production in the area influenced by the thermal discharge was unchanged. Although secondary production was also unchanged the standing crop of selected zooplankton species was increased manyfold.[22] At another Lake Ontario site, kills were variable but generally small.[19] It is apparent that some damage is done by the entrainment of suspended organisms, but the effect of this damage on a long term basis is difficult to assess. One problem is in the amount of sampling effort required to obtain statistically significant data on populations which can undergo marked natural, short-term fluctuations.

(iii) <u>Sublethal Functional Response</u>

Extreme temperature kills; but within the zone of tolerance temperature is a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller. Temperature is one of the most important and influential water quality characteristics to life in water.

Physiological responses which force a species into a more unfavourable competitive position may be termed sublethal. Such responses include reduced growth rate, increased susceptibility to disease and predation, and reduced rate of reproduction. Gas bubble disease has recently been observed at generating stations during the winter[23,24]. Numerous laboratory experiments have

22 *Fenlon, M.W. et al, "Influences of Thermal Effluents Upon Aquatic Production in Lake Ontario". 14th Conference of Great Lakes Research, Toronto, 1971.*

23 *Industrial Bio-Test Laboratories Inc., "Physiological Effects on Fish". Report W8957. For Commonwealth Edison Co. 1971.*

24 *De Mont, D.J., R.R.W. Miller, "First Reported Incidence of Gas Bubble Disease in the Heated Effluent of a Stream Generating Station". 25th Annual Southeastern Association of Games & Fish Commissioners, October 1971, Charleston, S.C.*

demonstrated sublethal effects due to temperature changes[25], but these effects have not been generally confirmed by on-site observations of localized thermal discharges in fresh water bodies. This may be due to the difficulties of making such observations, and to the movement of fish away from influences which place it in a poor competitive position.

(iv) Decreased Resistance to Toxic Substances

Although literature on fish toxicology is voluminous and excellent summaries of published data are available, the specific effects of temperature on the toxicity of many pollutants are not well documented.

Generally, two conclusions can be drawn from existing data. Toxicity usually increases with increased temperature, and specimens subjected to toxic materials are less tolerant of temperature extremes. Since chemical reaction rates increase with increased temperature and metabolic rates generally increase at higher temperatures, these results should be expected.

ADDITIONAL BIOLOGICAL CONSIDERATIONS IN ASSESSING THE POTENTIAL FOR THERMAL POLLUTION

Several characteristics of biological life are important in evaluating the magnitude of the thermal pollution problem and devising methods of control. These characteristics are:

(a) Heat tolerance range
(b) Ability to acclimate to changes in the ambient environment
(c) Avoidance reactions

[25] *Levin, A.A., et al., "A Comprehensive Appraisal of the Effects of Cooling Water Discharge on Aquatic Ecosystems". Symposium "Why Nuclear Power". Atomic Industrial Forum Inc., Pennsylvania Academy of Sciences, 1962, Vol. 37.*

Adaptability is fundamental to biological life. This means that an organism will respond to some alteration in the environment, allowing the organism to survive under the changed conditions. Heat discharged into the aquatic environment becomes a problem only when these protective mechanisms are overwhelmed.

Any organism is a regulator. In the face of applied stress, it attempts to maintain a steady state in its internal environment. Regulation may be accomplished internally or externally. The process of internal regulation is manifested in heat tolerance and in acclimation. Temperature selection is a type of external regulation.

Animals fall into two general groups, the warm-blooded and cold-blooded. The warm-blooded animals, such as birds and mammals, have well-developed temperature-regulating mechanisms which keep the body in a very narrow temperature range, regardless of ambient environment. The lower vertebrates and invertebrates are cold-blooded, i.e., their body temperature follows that of the surrounding environment. In other words, body temperature is not regulated. However, regulation must occur in some other physiological function of the organism. The nature of the regulatory mechanism has been studied by Troshin[26] but will not be discussed in this paper.

[26] *Troshin, A.S., "The Cell and Environmental Temperature". Proceedings of the International Symposium on Cytoecology (Leningrad) 1967, Pergamon Press, New York.*

The thermal tolerance of a particular species is, in all probability, the factor which limits that species to a particular area[27], since at the southern extremity of the range of the species, natural temperatures frequently approach lethal limits.

Mount[28] said that there is a substantial amount of evidence that fish frequently are more sensitive to elevated temperatures than are most food web organisms. If this is true, then fish may serve as indicator organisms for the lethal effects of harmful agents upon the macro-invertebrate population. Fish movement away from the applied stress, however, tends to limit their value as indicators of short term or periodic stresses.

According to McKee and Wolf[11], tolerance to any potentially harmful agent is a function of the time-concentration (or intensity) relationship. Thus, an organism may survive a 10-minute exposure to 200 mg/l of a certain chemical followed by return to clean water, yet may succumb to a continuous exposure over a period of an hour to only 20 mg/l of the same substance. Of course, a temperature that kills half the fish in a given section of river in 100 minutes or 100 hours is entirely unsatisfactory. Yet, it must be realized that a certain finite period of time must elapse before a fish is killed at a certain temperature, thereby allowing the fish a period of grace during which he may make his escape into safe waters.

27 *Mount, D.I., "Developing Thermal Requirements for Fresh-water Fishes". Biological Aspects of Thermal Pollution, 1969, Edited by Parker and Krenkel, Vanderbilt University Press.*

28 *Mount, D.I., "Research on Temperature Effects on Fishes", 1969. Presented at Eighth Annual Environmental and Water Resources Engineering Conference, Nashville, Tenn.*

Fortunately, the upper limit of the heat tolerance range is not an unalterably fixed point, since most organisms can be trained to live at higher temperatures (up to a certain limit) by intermittent or gradual exposure to temperatures higher than those of the environment in which they are presently living. This training process is called acclimation or acclimatization. In general, young animals are more easily acclimated than more mature animals[29]. Acclimation to the higher temperatures can last for some time after return of the organisms to an environment at a lower temperature.

Observations of heated water discharges have indicated that fish tend to move toward them in colder months and to move away during summer months. This is an example of so-called temperature selection by motile organisms. In other words, they move toward some preferred temperature. Considered another way, this is also temperature avoidance, since the organism is migrating away from an undesirable temperature. This pehnomenon of temperature selection then is a type of protective response. It is well established that most organisms when free to move in a gradient of temperature, tend to congregate in a definite narrow range of temperature[30]. Avoidance reactions (temperature selection) are common in nature, e.g., seasonal bird migrations.

[29] *Shelford, V. E., "Laboratory and Field Ecology", 1929. Williams and Wilkins Co., Baltimore, Md.*

[30] *Fisher, K. C., and Scott, G. W., "On the Physiological Mechanism of Temperature Selection by Fish", 1942. The Collecting Net, Vol. 17.*

Published data on temperature selection (or avoidance) indicate that fish will not remain in a potentially harmful environment but instead will move toward a more favourable situation if an escape route is available and the more favourable situation is presented, as for example, cooler depths in a stratified lake or river. The general conclusion is that the majority of fish, given the opportunity, successfully avoid lethal temperatures.

Unfortunately, during some of the critical life stages, i.e., egg and fry development, the organisms are capable of little or no motility and, therefore, they are caught up in littoral drifts and subjected to the environmental conditions within a relatively small area. This is of particular interest to fisheries biologists who are concerned about the effects of once-through on-shore heated discharges on the shallow in-shore nursery areas of the Great Lakes system.

Although little information is available on temperature selection by other aquatic vertebrates and invertebrates, it is reasonable to assume that all motile organisms possess some capacity to select desirable temperature conditions. Sessile organisms, on the other hand, would lack this protection response.

SUMMARY

This paper has concentrated on some of the adverse effects of thermal pollution. However, there can be beneficial effects of heat inputs to watercourses. In winter, heated water may prevent ice formation and promote navigation in water passages normally blocked, as well as allowing oxygen transfer to occur through surface re-aeration. Growing seasons can be extended and rates of growth increased for fish in their natural environment and in fish farms because of higher water temperatures. Swimming areas could be provided in certain cold water lakes where this type of activity is minimal, thus increasing the recreational potential of those lakes.

Although thermal discharges to the aquatic environment are not known to be a problem in Ontario at this time, available information is limited to adequately assess environmental effects and extensive studies are being conducted primarily by Ontario Hydro together with the Ministries of the Environment and Natural Resources.

The Ministry of the Environment has set down certain guidelines for the protection of fish, other aquatic life and wildlife with respect to thermal discharges to receiving bodies of water. These guidelines for the control of heated discharges from thermal electric generating stations are available from the Ministry and are continually under review as new information becomes available.

The location of thermal electric generating stations on the shores of the Great Lakes takes advantage of the capacity of these lakes to accept and dissipate waste heat from the power generation process. The Ministry of the Environment has taken the position that this capacity may be utilized provided that such use does not contribute to the deterioration of the quality of the aquatic environment. Where significant adverse effects do (or may) occur, Ontario Hydro has agreed that appropriate remedial measures will be implemented or incorporated into future station design.

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