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Discharge of Cooling and Process Wastewater from The Standard Oil Company (Ohio) Toledo Refinery to Maumee Bay of Lake Erie

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EXECUTIVE SUMMARY

In compliance with Ohio Environmental Protection Agency Requirements, a 316(a) Type II Demonstration study* was conducted for the discharge of cooling and process wastewaters from the Standard Oil Company (Ohio) Toledo Refinery to Maumee Bay of Lake Erie. The Standard Oil Company has proposed a relocation of the refinery discharge to a point near the navigation channel in Maumee Bay. This report attempts to predict the environmental consequences of the proposed relocation,

Because of the extensive data base which presently exists on the hydraulic, water quality and biological nature of Maumee Bay in the vicinity of the proposed project it was unnecessary to acquire new field data for this assessment. The 10-year period of record, 1963-1973, was selected for plume calculation. This period contains both record high water levels (1973) and near-record low levels (1964). Information from a 9-year study of fish temperature preferences and tolerances for the Davis-Besse Nuclear Power Station plume and a 1-year fish impingement population study at the Bay Shore Power Station was used to predict fish (21 representative aquatic species) response to the calculated thermal plume patterns.

The general finding of this study is that, based on Ohio EPA-approved 316(a) Type II procedures and our findings with regard to the list of species (RAS) designated by Ohio EPA for this study, the proposed relocation of the Standard Oil Company (Ohio) Toledo Refinery cooling and wastewater discharge outfall from the Otter Creek to Maumee Bay will not prevent the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in or on the waters of Maumee Bay. No water quality degradation which would be injurious to aquatic life in Maumee Bay is anticipated from this action.

The specific conclusions of the study are summarized here. The navigation channel in Maumee Bay, which is dredged to a depth of 28 feet below Low Water Datum, provides an ample reservoir of water, coupled with river flow, to serve as an effective mixing zone for the proposed discharge. The maximum surface area of the thermal plume enclosed by the 10°F ΔT isotherm is predicted to be approximately 20,000 square feet. The bay has a cross-sectional area of about 26,000 square feet in the vicinity of the proposed outfall. The cross-sectional area of maximum 10°F ΔT along the centerline of the plume will be less than 1,000 square feet or less than 4 percent of the available vertical area of the bay. The maximum monthly ΔT at the navigation channel is expected to range from 1° to 5°F.

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*A "316(a) Type II Demonstration Study" was conducted in lieu of a study under subsection (c), Section 316, Clean Water Act, because no procedures exist for a study under subsection (c).

The maximum 1°F ΔT at the centerline of the navigation channel is predicted to be approximately 2,000 feet upstream from the entrance to the Bay Shore Power Station intake canal and 6,000 feet away from the Bay Shore pumphouse. The relocation of the SOHIO discharge outfall is not expected to adversely impact the cooling capacity of Maumee Bay water at the Bay Shore intake canal or to result in an increase in fish accumulations in the intake canal.

Based on the predicted plume patterns and temperatures at the centerline of the navigation channel, no thermal barriers to normal upstream and downstream fish migration will be created by the proposed outfall relocation. The northwestern half of the navigation channel will experience only minor temperature increases and will remain an adequate migration corridor for anadromous fish species. One species, rainbow smelt, may exhibit avoidance behavior to temperatures at the centerline in spring. This species is not considered a Maumee River inhabitant and it is at its lowest density in Maumee Bay during spring. However, cooler subsurface waters and cooler surface waters on the northwest side of the channel should continue to provide an adequate passageway even for this most sensitive species on the representative aquatic species list. The critical thermal maximum temperature is not predicted to be exceeded, with a 10°F margin of safety, for any species, in any season at the centerline of the channel with the exception of rainbow smelt.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Dr. Jeffrey M. Reutter in the preparation of this report. Dr. Reutter compiled data on fish temperature preferences and thermal tolerances. He also calculated monthly species composition of fish impinged at the Bay Shore Power Station for the period September 1976 to September 1977.

INTRODUCTION

Background

The following document constitutes a 316(a) Type II Demonstration for the discharge of cooling and process wastewaters from the Standard Oil Company (Ohio) Toledo Refinery to Maumee Bay of Lake Erie. The Toledo Refinery is located in the Toledo Harbor area near the south shore of Maumee Bay on the east bank of Otter Creek (Figure 1). This small stream flows into Maumee Bay near the mouth of the Maumee River. Presently the refinery discharges wastewater to Otter Creek approximately 2,300 feet upstream from the creek mouth.

Objective

The Standard Oil Company is considering relocation of the refinery discharge to a point near the navigation channel in Maumee Bay (Figure 2.) The study reported in this document was designed to predict the environmental consequences of the proposed relocation. Because of the extensive data base which presently exists on the water quality and the hydrological and biological nature of the Maumee Bay in the vicinity of the proposed project, acquisition of new field data was not necessary to perform a 316(a) Type II Demonstration.

STUDY METHODS

Data Acquisition and Analysis

Hydraulics. The hydrologic period of record selected for this demonstration is 1963-1973; therefore the data collected for this study were extracted for this period. Data not available for this period were selected from the best period of record available.

The morphometry and bathymetry for this region are known in some detail and have been published elsewhere by the Natural Ocean Survey Navigation Charts, the U.S. Army Corps of Engineers (1974), Pinsak and Meyer (1976), Herdendorf and Cooper (1976) and Bedford and Shah (1978). All depth readings in the vicinity of the proposed outfall were tabulated and a cross-sectional map of the channel was plotted (Figure 3). From this plot, the width of the navigation channel, the region of maximum water transport and dilution volume and the channel depth relative to International Great Lakes Datum of 578.6 feet were noted.

Meteorological data is available in analyzed form from Pinsak and Meyer (1976), Bedford and Shah (1978) and Fraleigh et al. (1975). Information on wind speed and direction rises, rainfall intensity and air temperature is, however, not necessary for this demonstration. Therefore this material is not, in the spirit of economy, reproduced here. This information is in the project files of Dr. Bedford.

Necessary hydraulic information includes lake levels and Maumee River flows. Lake level information is published on an hourly basis by NOS-NOAA as collected from the Toledo gage. These water levels are on file in The Ohio State University Coastal Engineering Laboratory Storm Surge Library. Flow information is available hourly at the USGS Waterville gage, and these records, as well as all general Maumee River Basin hydraulic and hydrologic parameters, were obtained from the computer files of the Columbus bureau of the USGS.

The hydraulic information was processed into average and extreme value form. The time periods over which the averages were performed are delineated by the criteria that the minimum averaging period be that by which all relevant data can be averaged. For the thermal plume analysis the relevant data will permit monthly averages; therefore the flows and lake levels were averaged into monthly values. Table 1 contains this information. Since the Waterville gage is upstream of the outfall site, the flow must be adjusted for additional flow at the site due to increased runoff and the outfall of the Toledo Wastewater Treatment Plant. Records and procedures used by McKee (1978) were used to calculate the site flow as listed in Table 1.

Since this demonstration is for a ten-year period of record, the flow information was analyzed by extreme value analysis (Linsley et al., 1971) to find the seven-day, ten-year flow of 95 cfs.

Refinery Discharge. Data for the refinery discharge were provided by environmental staff of Standard Oil Company (Ohio) in Toledo (Appendix A). The data employed in this analysis covers the period 1 January 1974 through 31 December 1980. Data for the period 1 January 1974 through 31 December 1976 were provided as copies of the monthly "Report Form" submitted by the Standard Oil Company (Ohio) to the Ohio Environmental Protection Agency. Data for the remainder of the study period were provided as copies of the "Toledo Refinery Special Lab Summary." These documents contain values for the total volumetric refinery discharge, the temperatures of the intake and combined effluent streams and for various substances in the effluent. The flow data are 24-hour averages. The temperatures and concentrations represent single daily grab samples, at least through 31 December 1976. Flows and effluent temperatures are generally recorded daily, whenever the refinery was in operation. Other variables are recorded once every two to four days. There is no record of flow for April, 1978, and there is no record of intake temperatures for October of 1975, October, November and December of 1976, January of 1977 or April of 1978.

The variables analyzed in this study include the refinery's volumetric discharge, its waste head load and the temperature increment between the intake water and the effluent water. A histogram of each variable was prepared and estimates were made of its maximum 24-hour and 7-day average values with 10-year return periods. These latter values were estimated using both the Gumbel and log Pearson Type III models of extreme values (Linsley, Kohler and Paulhus, 1975).

Thermal Plume Analysis

There are two general approaches to calculating plume information, integral jet plume procedures and multidimensional numerical models (Jirka et al., 1976). Since integral procedures inexpensively and accurately predict the steady heat and momentum transport patterns required in this demonstration, an integral analysis technique has been selected for use (Appendix B).

Heated water discharging into receiving water passes through several stages of heat and momentum transfer. The first stage, the near field stage, is marked by jet-like outfall behavior. Here mixing of jet with undisturbed water is accomplished by turbulence generated by the large velocity difference between the outfall and receiving water and modified by the buoyancy effect. The fan field region is defined as the region where jet turbulence has been reduced to receiving water levels; jet buoyancy effects are eliminated and heat transfer is totally a function of the convective and inertial characteristics of the receiving channel.

Detailed reviews of outfall physics are available in a number of places, and the works of Jirka (1975), Harleman and Stolzenbach (1972) and Koh and Brooks (1975) indicate that near field outfall dynamics are governed by: 1) the initial outfall velocity; 2) the outfall configuration (i.e., square or round, etc.) and cross-sectional area; 3) the discharge temperature; 4) the outfall and discharge angle relative to the major flow direction of the receiving water; 5) the receiving water temperature; and 6) the receiving water flow. It should be pointed out that all heated effluent discharges are three dimensional.

Integral models for performing thermal plume analyses have been reviewed and compared by Policastro and Tokar (1972) and Dunn, Policastro and Paddock (1975), and in general all integral near field jet models assume the following: 1) the flow is three dimensionsal; 2) steady flow; 3) negligible viscous terms; 4) hydrostatic pressure; 5) the Boussmerg approximation that density changes are only important in the gravity term; 6) boundary layer flow a consequence of hydrostatic pressure; 7) small density differences; 8) small jet deflection by mean river flow; 9) a large receiving water body; and 10) no restrictions or boundary efforts.

Jirka et al. (1976), in a review for the Nuclear Regulatory Commission of techniques for hydrothermal prediction, reviews eight models for near field calculation: Hayashi and Shuto (1976), Hoopes et al. (1967), Motz and Benedict (1970), Koh and Fan (1970), Stolzenbach and Harleman (1971), Stefan et al. (1971), Prych (1972) and Shirazi and Davis (1974). In their assessments, the author's concentrate on the Stolzenbach, Prych and Shirazi models as being foremost in the field and following a detailed thrity-page quantified comparison suggest that there is no marked difference between these models. Further, when verified with field data, favorable agreement was reached with all three models. All three were well documented and have easy, inexpensive-to-operate computer codes. Therefore, due to the availability of the Stolzenbach-Harleman model in the author's (Keith W. Bedford's) computer program library, this model was selected to perform the thermal field predictions for the SOHIO Toledo Refinery outfall.

The structure of the Stolzenbach-Harleman model assumes four different regions with a major feature being a detailed representation of the zone of establishment region from buoyancy and momentum consideration. The system of governing equations is then written for each zone and linked by a system of boundary transfer conditions. The effects of cross flow due to river flow are included, but limited to the situation where the river velocity is much less than the discharge outfall, the situation in this study.

The system of governing equations is scaled with relevant variables and calculations parameterized by the following nondimensional variables:

a) the densimetric Fronde Vo. $\mathbb{F} = Uo/\left(\frac{\Delta Po}{po} g.\ ho\right)^{1/2}$ . . . 1

b) outfall aspect ratio = ho/bo 2

c) cross flow parameter = Ua/Uo 3

d) heat loss parameter = $K/p_oCp\ U_o$ 4

e) discharge angle = θ 5

where Uo = the average discharge velocity; ΔPo = the density difference between the outfall (po + ΔPo) and receiving water (Po); ho = the height of the outfall diffuser; bo = the outfall diffuser width; K = the water surface heat exchange coefficient; Cp = the specific heat of instant pressure; and Ua = the average river velocity.

The resulting system of 13 first order ordinary differential equations is, after imposition of the parameters 1-5, achieved by a fourth order correct Runge Kutta equation solver. Output includes horizontal patterns of water surface temperature and the depth contours of temperature along the plume centerline. At the suggestion of Jirka et al. (1976) this program was modified for use in predicting thermal plumes from outfalls placed a small distance underwater. Using the data of Abraham (1963), Fan (1967), Hirst (1971) Pontheniades et al. (1973) and Koester (1974) the submerged and surface jet paths were both geometrically and dynamically patched together. It is realized that this is an approximation; but since no analyses of this problem have been reported in the literature, it was felt that this was a correct engineering approach.

Biological Assessment

Biological Data. The biological data base for the lower Maumee River and Maumee Bay is one of the best available for the Lake Erie region. Herdendorf and Cooper (1975) summarized the available data on plankton, benthos and fish populations in the river-bay system. Fraleigh (1975) reported on the biota of Maumee Bay, and Cafero (1976) reported on the biota of Otter Creek. Studies of phytoplankton and zooplankton were undertaken by Herdendorf et al. (1977) and Herdendorf et al. (1979) at several stations in Maumee Bay. Investigations of adult and larval fish in the lower river and bay were conducted by Herdendorf and Cooper (1975 and 1976), Herdendorf (1977), Bartholomew (1979) and Snyder (1978). Barnes (1979) reviewed all existing literature on fisheries research in the nearshore zone of Lake Erie.

The most comprehensive study of fish populations in the vicinity of the proposed project was implemented as part of a 316(b) demonstration for the Toledo Edison Company Bay Shore Power Plant (Reutter, Herdendorf and Sturm, 1978). This study included year-around sampling of adult and larval fish species at several locations within one mile of the proposed relocation of the refinery discharge.

The information contained in the reports listed above has been used to characterize the aquatic habitats biota of the study area. Assessment of impacts of the proposed discharge on the biota was based on calculations of thermal and water quality characteristics of the effluent and the tolerances and preferences of various fish species. Mixing zone calculations and the available biological data permitted a reasonable assessment of the habitat and biotic response to the proposed discharge relocation and the biological consequences to water intakes in the vicinity of the proposed discharge. The works of Barans and Tubb (1973), Reutter and Herdendorf (1975 and 1976) and Reutter (1978) on fish thermal preferences in Lake Erie, as well as studies by numerous other investigators in North America, were used to derive tolerance tables for most of the fish on the representative aquatic species (RAS) list.

Biological Response Analysis

Fish lack the ability to maintain body temperatures substantially different from ambient temperatures; therefore, they are classified as obligatory poikilothermic organisms. This characteristic is primarily due to a high conductance of metabolic heat through the gills and across the general body surfaces. As a result, metabolic rate, activity and other thermally-sensitive physiological functions of fish are governed to a great extent by the environmental temperature. In a majority of fish species (especially those in the size range commonly occurring in Maumee Bay of Lake Erie) the body temperature differs by only 0.5 to 1.0°C or less from that of the surrounding water (Nikolsky, 1963).

Therefore, the external environmental temperature must be well suited to internal tissue functionality. Brett (1971) examined the effects of temperature on a variety of physiological functions and determined that a single optimum temperature exists for most of the functions, including active metabolic rate and growth. He also observed a correlation of this optimum temperature with the temperature selected by test species in a thermal gradient. This temperature has been termed the ultimate or final preferred temperature.

The upper and lower limits of temperature which aquatic organisms can withstand define the extremes of the tolerable thermal environment. A variety of experimental procedures have been developed to provide a definition of the thermal tolerance limits, usually expressed as the upper and lower temperatures causing 50 percent mortality of a population sample exposed for some predetermined time interval. Designated as median lethal temperature (TL50), it represents the temperature lethal to one-half of the organisms of the population tested. Both acclimation temperature and exposure duration influence the median lethal temperature. Generally, the median lethal temperature is positively related to acclimation temperature. However, a point is eventually reached when an increase in acclimation temperature no longer increases the median lethal temperature and a tolerance plateau results. This lethal temperature is referred to as the ultimate median lethal temperature. Exposure duration is generally negatively related to the median tolerance limit, for, as the exposure time increases, the temperature tolerated by 50 percent of the sample decreases. A point is eventually reached where further increases in exposure time fail to lower the median lethal temperature. At this point, the lethal temperature is termed the incipient lethal temperature. The laboratory method for determining the incipient lethal temperature was developed by Fry (1947), and is discussed by Brett (1956) and Otto (1973). The ultimate incipient lethal temperature results from both maximum acclimation temperature and exposure time.

In an effort to better estimate the constraints on water temperatures sufficient to protect aquatic populations, other indicators of stress have been utilized. One such indicator is the loss of locomotor control or equilibrium. The temperature at which an aquatic organism loses equilibrium during a rising temperature regime is known as the critical thermal maximum (CTM). The CTM serves as a basis for comparing the thermal tolerances of the various species inhabiting Maumee Bay.

SITE DESCRIPTION: AQUATIC BIOLOGY

Representative Aquatic Species

Twenty-one fish species have been selected as representative of the aquatic environment of Maumee Bay of Lake Erie (Table 1). These species represent 2 classes, 8 orders and 12 families of fish which have been reported in recent years from Maumee Bay in the vicinity of the proposed project (Table 2). The RAS list contains fishes at various trophic levels in the ecosystem and of various utility to man. Approximately six forage species, eight sport fish, nine commercial species, two bait fish and four endangered species are on the list. Descriptions of these species and their occurrence in Lake Erie are presented in the works of Hubbs and Lagler (1958), Langlois (1954), Scott and Crossman (1973) and Trautman (1957 and 1981). Highlights of the biology of these species and their relation to man, with particular attention to the proposed discharge modification, are summarized in Appendix C.

The spawning characteristics of the RAS are listed in Table 3. Most species are spring and early summer spawners. All but 3 of the species are believed to spawn in Maumee Bay, but only 11 species (52 percent) migrate from Maumee Bay into the Maumee River to spawn. Spawning and nursery habitats preferred by each species are indicated in Table 4. Fish on the RAS show a wide diversity of habitat preference.

Adult swimming speeds for selected RAS fish are listed in Table 5. Swimming speeds are generally related to body form and length. Burst speeds of 10 body lengths (BL) per second and cruising speeds of 3 BL per second are generally accepted for fish common to Maumee Bay (Bainbridge, 1958; Blaxter, 1969). Fry and Hart (1948) observed that swimming ability decreases rapidly when the temperature is extremely high or low.

The relative abundance of the 21 RAS for Maumee Bay, compiled on a monthly basis, is presented in Table 6. This information was obtained from estimates of fish impingement at the Bay Shore Power Station, located within a mile of the proposed project. The Bay Shore fish impingement study will be discussed in greater detail later in this report as it relates to fish movements in the Maumee Bay/Maumee River system. The forage species (gizzard shad, alewife, emerald shiner and spottail shiner) dominate the total fish population (91 percent). The most numerous sport/commercial species are white bass, yellow perch and freshwater drum; these species account for an additional eight percent, leaving all others on the RAS list combined at less than one percent. Other species found in Maumee Bay (approximately 30) account for only 0.05 percent of the total fish population.

Preference and critical thermal maximum (CTM) temperatures for the RAS, where experimental data exists, are presented in Table 7 for each season. Maximum and minimum preference and CTM temperatures are summarized in Table 8. Because of the diverse species on the RAS list, a wide range of temperature preferences exist for each season; however, the CTM range is much narrower, generally less than 15°F (Appendix D).

In conjunction with USEPA investigations of larval fish populations in western Lake Erie, the Center for Lake Erie Area Research (Snyder, 1978) studied the contribution of the Maumee River to fish populations of western Lake Erie during 1975 and 1976. Sampling stations in the Maumee River extended from the riffle area at the head of the estuarine portion of the river to Maumee Bay. The following discussion of habitat preferences for the major species in the Maumee River is derived from the results of this study.

During the two years of the study, 19 species of larval fishes were recorded; another 4 taxa were identified to the genus or family level. Over 98 percent of the total catch was composed of 4 species: gizzard shad, freshwater drum, white bass and carp. Four other species could be considered temporarily abundant; emerald shiners, log-perch, walleye and white suckers each were the dominant species in the catch during the peaks of their populations.

Gizzard Shad. The most abundant of all species found in the Maumee River was the gizzard shad, which comprised 67.4 percent of the total catch. Concentrations of these larvae in the Maumee River frequently exceeded 1000 per 100 m^3 in 1975 and 2000 per 100 m^3 in 1976. Gizzard shad were well-distributed and abundant in all sampling stations. Studies in western Lake Erie show that gizzard shad larvae are most abundant in areas where turbidity is high. Secchi disc readings in the river were often as low as 20 cm. This level of turbidity is fairly constant in the Maumee River throughout most of the year. Analysis of 1976 data showed that gizzard shad were randomly scattered in the water column until 29 May, after which a preference for the surface was seen. At the end of May, most gizzard shad were in the 8-10 mm length range, giving some indication of the size at which larvae may exhibit the ability to maintain a preferred depth. This preference for surface waters probably indicates a response to the phototrophic movement of planktonic algae upon which the young shad feed. A preference for the lee of an island over the main channel or a sheltered backwater was implied by analysis of the data. This apparent attraction may be partially caused by the fact that the water depth at this station was only 1.5 meters, causing both the surface and bottom tows to be taken relatively near the surface.

Walleye. Larvae of this species collected at riffle stations were found to be randomly distributed, indicating that newly-hatched walleye pro-larvae are at the mercy of the river currents for their movements. Thus, early pro-larval walleye must remain in the main river current to survive; those which are carried into areas without currents could perish if their yolk sacs are absorbed before they are carried downstream into areas of zooplankton abundance. Walleye eggs collected at riffle stations exhibited a patchy distribution. Walleye eggs are demersal and nonadhesive after water hardening, usually being deposited in areas having clean gravel where they generally slip into crevices among the stones. Although many undeveloped eggs were seen that could have been recently spawned and not yet lodged into crevices, a large percentage were also seen in various advanced stages of embryonic development. This suggests that the eggs had been relatively stable for some period of time before being disturbed and carried by the current. Disturbances could be hydrological to some extent, such as increases in flow rate, or could be due to the activity of other organisms, including man. Walleye spawning areas in both rivers receive intense fishing pressure during spawning migrations with fishermen wading just feet apart in some locations where spawning walleye congregate. Walleye are not territorial during spawning and nests are not established. Most spawning occurs at night as spawners enter shallow areas from deeper sections downstream (Priegel, 1970). This allows some possibility that courtship and spawning behavior could disturb some previously deposited eggs. During 1976 walleye larvae did not exceed 3/100 m^3 in the Maumee River although peak densities on the riffles reached 9/100 m^3.

White Bass. A species commonly encountered during May and June by sport fishermen around the riffle stations was the white bass. Sport fishing success for this species appeared rather high on most sampling dates; many times white bass were actually hooked in front of the net as samples were being taken. During the 1976 segment of this study in which riffle areas were sampled, no white bass larvae were captured at the Maumee River riffle stations. During this same period, white bass larvae in the estuary reached densities as high as 499/100 m^3 (8 June). This may indicate that white bass utilized spawning areas within the estuaries to a greater extent than riffle areas. White bass demonstrated a preference for sheltered backwater areas having reduced current rather than the main river channel or the lee of an island, and for bottom rather than surface waters. On almost all sampling dates during which freshwater drum eggs were collected the eggs were found to be more abundant in the main river channel than in the lee of an island or in a sheltered backwater area. Drum eggs are non-motile and at the mercy of river currents for their movements. Since white bass larvae were most abundant in the backwater areas which held the fewest drum eggs, this provides strong evidence that the larvae actively sought the quieter waters rather than being concentrated there by currents. This trend was seen best when larval densities were highest. During that period most white bass were in the post-larval stage, providing them with sufficient physical development to allow lateral movements.

Freshwater Drum. This species was also found to be abundant at all river stations. Although adult drum may be found in the estuary throughout the year, large numbers of adults ascend the tributaries in May and June to spawn. The eggs of freshwater drum contain a large, distinct oil globule which makes them the only species in Lake Erie with buoyant eggs. This buoyancy carries through to the pro-larvae causing them to float at the surface along with the eggs. Both the eggs and larvae of freshwater drum were found to be in the greatest abundance in the downstream areas near the river mouths. Since spawning occurs throughout the estuary, as evidenced by the presence of eggs, this downstream tendency quite likely represented the effect of eggs and larvae being carried down by currents and concentrated at the river mouths. Drum larvae, as with walleye and white bass, exhibited a preference for the bottom.

Carp. Larvae of this species usually first appeared in mid-May and were encountered on most sampling dates thereafter. This species was found in far greater abundance at riffle stations rather than estuarine stations. Densities as high as 582/100 m^3 were observed in the riffles whereas estuarine densities did not exceed 20/100 m^3. Populations of larval carp were estimated to be higher in 1976 than in 1975 for the Maumee River estuary. However, the abundance of carp larvae in the shallow riffle zones and the high level of shoreline spawning activity witnessed during sampling suggest that limnetic sampling as performed in this study may not reveal the extent of larval carp production in the littoral areas of these estuaries. Carp appear to be one of the most cautious and evasive of all larval species encountered. A single specimen, 10.0 mm in length, was captured in 1975; otherwise no specimens in excess of 8.5 mm were taken.

Emerald Shiners. Larvae of this species were captured in all life stages from 6-mm pro-larvae to 41-mm juveniles. Like gizzard shad, emerald shiners display little net avoidance and large juveniles were common in late-summer collections; adults were also frequently captured in the plankton net. In 1975, the earliest appearance of emerald shiners was on 25 June in the Maumee River. This species, as with many shiners, has a prolonged spawning period; eggs are deposited and fertilized periodically throughout most of the summer (Scott and Crossman, 1973). Therefore, between June and August young-of-the-year emerald shiners may be collected in all stages of development.

Log-perch and White Suckers. These larvae were found to share several similarities. Both species spawn at water temperatures of 9-12°C, closely following the walleye which spawns at 5-11°C (Scott and Crossman, 1973). Both larval species may appear during the same week. In 1976, the white sucker became the dominant species at the end of April, but was succeeded by the log-perch in even higher numbers by mid-May. Rapid growth was displayed by both the log-perch and white sucker; lengths in excess of 10 mm are often attained by the beginning of June.

Yellow Perch and Rainbow Smelt. These species are common in Lake Erie (Emery, 1976), but apparently do not use the estuaries to a significant degree. Larvae of both species were often found to be common at river mouth stations in the Maumee River but no larvae of either species were found at any upstream stations during the two years of the study. The U.S. Army Corps of Engineers has constructed a diked disposal area at the mouth of the Maumee River using limestone riprap. New spawning area provided by this disposal area may have resulted in the increased presence of perch and smelt larvae at the mouth of the Maumee since neither species was collected at the mouth of the Sandusky River.

Alewife. Certain species which one might expect to encounter in the estuaries were not collected, at least not in large numbers. Alewives were not encountered in the estuaries during this study despite the abundance of the species in Lake Erie. Great Lakes alewives usually spawn on the beaches and in ponds having outlets to the lakes, rather than in tributaries, throughout the spring and early summer (Scott and Crossman, 1973). Gill netting efforts in the Maumee River conducted throughout 1975 yielded no adult alewives within the estuary on any collection date, except at the river mouth (Herdendorf and Cooper, 1975).

Sunfish and Crappie. These larvae were very rarely encountered during the study, yet streamside observations and informal interviews with fishermen indicate that both taxa are common to the estuaries. Ictalurids were also infrequently encountered in the samples although several species are common to the estuaries (Trautman, 1957). Faber (1976) surveyed larval fishes in two northern Wisconsin lakes and found that certain species exhibited a preference for littoral areas and seldom ventured into limnetic regions. This tendency may be based upon avoidance of predators, a need to maintain visual contact with the shore or bottom, or other reasons. In any case, it must be recognized that the limnetic sampling performed in this and most other ichthyoplankton studies may not adequately sample all of the larval species inhabiting a given body of water.

The volume of the Maumee River estuary is less than two percent of the volume of the western basin of Lake Erie. Using data from a companion study to this investigation which surveyed the larval fishes found in a portion of the western basin (Heniken, 1977), the Maumee River estuary was found to be more productive on a fish per volume basis than the western basin for gizzard shad, freshwater drum, white bass, walleye and log-perch. The estimated abundance of larvae in the estuary was, at times, as great as the estimated abundance in the entire Ohio portion of the western basin.

In 1976 and 1977, the Center for Lake Erie Area Research conducted investigations of fish impingement and entrainment at two Toledo Edison Company power plants in the vicinity of the Sohio Toledo Refinery. The Acme Power Station is located 3.7 miles upstream from the mouth of the Maumee River and the Bayshore Power Station is situated on the southern shore of Maumee Bay near the mouth of the Maumee River. These studies constituted 316(b) requirements for these plants. The results of these investigations provide detailed information on fish populations in the lower river and the bay as well as insight as to the preference of RAS for river or bay habitats. Information from 65 sampling periods at these plants is summarized below.

Impingement results indicated that alewife, emerald shiner, rainbow smelt, spottail shiner, white bass and yellow perch were species of probable Maumee Bay origin. This hypothesis could not be tested for alewife using entrainment results, as any alewife larvae which may have occurred in the samples were not differentiated from gizzard shad larvae. However, Snyder (1978) did not find any alewife larvae in the river during his study.

Emerald shiner entrainment results agree with the impingement results, in that this species appears to be of bay origin. This species was entrained on only four sampling dates during the study and each when the source water was considered to be of bay origin based on low electrical conductivity measurements of the water. In addition, 67 percent of its occurrences in river samples were also on days when the water was suspected to be of bay origin. The concentration of this species observed in the bay near the Bay Shore plant was 26 times greater than the concentration observed upstream during 316(b) studies at the Acme plant.

The occurrence of rainbow smelt in the Bay Shore intake canal does not appear to be correlated with bay or river source water. However, this species was not collected during the 316(b) study at Acme, upstream from Bay Shore, and therefore is considered a "bay or lake" species.

Spottail shiners occurred only once in the Bay Shore intake canal samples and on six occasions in the river. It is considered a "bay or lake" species since the occurrence in the intake canal and five of the six occurrences in the river were on days when the source water was considered to be of bay origin.

The white bass is generally considered a river spawner; however, the results did not substantiate this. Only 21 percent of its occurrences in the river were on days with a river water flow, and only 25 percent of its occurrences in the intake canal were on days when the source water was considered to be of river origin. However, Snyder (1978) felt that this species may spawn in the estuary itself which would explain its occurrence on days when the dominant source water was of bay or lake origin.

Walleye, which, in the vicinity of the Maumee River spawn primarily in the river, occurred on five occasions in the Bay Shore intake canal. Four occurrences at Bay Shore were on days when the water source was of river origin.

Yellow perch must be considered a lake or bay species as 65 percent of its occurrences in the bay, and 83 percent of its occurrences in the intake canal in the vicinity of Bay Shore were on days when the source water was suspected to be of bay or lake origin. Furthermore, concentrations observed in the bay at Bay Shore were 6.5 times greater than concentrations observed farther upstream during 316(b) studies at the Acme plant.

In general, the above discussion indicates that the Bay Shore Power Station does not entrain everything flowing down the Maumee River. In fact, although the intake volume is equal to approximately 25 percent of the mean river flow, most of the cooling water is definitely a mixture of river and lake water, and many of the entrained larvae appear to be of bay or lake origin.

In an effort to further explain entrainment at the Bay Shore Power Station, correlation coefficients were developed for the concentrations in the intake canal of carp, channel catfish, freshwater drum, emerald shiner, gizzard shad, walleye, white bass and yellow perch with several environmental parameters. This was done only for the period of occurrence of each species and was all but fruitless due to few observations for several species and the fact that the presence of larvae is a very seasonal phenomenon that will generally occur at the prescribed time relatively independent of most environmental factors.

The major causes of unusually high or low values for the percentage of the river population entrained is due to behavioral characteristics or preferences of the species in question and the sampling techniques employed (limnetic or open water).

The channel catfish and the carp are good examples of this. Channel catfish were not in the bay adjacent to the intake canal but were entrained at the power plant. Similar results were observed for trout-perch and white suckers and could be indicative of spawning in the intake canal. However, it is more likely that the limnetic sampling procedures did not adequately sample these populations. Snyder (1978) considered larvae of the ictalurids to prefer littoral areas.

Carp occurred during 13 collection periods in the Bay Shore intake canal; 77 percent of the occurrence from the intake canal was on days when the flow was considered to be of bay origin. This indicates that most of the carp entrained were of bay origin. This is contradictory to the results of Snyder (1978) who found the greatest concentrations of carp larvae in the riffle areas and littoral zone. However, Snyder (1978) also found the carp to be very evasive and this, along with its preference for the littoral zones, may account for the relatively high percentage found in the intake canal as our limnetic river sampling may have missed them.

Habitat

The western basin of Lake Erie, including Maumee Bay, has long been considered important in the reproduction of many fish species, due to its shallow nature and many reefs and shoals (Hartman, 1970). Trautman (1957) and Scott and Crossman (1973) provide life history information on Lake Erie fish species and indicate that many lake-dwelling populations are migratory, utilizing tributary waters, such as the lower Maumee River and Maumee Bay, as spawning and nursery areas. This attraction of spawners to tributary waters results in the concentration of spawning activity and consequently fish eggs and larvae in relatively small areas.

The Maumee River is a large, warm-water, low gradient stream draining relatively flat farm land in northwestern Ohio. The soilds in the drainage basin are formed primarily from glacial till and lacustrine deposits left from earlier stages of Lake Erie. The underlying bedrocks are mostly Silurian and Devonian dolomites and limestone; less prevalent bedrocks are sandstone and shale (Herdendorf and Cooper, 1975; Forsyth, 1975). Miller (1968) stated that due to the sluggish flow and numerous wind-induced lake seiches, an outflow into the bay occurred only about 60 percent of the time. Planimeter measurements from a NOAA navigational chart (scale 1:15,000) indicate the area of the estuary to be approximately 14.0 square kilometers. The mean depth of the Maumee River estuary based upon 1,155 soundings appearing on the chart is 2.9 meters. A dredged navigational channel extending from the mouth of Maumee Bay to Rossford is maintained by the U.S. Army Corps of Engineers; about 12.9 kilometers of this channel with a mean depth of 6.8 meters lies within the estuary. In addition, present levels are 1.0 meters higher than the depths appearing on the chart which represent levels referenced to Low Water Datum (568.6 ft., International Great Lakes Datum). From the area and average depth of the Maumee River estuary, the volume of the estuary was calculated to be approximately 5.80 x 10^7 cubic meters.

Maumee Bay lies at the western end of Lake Erie, separated from the lake by two spits, Woodtick peninsula extending southerly from the Michigan shoreline and Cedar Point extending northwesterly from the Ohio shore. For the purposes of this study, the northeastern boundary of the bay includes the water at the mouth of Maumee Bay out to the 4-m depth contour. This yields an area of 88.3 km^2 and a water volume of 15.0 x 10^7 m^3. Maumee Bay is a productive spawning area because of its generally shallow nature and the various sand deposits located in the bay. The bay also acts as a catch basin for larvae produced upriver and, therefore, serves as a nursery ground.

SITE DESCRIPTION: ENVIRONMENTAL CHARACTERISTICS

Bathymetry

Information obtained from the available data was graphically assembled into both planform (Figures 1 and 2) and vertical profile sections (Figure 3). The vertical section is portrayed out the side of the proposed outfall and reveals that the cross-sectional area of the navigation channel is roughly 21,000 square feet. The dredged depth being 28 feet (from IGLD). The average slope of the river bed is 1.3 feet per mile.

Hydraulics

Two types of hydraulic information are required for the demonstration--the site river flow and the site water level. Water level fluctuations are caused by both storms and seasonal/monthly changes caused by seasonal changes in the weather patterns. Since water level disruption caused by storm surges cause water level changes over periods of days or less, they are excluded from this demonstration. Monthly/seasonal water level averages show for the period of record a range of 1.2 to 2.4 feet relative to IGLD. The monthly average water level changes relative to IGLD are listed in Table 9.

Monthly average site flows, adjusted for additional inflow from the Waterville gaging station range from 713 (August to 9,774 (April) with an average flow of 4,894 cfs. The instantaneous maxima is 94,000 cfs and the instantaneous minima is 32 cfs. The 7 day, 10 year low flow is 95 cfs and occurs during late August-early September. The relevant hydraulic flow variables are listed in Table 9.

SITE DESCRIPTION: REFINERY DISCHARGE

Nonexceedance probabilities for the total volumetric refinery discharge are plotted in Figure 4. The distribution of flows is nearly normal. The maximum 24 hr average discharge for the period of record is 58.5 MGD. The median discharge is approximately 29 MGD. Statistical analysis of the annual extremes indicates that the maximum 24 hr average discharge with a 10 year return period is 57 MGD. The maximum 7 day average discharge with a 10 year return period is 52 MGD. There was no significant difference between the estimates obtained with Gumbel and log Pearson Type III models for either the 24 hr or 7 day averaging periods.

Nonexceedance probabilities for the increase in temperature between the refinery intake and the refinery discharge are plotted in Figure 5. Intake temperatures are available only every fourth day, on average. An attempt to supplement the intake record with data from the USGS monitoring station at Waterville, Ohio, was abandoned when it was discovered that temperatures in the two records are not correlated ($R^2 = 0.46$). The maximum "24 hr average" temperature increase in the record is 98.1^{o}F (36.7^{o}C). The median "24 hr average" increase is 69.8^{o}F (21.8^{o}C). Statistical analysis of the annual extrema indicates that the maximum "24 hr average" temperature increase with a 10 year return period is 97.9^{o}F (35.5^{o}C). Again, there is no significant difference in the estimates obtained with the Gumbel and log Pearson Type III models for either averaging period.

It was assumed that the temperature increments computed above apply to the entire refinery discharge. The nonexceedance probabilities are plotted in Figure 6. The largest "24 hr average" waste heat load on record is 0.98 x 10^9 Btu/hr. The median waste heat load is 0.37 x 10^9 Btu/hr. Statistical analysis of the annual extrema indicates that the maximum "24 hr average" heat load with a 10 year return period is 0.89 x 10^9 Btu/hr. The maximum "7 day average" waste heat load with a 10 year return period is 0.83 x 10^9 Btu/hr. There was no difference between the Gumbel and log Pearson Type III estimates.

PROPOSED OUTFALL MODIFICATIONS

There are two proposed modifications to the existing outfall--first, the heated cooling water and the waste water are to be combined into one discharge; and second, the single combined discharge is to be relocated from its present site to a location on the edge of the navigation channel. Figures 2 and 3 portray the schematic details of this new location.

At the time of these calculations the exact engineering details of the outfall, particularly the source of the potential energy for creating the discharge velocity, are unknown. Yet the following information is known and is of sufficient detail to permit this demonstration. The waste material is to be carried by a 54-inch main from the shore to the edge of the navigation channel. The outfall diffuser is a simple rectangular shape two feet tall by five feet wide. The diffuser is to be located eighteen feet below IGLD. An estimate of the outfall operating behavior is necessary in order to establish the discharge velocity required for the plume prediction model. Preliminary engineering schematics of the problem by The Design Consultants Center are either a pumped storage quasiconstant head tank design, which would yield a constant outfall velocity of nine feet per second, or a simple gate-pump system, which would result in a yearly outfall velocity pattern similar to that existing at this time. Therefore, the existing discharge flow and heat load statistics would apply. Predicted thermal discharge patterns must be conservative to account for the variability in design and operating strategy.

PREDICTED THERMAL PLUME PATTERNS

Selection of Relevant Case Studies

Of course an overwhelming variety of calculations can be made with the thermal model; therefore, some rational criteria must be selected by which only relevant cases are selected and considered. Several types of criteria apply. For instance, the OEPA guidelines suggest that thermal fields be considered for typical river flows and heat loads with consideration given to a 7 day, 10 year worst case situation. Another non-legal biological consideration becomes the maximum vertical penetration of the plume during typical conditions and the extent to which this penetration blocks fish migration. A third physical consideration becomes the maximum horizontal areal extent of the surface plume and whether it properly penetrates and mixes with the receiving water or stays shore attached with poor mixing and pockets of very high temperature water.

The predictions presented here represent 10 year worst case events. The motivation for this choice is a simple desire to define a suite of 10 year worst case conditions within which all other typical operating conditions would fall.

The major factors affecting the plume shape are the outfall discharge velocity, the river velocity and the temperature difference between the river and the outfall. In general the river flow will bend the surface plume pattern in the direction of flow, a large ΔT will cause larger surface contours of heated water with thin vertical penetration, while increasing outfall flow causes thicker vertical penetration of heated water with much smaller surface isotherm areas. Therefore since a primary concern is fish migration and its hindrance by thermal blockage, a set of calculations was performed for average monthly river flows and ΔT's assuming maximum 10 year outfall velocity. The specific input conditions for these runs, Nos. 1-12, are listed in Table 9. This sequence of runs portrays the situation of maximum vertical penetration expected for the monthly average river and temperature condition.

Three other 10 year extreme value predictions were performed to assess the maximum expected behavior of the plume. Run No. 13 represents the expected plume pattern for the 7 day, 10 year low flow of 223 cfs assuming the average yearly ΔT of 38.7°F and the median outfall of 43 cfs. Run No. 14 portrays the expected plume for the median outfall velocity of 43 cfs, the average yearly river flow of 5,033 cfs and the 10 year extreme T of 63.9°F. The last run (15) predicts the contours for a 10 year outfall velocity of 9 fps, the yearly average river flow of 5,033 cfs and the yearly average ΔT of 38.7°F. The complete list of case studies performed in this demonstration is found in Table 9.

Output from these calculations is graphically and tabularly displayed. Thermal plume patterns for each study are found in Appendix B. Each plot contains the surface thermal isotherms, to assess maximum areal extent, and the vertical temperature isotherms down the plume centerline, again to assess the maximum vertical blockage. Each plot also contains the total area contained within each isotherm. Note that because of the relatively modest plume size it was not necessary to plot these contours past the centerline of the channel. Finally, two sets of thermal plots were prepared; the first set plotted absolute temperature isotherms and this entire set is included in the Appendix. For use in fish avoidance several plots were redrawn to show the 1^{o}, 5^{o} and 10^{o} temperature difference isotherms. These plots are also included for selected runs in the Appendix.

Results

In general all the cases explored here portray a relatively modest discharge excursion into the channel. In all cases no significant activity is predicted past the channel line. In all cases the 5^{o} ΔT surface isotherms never progressed upstream or downstream more than 150 feet, while the 10^{o} ΔT isotherms progressed no more than 100 feet. The maximum horizontal area occupied by the surface contours was calculated in the 10 year extreme ΔT case (run no. 14) but this large surface area was accompanied by virtually no vertical isotherm penetration. The 10 year maximum outfall velocity plus January's average ΔT (run no. 1) produced the deepest vertical penetration. This is of course a bit misleading since never have the January operating conditions ever exhibited a maximum outfall velocity. By far case no. 1 represents the maximum or extreme value heat load entering the river. Since all the cases studied here represent 10 year extreme value simulations, i.e., an event to be equalled or exceeded once every 10 years, these results indicate that a very modest discharge plume will be manifest.

BIOLOGICAL RESPONSE TO PREDICTED PLUMES

Existing Maumee Bay temperatures (10-year mean) and predicted temperatures at the centerline of the navigation channel with the proposed discharge are listed monthly and seasonally in Table 10. Based on the data in Table 7, during the winter months the ambient temperature is now below the thermal preference temperature for all RAS except rainbow smelt. With the proposed discharge, the temperature at the centerline of the navigation channel will continue to be below the preference temperature of all species except rainbow smelt and emerald shiner. In late spring, the bay presently rises above the preference temperature for emerald shiner, spottail shiner, white bass, white crappie and yellow perch (YOY). With the proposed discharge, alewife and freshwater drum will be added to this list. For the summer months, the maximum bay temperature exceeds the preference temperature for emerald shiner, white crappie and yellow perch. The operation of the proposed discharge may add channel catfish to the summer list. In fall, the existing bay temperatures are below the preference temperatures of all species except white crappie. The proposed discharge will add spottail shiner and emerald shiner (YOY) based on predicted temperatures at the centerline of the navigation channel. Throughout the year, the CTM of none of RAS is exceeded by the existing thermal conditions in Maumee Bay. The proposed discharge will increase the temperature about 5°F at the centerline of the navigation channel in the spring; this increase will approximate (within 5°F) the CTM of rainbow smelt. No other species in any season has a CTM which is less than 10°F above the predicted temperature at the centerline. These predictions of fish response to the proposed discharge are based on the available data for each species (Table 7). The data base is incomplete for several species, but the general response indicated above appears to be valid based on the thermal preference and CTM behavior of related species.

In general, the following RAS response is anticipated at the centerline of the navigation channel adjacent to the proposed discharge.

Winter

Rainbow smelt will be thermally attracted to the centerline during winter, but all other species will prefer warmer temperatures, those closer to the outfall. No CTM problems are anticipated at the centerline of the channel or below the centerline in the northwest half of the channel as a result of the discharge.

Spring

In late spring the bay normally rises above the preference temperature for a number of species. The proposed discharge will increase the temperature at the centerline of the navigation channel by approximately 5°F causing other species, such as alewife and freshwater drum, to also be repelled from the plume at the centerline. At the centerline, the water temperature is predicted to be at least 10°F below the CTM of all species except rainbow smelt, which has a CTM within 5°F of the predicted water temperature. However, rainbow smelt is not believed to be a Maumee River spawning fish requiring a migration route into the river during spring. This is borne out by its low abundance in spring as compared with other seasons (Table 6).

Summer

The normal bay temperature in summer also exceeds the preference temperature of several resident species. The temperature at the centerline of the navigation channel will be increased by approximately 5°F, and may also cause channel catfish to be repelled from the plume at the centerline. The predicted temperature of the water at the centerline with the proposed discharge will be at least 15°F below the CTM of all RAS for which data is available.

Fall

In fall, the normal temperature at the centerline of the navigation channel is predicted to be below the preference of all species except white crappie, therefore most species will be attracted to the vicinity of the plume. With the proposed discharge the temperature at the centerline is predicted to be well below the CTM of all species.

CONCLUSIONS

The general conclusion of this study is that, based on Ohio EPA-approved 316(a) Type II procedures and our findings with regard to the list of species (RAS) designated by Ohio EPA for this study, the proposed relocation of the Standard Oil Company (Ohio) Toledo Refinery discharge from Otter Creek to Maumee Bay will not prevent the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in or on the waters of Maumee Bay. Specific findings of the study are summarized below:

1. The navigation channel in Maumee Bay provides an ample reservoir of water to serve as an effective mixing zone for proposed discharge (maximum surface area enclosed by the 10°F ΔT isotherm is equal to approximately 20,000 square feet). The maximum monthly ΔT at the centerline of the navigation channel ranges from 1° to 5°F.

2. The maximum 1°F ΔT at the centerline of the navigation channel is approximately 2,000 feet upstream from the entrance to the Bay Shore Power Station intake canal and 6,000 feet from the Bay shore pumphouse (Figure 7). The relocation of the discharge will not adversely impact the cooling capacity of Maumee Bay water at the Bay Shore intake canal or will it result in an increase of fish accumulations in the intake canal.

3. Based on predicted temperatures at the centerline of the navigation channel resulting from the discharge relocation, no thermal barriers to normal upstream or downstream fish migration will be created by the proposed action. The northwestern half of the navigation channel will experience only minor temperature increases and will remain as an adequate migration corridor for anadromous fish species (only rainbow smelt, which is not considered a river species, may exhibit avoidance behavior at the centerline, by moving to cooler subsurface waters of the northwest part of the channel for passage). The critical thermal maximum temperature will not be exceeded, with a 10°F margin of safety, for any species in any season at the centerline of the channel with the exception of rainbow smelt.

Based on these findings, no water quality degradation injurious to existing aquatic life should be expected as a result of the design modifications specified in this report.

REFERENCES CITED

Abraham, G. 1963. Jet diffusion in stagnant ambient fluid. Delft Hydraulics Lab, Publ. No. 29, 1963.

Adams, E.E., K.D. Stolzenbach and D.R.F. Harleman. 1975. Near and far field analysis of buoyant surface discharges into large bodies of water. MIT R.M. Parsons Lab., Dept. No. 205, August 1975.

Allen, K.O. and K. Strawn. 1968. Heat tolerance of channel catfish, Ictalurus punctatus. Proc. Conf. of S.E. Assoc. of Game & Fish Comm., 1967.

Andrews, J.W., L.H. Knight and T. Murai. 1972. Temperature requirements for high-density rearing of channel catfish from fingerling to market size. Prog. Fish Cult. 34:240-241.

Bainbridge, R. 1958. The speed of swimming of fish as related to size and to the frequency of the tail beat. J. Exp. Biol., 35(1):109-133.

Barans, C.A. 1972. Seasonal temperature selections of white bass, yellow perch, emerald shiners and smallmouth bass from western Lake Erie. Ph.D. diss. The Ohio State Univ. 88 p.

Barans, C.A. and R.A. Tubb. 1973. Temperatures selected seasonally by four fishes from western Lake Erie. J. Fish. Res. Bd. Canada 30(11): 1697-1703.

Barnes, M.D. 1979. Inventory and review of literature data sources pertaining to ichthyological and fisheries research in the nearshore zone of Lake Erie. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 127. 80 p.

Bartholomew, W.C. 1979. Abundance and distribution of larval fishes of the family Percidae in Maumee River and Maumee Bay of Lake Erie. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 159. 166 p.

Bedford, K.W. and B.C. Shah. 1978. Maumee Bay sediment transport mechanics during spring runoff. USEPA/IJC, PLUARG Task D Rep., May 1978.

Bell, M.C. 1973. Fisheries handbook of engineering requirements and biological criteria. Fisheries-Engineering Res. Program, Corps of Engineers, North Pacific Div., Portland, Oregon.

Black, E.C. 1953. Upper lethal temperatures of some British Columbia freshwater fishes. J. Fish. Res. Bd. Canada. 10:196-210.

Blaxter, J.H.S. 1969. Swimming speeds of fishes. F.A.D. Fish Rept. 62(2):69-100.

Blaxter, J.H.S. and W. Dickson. 1959. Observations on the swimming speeds of fish. J. Cons. Perm. Int. Explor. Mer. 24(3):472-477.

Brett, J.R. 1946. Rate of gain of heat tolerance in goldfish (Carassius auratus). Pub. Ont. Fish. Res. Lab., Toronto, Ont. 64:9-29.

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (Onchorhynchus nerka). Amer. Zool. 11: 99-113.

Burns, J.W. 1966. IN: Inland Fisheries Management. A. Calhoun, ed., Calif. Div. Game and Fish.

Cafaro, D.J. 1976. An assessment of effects of the thermal discharge from the Toledo oil refinery (SOHIO) on Otter Creek. Ecological Sciences Div., NUS Corp., Pittsburgh, Pa.

Cherry, D.S., K.L. Dickson and J. Cairns, Jr. 1974. The use of a mobile laboratory to study temperature response to fish. Paper presented at the 29th Purdue Indus. Conf., May 7-9, 1974. Purdue Univ.

Clemens, H.P. and K.F. Sneed. 1957. The spawning behavior of the channel catfish, Ictalurus punctatus. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 219.

Colby, P.J. 1973. Response of the alewives, Alosa pseudoharengus, to environmental change. IN: Responses of Fish to Environmental Change. W. Chavin, ed. C.C. Thomas, Springfield, Ill.

Dorfman, D. and J. Westman. 1970. Responses of some anadromous fishes to varied oxygen concentrations and increased temperatures. Rutgers Univ., New Brunswick, N.J.

Edsall, T.A. 1970. Effects of temperature on the rate of development and survival of alewife eggs and larvae. Trans. Amer. Fish. Soc. 99:376-380.

Emery, L. 1976. Fish inhabiting U.S. waters of the Great Lakes, with indications of their relative abundance and of their importance as commercial, sport or forage species, p. 201-206. IN: J. Boreman (ed.) Great Lakes fish egg and larvae identification (Proc. of a workshop). U.S. Fish and Wildl. Serv., OBS Natl. Power Plant Team (Ann Arbor, Mich.), FWS/OBS - 76/23:220 p.

Dunn, W.E., A.J. Policastro and R.A. Paddock. 1975. Surface thermal plumes: evaluation of mathematical models for near and complete field. Argonne National Laboratory.

Faber, D.J. 1976. Limnetic larval fishes in northern Wisconsin lakes. J. Fish. Res. Bd. Canada. 24(5):927-937.

Fan, L.N. 1967. Turbulent buoyant jets into stratified or flowing ambient fluids. Calif. Inst. of Tech., W.M. Keck Laboratory, Rep. KH-R-15.

Forsyth, J.L. 1968. A study of physical features for the Toledo regional area. Prepared for The Toledo Regional Area Plan for Action. 111 p.

Fraleigh, P.C., J.E. Burnham, G.H. Gronau, T.L. Kovacik and E.J. Traner. 1975. Maumee Bay environmental quality study. Rept. Lucas County Port Authority.

Fry, F.E.J. 1947. Effects of the environment on animal activity. Ont. Fish. Res. Lab., Toronto, Ont. Pub. 68. 62 p.

Fry, F.E.J., J.R. Brett and G.H. Clawson. 1942. Lethal limits of temperature for young goldfish. Rev. Can. de Biol. 1:50-56.

Fry, F.E.J. and J.S. Hart. 1948. Cruising speed of goldfish in relation to water temperature. J. Fish. Res. Bd. Can. 7:169-175.

Graham, J.J. 1956. Observations on the alewife, Pomolobus pseudoharengus (Wilson), in freshwater. Univ. of Toronto Biol. Ser. 62:1-43.

Harleman, D.R.F. and K.D. Stolzenbach. 1972. Fluid mechanics of heat disposal from power generation. Ann. Review of Fluid Mech., Vol. 4.

Hart, J.S. 1947. Lethal temperature relations of certain fish of the Toronto region. Trans. Roy. Soc. Can. 41(III):57-71.

Hart, J.S. 1952. Geographical variations of some physiological and morphological characters in certain freshwater Fish. Univ. Toronto Bio. Ser. 60.

Hartley, S.M. and C.E. Herdendorf. 1977. Spawning ecology of Lake Erie fishes. The Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 62., Columbus, Ohio. 10 p.

Hartman, W.L. 1970. Resource crises in Lake Erie: the Explorer 12(1): 6-11.

Hayashi, T. and N. Shuto. 1967. Diffusion of warm water jets discharged horizontally at the water surface. Proc. IAHR Fort Collins, Colo., 1967.

Heniken, M.R. 1977. Distribution and abundance of larval fish in a portion of the western basin of Lake Erie. M.S. thesis. Ohio State Univ., Columbus. 95 p.

Herdendorf, C.E. 1977. Assessment of the larval fish populations in Maumee River Estuary and Maumee Bay of Lake Erie. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 75. 136 p.

Herdendorf, C.E. and C.L. Cooper. 1975. Environmental impact assessment of commercial sand and gravel dredging in Maumee River and Maumee Bay of Lake Erie. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 41. 380 p.

Herdendorf, C.E. and C.L. Cooper. 1976. Investigations of larval fish populations in Maumee River Estuary and Bay, an assessment of the impact of commercial sand and gravel dredging on the populations. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 49. 86 p.

Herdendorf, C.E., L.A. Fay, D.D. Larson and L.S. Walters. 1979. Results of 1978 nearshore water quality surveillance program for western Lake Erie. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 109. 36 p.

Herdendorf, C.E., D.E. Rathke, D.D. Larson and L.A. Fay. 1977. Suspended sediment and plankton relationships in Maumee River and Maumee Bay of Lake Erie. In Geobotany, Plenum Pub. Co. p. 247-282.

Herdendorf, C.E. and J.E. Zapotosky. 1977. Effect of tributary loading to western Lake Erie during spring runoff events. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 65. 153 p.

Hirst, E. 1971. Buoyant jets discharged to quiescent stratified ambients. J. Geo. Res., Vol. 76, No. 30.

Hocutt, C.H. 1973. Swimming performance of three warm water fishes exposed to a rapid temperature change. Chesapeake Sci. 14(1): 11-16.

Hokanson, K.E.F. and C.F. Kleiner. 1974. Effects of constant and rising temperatures on survival and developmental rate of embryo and larval yellow perch, Perca flavescens (Mitchill) IN: The Early Life History of Fish. J.H.S. Blaster, ed. Springer-Verlag, Heidelberg, W. German. p. 437-448.

Hoopes, J.A., R.W. Zeller and G.A. Rolich. 1967. Heat dissapation and induced circulations from condensor cooling water discharges into Lake Monona. Univ. of Wisconsin, Dept. of Civil Engineering Rep. No. 35, Madison, Wisc.

Houde, E.D. 1969. Sustained swimming ability of larvae of walleye and yellow perch. Fish. Res. Bd. Can. 26:1647-1659.

Hubbs, C.L. and K.F. Lagler. 1958. Fishes of the Great Lakes region. Univ. of Mich. Press. Ann Arbor, Mich. 213 p.

Jirka, G.H., G. Abraham and D.R.F. Harleman. 1976. An assessment of techniques for hydrothermal prediction. U.S. Nuclear Regulatory Comm., NUREG-0044, NRC-6, March 1976.

King, L.R. 1969. Swimming speed of the channel catfish, white crappie and other warm water fishes from Conowingo Reservoir, Susquehanna River, PA. M.S. Thesis, Cornell Univ. 83 p.

Koester, G.E. 1974. Experimental study of submerged single-port thermal discharges. M.S. Thesis, MIT.

Koh, R.C.Y. and N.H. Brooks. 1975. Fluid mechanics of waste water disposal in the ocean. Ann. Review of Fluid Mech., Vol. 7.

Kothas, E. 1970. Study of the swimming speed of some anadromous fishes found below Conowingo Dam, Susquehanna River, MD. Ichthyological Assoc., Progress Rep.

Kreitmann, M. 1933. Les barrages et al circulation des poissons. Bull. Soc. Centr. d'Agriculture et de Peche. 40(4-6).

Langlois, T.H. 1954. The western end of Lake Erie and its ecology. J.W. Edwards, Publisher, Inc. Ann Arbor, Mich.

Linsley, R.K., M.A. Kohler and J.L.H. Paulhus. 1971. Hydrology for engineers. McGraw-Hill Publishing Co., Inc., New York.

McCormick, J.H., B.R. Jones and K.E.F. Hokanson. 1972. Effects of temperature on incubation success and early growth and survival of the white sucker (Catostomus commersoni (Lacepedi)). Unpubl. data. Nat. Wat. Qual. Lab., Duluth, Minn.

McCormick, J.H. and C.F. Kleiner. 1970. Effects of temperature on growth and survival of young-of-the-year emerald shiners (Notropis atherinoides). Unpubl. data. Nat. Wat. Qual. Lab., Duluth, Minn.

McKee, Arthur. 1978. Thermal discharge dispersion study prepared for the Standard Oil Company (Ohio) Toledo Refinery. McKee Contract Rep. 4841.

Meldrim, J.W. and J.J. Gift. 1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthyological Assoc. Inc., Middletown, Del., Bull. No. 7. 75 p.

Meldrim, J.W., J.J. Gift and B.R. Petrosky. 1974. The effect of temperature and chemical pollutants on the behavior of several estuarine organisms. Ichthyological Assoc. Inc., Middletown, Del., Bull. No. 11. 129 p.

Miller, G.S. 1968. Currents at Toledo Harbor. Proc. 11th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res. 1968:437-453.

Motz, L. and B. Benedict. 1970. Heated surface jet discharged into a flowing ambient stream. Vanderbilt Univ., Dept. of Environmental and Water Resources Engineering Rep. No. 6.

Nikolsky, G.V. 1963. Theory of fish population dynamics as a biological background for rational exploitation and management of fishery resources. Nanka Press, Moscow. 382 p.

Ohio Division of Wildlife. 1981. Status of Ohio's Lake Erie fisheries. Ohio Dept. Nat. Res., Lake Erie Fish. Unit. 19 p.

Otto, R.G. 1973. Temperature effects on fish. Laboratory studies, June 1972-June 1973. Report to Commonwealth Edison Co., Chicago, Ill., by Industrial Bio-Testing Laboratories, Inc. 69 p.

Partheniades, E., B.C. Beechley and Y. Jen. 1973. A parametric study for surface temperature concentration due to submerged heated water jets in shallow water. Univ. of Florida, Coastal Eng. Lab.

Pinsak, A.P. and T.L. Meyer. 1976. Maumee River basin, level B study. Great Lakes Basin Commission MRB Series No. 9, August 1976.

Policastro, A.J. and J. Tokar. 1972. Heated effluent dispersion in large lakes: state-of-the-art of analytical modeling, Argonne National Laboratory, ANL/ES-11.

Priegel, G.R. 1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Tech. Bull. Wisc. Dept. Natur. Res. 45:105 p.

Prych, E.A. 1972. A warm water effluent analyzed as a buoyant surface jet. Suoriges Meteorologiska Och Hydrologiska Institut, Serie Hydrologi, nr 21, Stockholm, Sweden.

Reutter, J. 1978. Laboratory estimates of fish response to the heated discharge from the Davis-Besse reactor, Lake Erie, Ohio. Center for Lake Erie Area Res., Ohio State Univ., Tech. Rep. No. 115. Columbus, Ohio.

Reutter, J.M. and C.E. Herdendorf. 1975. Laboratory estimates of fish response to the heated discharge from the Davis-Besse reactor, Lake Erie, Ohio. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 31. 65 p.

Reutter, J.M. and C.E. Herdendorf. 1976. Thermal discharge from a nuclear power plant; predicted effects on Lake Erie fish. Ohio J. Sci. 76:39-45.

Reutter, J.M., C.E. Herdendorf and G.W. Sturm. 1978. Impingement and entrainment studies at the Bay Shore Power Station, Toledo Edison Company, 316(b) Program. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 78b. 160 p.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea and W.B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada, 4th edition. American Fisheries Soc., Spec. Pub. No. 12. 174 p.

Schuler, V.F. 1968. Progress report of swim speed study conducted on fish of the Conowingo Reservoir. Ichthyological Assoc., Progress Rep.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. No. 184. 966 p.

Shirazi, M.A. and L.R. Davis. 1974. Workbook of thermal plume prediction . Vol. 2, surface discharges. USEPA Rep. No. EPA-R2-72-0056, Corvallis, Oregon.

Snyder, F.L. 1978. Ichthyoplankton studies in the Maumee and Sandusky River estuaries of Lake Erie. Ohio State Univ. Center for Lake Erie Area Res. Tech. Rep. No. 92. 140 p.

Stefan, H. and F. Schiebe. 1968. Experimental study of warm water flow into impoundments, Part I. Puj. Rep. No. 101. St. Anthony Falls Hydraulic Laboratory, Univ. of Minnesota.

Stolzenbach, K.D. and D.R.F. Harleman. 1973. Three-dimensional heated surface jets. Water Resources Research, Vol. 9, No. 1.

Swedburg, D.V. and C.W. Walburg. 1970. Spawning and early life history of the freshwater drum in Lewis and Clark Lake, Missouri River. Trans. Am. Fish. Soc. 99:560-570.

Texas Instruments, Inc. 1973. Hudson River ecological study in the area of Indian Point, for the period January 1 to June 30, 1973. Sec. Semi-ann. Rep. Prepared for Consolidated Edison Co. of New York, Inc.

Trautman, M.B. 1957. The fishes of Ohio. The Ohio State Univ. Press, Columbus, Ohio. 683 p.

Trautman, M.B. 1981. The fishes of Ohio, 2nd edition. The Ohio State Univ. Press, Columbus, Ohio (in print).

U.S. Army Corps of Engineers. 1976. Biological and water quality monitoring program. Detroit District,

West, B.W. 1966. Growth, food conversion, food consumption and survival at various temperatures of the channel catfish, Ictalurus punctatus (Rafinesque). M.S. Thesis, Univ. Arkansas.

Yellayi, R.R. 1972. Ecological life history and population dynamics of white bass, Morone chrysops (Rafinesque) in Beaver Reservoir. Part 2. Rep. to the Arkansas Game & Fish Comm.

TABLES

TABLE 1

REPRESENTATIVE AQUATIC SPECIES (RAS) LIST FOR THE MAUMEE BAY OF LAKE ERIE

COMMON NAME	SCIENTIFIC NAME
1. Alewife	*Alosa pseudoharengus*
2. Carp	*Cyprinus carpio*
3. Channel catfish	*Ictalurus punctatus*
4. Channel darter[2]	*Percina copelandi*
5. Emerald shiner	*Notropis atherinoides*
6. Freshwater drum	*Aplodinotus grunniens*
7. Gizzard shad	*Dorosoma cepedianum*
8. Goldfish	*Carassius auratus*
9. Green sunfish	*Lepomis cyanellus*
10. Logperch	*Percina caprodes*
11. Mooneye[2]	*Hiodon tergisus*
12. Rainbow smelt	*Osmerus mordax*
13. Silver chub[2]	*Hybopsis storeriana*
14. Silver lamprey[2]	*Ichthyomyzon unicuspis*
15. Spottail shiner	*Notropis hudsonius*
16. Trout-perch	*Percopsis omiscomaycus*
17. Walleye	*Stizostedion* *v.* *vitreum*
18. White bass	*Morone chrysops*
19. White crappie	*Pomoxis annularis*
20. White sucker	*Catostomus commersoni*
21. Yellow perch	*Perca flavescens*

[1] Common names based on Robins et al. (1980)

[2] State Endangered Species (Ohio)

TABLE 2

PHYLOGENETIC LISTING OF REPRESENTATIVE AQUATIC SPECIES FOR MAUMEE BAY OF LAKE ERIE[1]

CLASS AGNATHA
- Order Petromyzontiformes
  - Family Petromyzontidae - lampreys
    1) *Ichthyomyzon unicuspis* - silver lamprey[2]

CLASS OSTEICHTHYES
- Order Clupeiformes
  - Family Clupeidae - herrings
    2) *Alosa pseudoharengus* - alewife
    3) *Dorosoma cepedianum* - gizzard shad

- Order Osteoglossiformes
  - Family Hiodontidae - mooneyes
    4) *Hiodon tergisus* - mooneye[2]

- Order Salmoniformes
  - Family Osmeridae - smelts
    5) *Osmerus mordax* - rainbow smelt

- Order Cypriniformes
  - Family Cyprinidae - minnows and carps
    6) *Carassius auratus* - goldfish
    7) *Cyprinus carpio* - carp
    8) *Hybopsis storeriana* - silver chub[2]
    9) *Notropis atherinoides* - emerald shiner
    10) *Notropis hudsonius* - spottail shiner

  - Family Catostomidae - suckers
    11) *Catostomus commersoni* - white sucker

- Order Siluriformes
  - Family Ictaluridae - freshwater catfishes
    12) *Ictalurus punctatus* - channel catfish

- Order Percopsiformes
  - Family Percopsidae - trout-perches
    13) *Percopsis omiscomaycus* - trout-perch

- Order Perciformes
  - Family Percichthyidae - temperate basses
    14) *Morone chrysops* - white bass

TABLE 2 (continued)

Family Centrarchidae - sunfishes
15) *Lepomis cyanellus* - green sunfish
16) *Pomoxis annularis* - white crappie

Family Percidae - perches
17) *Perca flavescens* - yellow perch
18) *Percina caprodes* - log perch
19) *Percina coplandi* - channel darter[2]
20) *Stizostedion v. vitreum* - walleye

Family Sciaenidae - drums
21) *Aplodinotus grunniens* - freshwater drum

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1. Phylogenetic classification based on Robins et al. (1980)
2. State Endangered Species (Ohio)

TABLE 3
SPAWNING CHARACTERISTICS OF REPRESENTATIVE AQUATIC SPECIES FOR MAUMEE BAY OF LAKE ERIE

Species	Maturity of Female (age class)	Longevity (years)	Spawning		Fecundity		Location	
			Season	Temp. (°C)	Female Size (mm)	Egg Production (no./female)	Maumee River	Maumee Bay
1. Silver lamprey	V-IIIV	5-8	May-June	16°	330	10,000	Yes	No
2. Alewife	III	9+	June-July	22°	180	12,000	No	Yes
3. Gizzard shad	II	9+	June-July	19°	280-450	23,000-350,000	Yes	Yes
4. Mooneye	V	8	April-June	14°	320-380	10,000-20,000	No	Yes
5. Rainbow smelt	II-III	6	May	10°	190-240	25,000-58,000	Yes	Yes
6. Goldfish	III	---	May-Aug.	18°	250-410	------	No	Yes
7. Carp	III-V	16	May-July	17°	390-850	36,000-2,200,000	Yes	Yes
8. Silver chub	II	4	June-July	21°	100-230	------	No	Yes
9. Emerald shiner	II	4	July-Aug.	24°	70-100	------	No	Yes
10. Spottail shiner	II	5	May-July	20°	90-130	2,000-4,000	No	Yes
11. White sucker	III-IX	12	March-April	10°	410-510	56,000-139,000	Yes	No
12. Channel catfish	IV-VI	8	June-Aug.	24°	410-510	4,000-106,000	Yes	No
13. Trout-perch	I-II	4	May-Aug.	10°	80-100	200-700	Yes	Yes
14. White bass	III	7	April-May	14°	250-300	242,000-933,000	Yes	Yes
15. Green sunfish	II-III	7-9	May-Aug.	20°	130	-------	No	Yes
16. White crappie	II-III	8	May-June	18°	200-250	5,000-30,000	No	Yes
17. Yellow perch	III-IV	8	April-May	16°	250	44,000	No	Yes
18. Logperch	I-II	---	June	20°	90-100	1,000-3,000	No	Yes
19. Channel darter	I-II	---	July	21°	40	400	Yes	Yes
20. Walleye	IV	13	March-May	05°	460-580	48,000-614,000	Yes	Yes
21. Freshwater drum	V-VI	12	July-Sept.	21°	330-450	43,000-508,000	Yes	Yes

Data Sources: Hartley and Herdendorf (1977), Scott and Crossman (1973), and Trautman (1957 and 1981)

TABLE 4

SPAWNING AND NURSERY HABITAT PREFERENCE OF REPRESENTATIVE AQUATIC SPECIES FOR MAUMEE BAY OF LAKE ERIE

Species	Tributary	Shallow Protected Sand or Mud Bottom		Shallow Exposed Bottom		Gravel or Rubble with Current	Medium Depth Mud Bottom	Mid-Water	Deep Water	
		Vegetation	No Vegetation	Sand or Gravel Bottom	Rock or Rubble Bottom				Mud Bottom	Sand or Gravel Bottom
1. Silver lamprey	X									
2. Alewife				X						
3. Gizzard shad		X	X	X	X		X			
4. Mooneye	X									
5. Rainbow smelt					X	X		X		X
6. Goldfish		X	X				X			
7. Carp		X	X				X			
8. Silver chub								X		
9. Emerald shiner								X		

TABLE 4 (continued)

Species	Tributary	Shallow Protected Sand or Mud Bottom		Shallow Exposed Bottom		Gravel or Rubble with Current	Medium Depth Mud Bottom	Mid-Water	Deep Water	
		Vegetation	No Vegetation	Sand or Gravel Bottom	Rock or Rubble Bottom				Mud Bottom	Sand or Gravel Bottom
10. Spottail shiner				X						
11. White sucker	X									
12. Channel catfish		X	X	X	X		X			
13. Trout-perch				X	X				X	X
14. White bass					X	X	X			
15. Green sunfish		X	X							
16. White crappie			X	X			X			
17. Yellow perch				X	X	X				

TABLE 4 (continued)

Species	Tributary	Shallow Protected Sand or Mud Bottom		Shallow Exposed Bottom		Gravel or Rubble with Current	Medium Depth Mud Bottom	Mid-Water	Deep Water	
		Vegetation	No Vegetation	Sand or Gravel Bottom	Rock or Rubble Bottom				Mud Bottom	Sand or Gravel Bottom
18. Logperch		X		X						
19. Channel darter				X		X				X
20. Walleye				X	X	X				
21. Fresh-water drum				X	X	X	X	X	X	X

Data Sources: Hartley and Herdendorf (1977), Scott and Crossman (1973), and Trautman (1957 and 1981)

TABLE 5

SWIMMING SPEEDS OF SELECTED REPRESENTATIVE AQUATIC SPECIES FOR MAUMEE BAY OF LAKE ERIE

SPECIES	SIZE (cm)	SWIMMING SPEED				DATA SOURCE
		Sustained Speed		Burst Speed		
		cm/sec	BL/sec[1]	cm/sec	BL/sec	
Alewife	7.1	18.6	2.6	-	-	Kothas (1970)
Alewife	7.9	56.1	7.1	-	-	Kothas (1970)
Alewife	-	-	-	-	13.8	Bell (1973)
Carp	-	-	-	-	12.6	Bainbridge (1958)
Carp	-	-	-	36.6	-	Kreitmann (1933)
Channel catfish	-	-	-	-	4.2	Hocutt (1973)
Channel catfish	3.0	27.5	9.2	-	-	King (1969)
Channel catfish	10.0	38.3	3.8	-	-	King (1969)
Goldfish	-	-	6.4	-	-	Fry and Hart (1948)
Goldfish	21.3	-	-	200.0	9.4	Bainbridge (1958)
Goldfish	-	-	-	-	10.0	Blaxter and Dickson (1959)
Spottail shiner	5.4	10.7	2.0	-	-	Schuler (1968)
Walleye	1.5	4.7	3.1	-	-	Houde (1969)
White crappie	6.0	11.7	2.0	-	-	King (1969)
White crappie	8.1	21.7	2.7	-	-	King (1969)
White sucker	-	-	-	-	8.0	Bell (1973)
Yellow perch	1.3	4.2	3.2	-	-	Houde (1969)

[1] BL = body lengths

TABLE 6

COMPOSITION OF RAS FISH POPULATIONS IN MAUMEE BAY OF LAKE ERIE

	MONTH												WEIGHTED ANNUAL MEAN
SPECIES	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	
Alewife	1.4	0.3	<0.05	<0.05	<0.05	<0.05	0.0	1.0	1.3	2.0	6.5	15.3	7.7
Carp	0.0	<0.05	<0.05	0.1	0.1	0.1	<0.05	0.1	<0.05	<0.05	<0.05	<0.05	<0.05
Channel catfish	<0.05	0.1	0.1	0.5	1.0	0.6	0.7	1.3	0.1	<0.05	<0.05	<0.05	0.1
Channel darter	0.0	0.0	0.0	0.0	0.0	<0.05	0.0	0.0	0.0	0.0	0.0	0.0	<0.05
Emerald shiner	0.3	16.3	41.0	69.3	55.1	12.4	0.4	8.0	8.1	22.6	13.4	27.4	18.4
Freshwater drum	0.5	1.8	2.2	2.1	11.6	4.3	11.2	18.2	6.1	4.6	0.4	0.2	2.1
Gizzard shad	97.6	79.0	49.4	11.1	8.3	12.3	11.6	30.3	68.7	68.3	76.7	55.4	63.7
Goldfish	<0.05	<0.05	0.6	0.3	0.1	<0.05	<0.05	<0.05	<0.05	0.0	<0.05	<0.05	<0.05
Green sunfish	<0.05	<0.05	0.3	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	0.0	<0.05	<0.05	<0.05
Log-perch	<0.05	0.2	0.1	0.1	0.2	0.1	<0.05	0.3	<0.05	<0.05	<0.05	<0.05	<0.05
Mooneye	0.0	0.0	0.0	<0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.05
Rainbow smelt	<0.05	0.1	0.0	<0.05	<0.05	0.3	0.2	0.2	0.1	0.1	1.6	0.4	0.5
Silver chub	0.0	0.0	0.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.0	0.0	0.0	<0.05
Silver lamprey	0.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.0	0.0	0.0	0.0	<0.05	<0.05
Spottail shiner	0.1	0.5	3.3	6.2	7.1	2.0	1.9	2.3	1.4	0.2	1.0	1.2	1.2
Trout-perch	<0.05	0.1	0.3	0.8	5.8	2.0	0.3	0.1	<0.05	<0.05	<0.05	<0.05	0.1
Walleye	0.0	<0.05	0.1	0.3	0.1	0.9	0.6	0.4	0.2	<0.05	<0.05	<0.05	0.1
White bass	<0.05	0.9	0.7	0.2	0.3	15.8	54.7	23.3	8.2	1.2	0.2	0.05	3.5
White crappie	<0.05	0.1	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
White sucker	0.0	<0.05	<0.05	<0.05	0.1	<0.05	<0.05	<0.05	<0.05	0.0	0.0	0.0	<0.05
Yellow perch	<0.05	0.5	1.5	8.5	9.7	49.0	18.3	14.4	5.7	0.8	0.2	0.1	2.5
Others	<0.05	<0.05	<0.05	0.3	0.4	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Monthly Percentage of Annual Population	16.8	1.3	2.1	2.3	1.1	1.3	3.8	3.1	4.2	6.0	19.0	39.0	

Data Source: Estimated from fish impingement samples at the Bay Shore Power Station on Maumee Bay of Lake Erie from September 1976 to September 1977 (Reutter, Herdendorf and Sturm, 1978).

TABLE 7

PREFERENCE AND CRITICAL THERMAL MAXIMUM (CTM) TEMPERATURES OF REPRESENTATIVE AQUATIC SPECIES (RAS) FOR MAUMEE BAY OF LAKE ERIE

Species	PREFERENCE TEMPERATURE °F (°C)				CTM TEMPERATURE °F (°C)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Alewife								
Adult		70.3 (21.3)				88.5 (31.4)		
Carp								
Adult		81.3 (27.4)	85.5 (29.7)				102.2 (39.0)	
Channel Catfish								
Adult	51.1 (10.6)		77.9 (25.5)	77.5 (25.3)			100.8 (38.2)	
Channel Darter								
NO DATA AVAILABLE								
Emerald Shiner								
Adult	46.9 (8.3)	60.8 (16.0)	71.6-75.2 (22-24)	59.0-62.6 (15-17)			98.6 (37.0)	
YOY[1]	50.0-53.6 (10-12)	55.4-59.0 (13-15)	71.6-73.4 (22-23)	55.4-57.2 (13-14)				
Freshwater Drum								
Adult		71.2 (21.8)	79.7 (26.5)	79.2 (26.2)			98.1 (36.7)	
YOY			88.3 (31.3)					
Gizzard Shad								
Adult			79.7 (26.5)	71.4 (21.9)			95.0 (35.0)	
YOY				78.3 (25.7)				

(continued)

TABLE 7 (continued)

Species	PREFERENCE TEMPERATURE ^{o}F (^{o}C)				CTM TEMPERATURE ^{o}F (^{o}C)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Goldfish								
Adult	75.6 (24.2)	77.0 (25.0)	80.6 (27.0)	79.5 (26.4)			103.1 (39.5)	
Green Sunfish								
Adult							102.0 (38.9)	
Logperch								
Adult							94.8 (34.9)	
Mooneye								
NO DATA AVAILABLE								
Rainbow Smelt								
Adult	39.7 (4.3)					76.8 (24.9)		
Silver Chub								
NO DATA AVAILABLE								
Silver Lamprey								
Adult					88.9 (31.6)			
Spottail Shiner								
Adult	48.2 (9.0)	57.7 (14.3)		57.0 (13.9)			95.7 (35.4)	
Trout-perch								
Adult					73.2 (22.9)			
Walleye								
Adult			83.7 (28.7)				93.9-95.5 (34.4-35.3)	
YOY	83.7 (27.1)							

(continued)

TABLE 7 (continued)

Species	PREFERENCE TEMPERATURE ^{o}F (^{o}C)				CTM Temperature ^{o}F (^{o}C)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
White Bass								
Adult	53.6 (12)	62.6 (17)	88.9 (31.6)	60.8-62.6 (16-17)			98.4 (36.9)	
YOY	50.0-55.4 (10-13)	60.8-64.4 (16-18)	87.8 (31.0)	82.4 (28.0)				
White Crappie								
Adult	67.6 (19.8)	64.9 (18.3)	70.3 (21.3)	50.7 (10.4)			97.2 (36.2)	
White Sucker								
Adult				72.3 (22.4)			96.8 (36.0)	
YOY	47.8 (8.8)							
Yellow Perch								
Adult	57.4 (14.1)	70.2 (70.2)	70.5 (21.4)	69.4 (20.8)			96.3 (35.7)	
YOY	50.0-55.4 (10-13)	64.4 (18.0)	77.0-80.6 (25-27)	82.4 (28.0)				

[1] YOY = young-of-the-year.

Data Sources: Reutter and Herdendorf (1975 and 1976), Reutter (1978) and other references listed in Appendix D.

TABLE 8

SPECIES WITH MAXIMUM AND MINIMUM PREFERENCE AND CTM TEMPERATURES FROM RAS LIST

	Adult	Species	Young-of-the-Year	Species
		Preference Temperature (°F)		
Winter				
Max	75.6	goldfish	83.7	walleye
Min	39.7	rainbow smelt	50.0	emerald shiner white bass yellow perch
Spring				
Max	81.3	carp	64.4	yellow perch
Min	57.7	spottail shiner	55.4	emerald shiner
Summer				
Max	88.9	white bass	88.3	freshwater drum
Min	70.3	white crappie	71.6	emerald shiner
Fall				
Max	79.5	goldfish	82.4	white bass yellow perch
Min	50.7	white crappie	55.4	emerald shiner
		Critical Thermal Maximum Temperature (°F)		
Winter				
Max	88.9	silver lamprey		
Min	73.2	troutperch		
Spring				
Max	88.5	alewife		
Min	76.8	rainbow smelt		
Summer				
Max	103.1	goldfish		
Min	93.9	walleye		
Fall--NO DATA AVAILABLE				

TABLE 9

SOHIO OUTFALL THERMAL DESIGN PARAMETERS

Month	Run No.	10 yr Avg Flow (a)	Site Flow (1.046a + 124)	Water Level[1] (b)	Cross Sect Area 700(28 + b)	Velocity (fps)	Outfall Flow 24 hr 10 yr	Proposed Design Outfall Area	Proposed Outfall Velocity	Proposed Outfall Temp (°F)	River Temp (°F)	Densimetric Fr
MONTHLY FLOWS												
Jan	1	4351 (cfs)	4675 (cfs)	1.2 (ft)	20440 (ft^2)	0.22	58 Mgd;90cfs	5x2 = 10 (ft^2)	9 (ft/sec)	82.4[2]	34.7[3]	18
Feb	2	7120	7571	1.2	20440	0.37	90[6]cfs	10	9	83.66	37.4	17.5
March	3	9546	10110	1.4	20580	0.49	90	10	9	87.1	41.5	16.4
April	4	9774	10347	2.0	21000	0.49	90	10	9	91.0	50.0	15.8
May	5	6048	6450	2.2	21140	0.3	90	10	9	99.0	62.0	14.9
June	6	2630	2875	2.4	21280	0.13	90	10	9	103.8	69.8	14.8
July	7	1857	2066	2.4	21280	0.09	90	10	9	106.9	75.4	14.9
August	8	713	870	2.2	21140	0.04	90	10	9	108.1	73.9	14.3
Sept	9	1250	1431	2.0	21000	0.07	90	10	9	98.2	68.0	16.1
Oct	10	1254	1436	1.5	20650	0.07	90	10	9	89.2	55.8	17.1
Nov	11	3918	4222	1.3	20510	0.2	90	10	9	89.1	47.7	16.2
Dec	12	7858	8343	1.2	20440	0.4	90	10	9	81.7	37.2	18.2
EXTREME CONDITION												
7 day 10 yr #1	13	95[8]	223	2.0	21140	0.01	43[7]	10	4.3	106.7[4]	68.0[4]	6.6
7 day 10 yr #2	14	4696[9]	5033	2.0	21140	0.23	43	10	4.3	101.1[5]	37.2[5]	6.2
7 day 10 yr #3	15	4696[9]	5033	2.0	21140	0.23	90	10	9	106.7[4]	68.0[4]	13.8

[1] Monthly average height above International Great Lakes Datum

[2] Monthly average

[3] Monthly average

[4] Yearly average ΔT = 38.7° F

[5] 10 year ΔT maximum

[6] 10 yr maximum outfall flow

[7] Median outfall flow

[8] 10 yr 7 day low river flow

[9] Yearly average river flow

TABLE 10

COMPARISON OF MAUMEE BAY TEMPERATURES AND RAS PREFERENCE AND CTM TEMPERATURES

Season	Maumee Bay 10-year Mean Temp. (°F)		Predicted Max. Temp. at ℄ Nav. Channel (°F)[1]		Approx. ΔT (°F)		Range of RAS Preference Temp. (°F)	Range of RAS CTM Temp. (°F)	Species with CTM < ℄ Nav. Channel Temp.[1]
Winter									
Jan.	34.7	38.0	37	42	2	4	39.7-75.6	73.2-88.9	N.A.
Feb.	37.4		41		5				
Mar.	41.5		47		1				
Spring									
Apr.	50.0	60.6	53	64	3	4	57.7-88.9	76.8-88.5	Rainbow Smelt
May	62.1		64		2				
June	69.8		72		4				
Summer									
July	75.4	72.5	77	74	2	2	70.3-88.9	93.9-103.1	N.A.
Aug.	73.9		76		2				
Sept.	68.0		70		2				
Fall									
Oct.	55.8	47.0	58	50	2	3	50.7-79.5	N.A.	N.A.
Nov.	47.7		50		2				
Dec.	37.2		40		3				

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[1] Based on proposed discharge characteristics described in this report for the centerline of the navigation channel with a 10°F CTM safety factor.

FIGURES

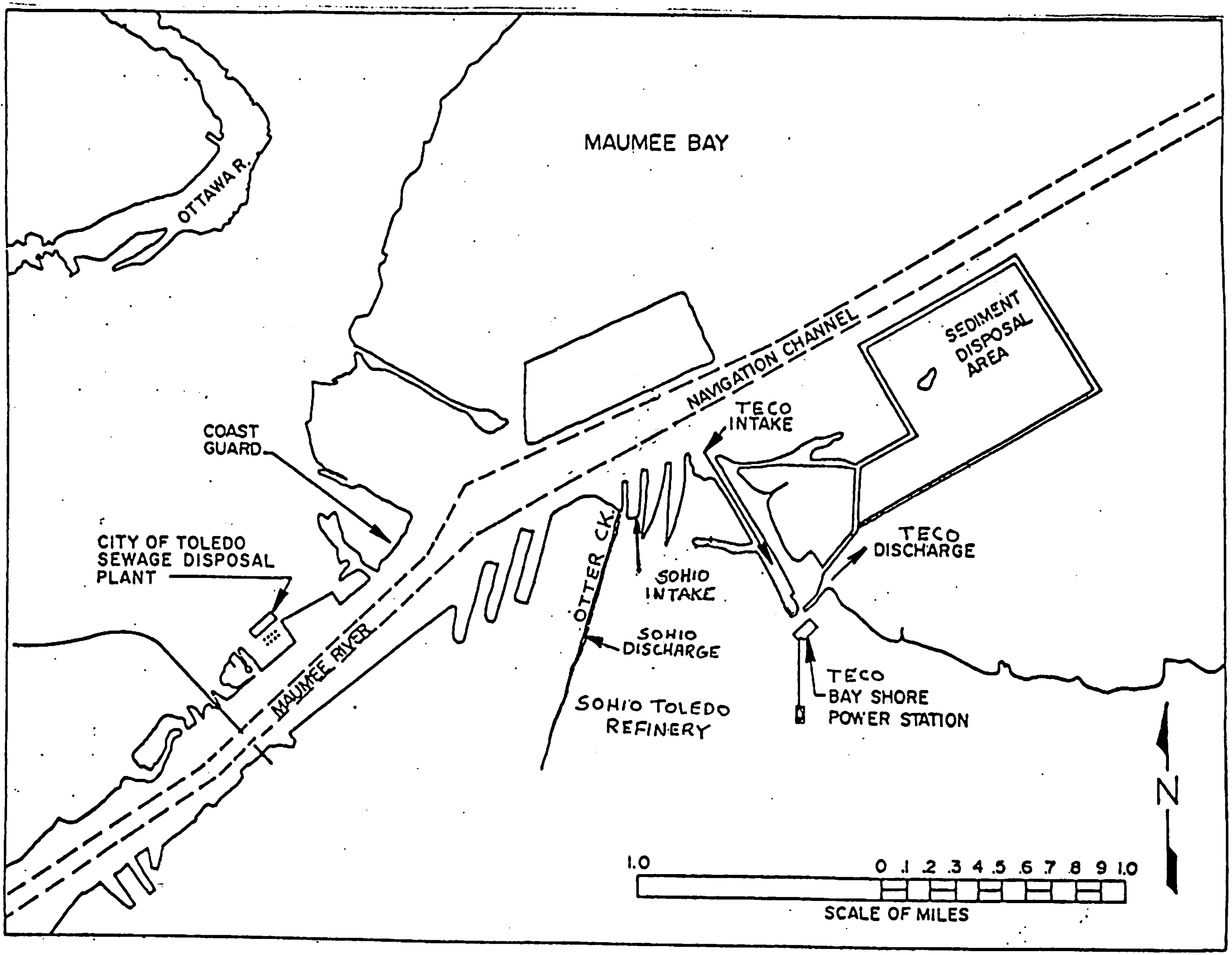


Figure 1. General Area of the SOHIO Toledo Oil Refinery

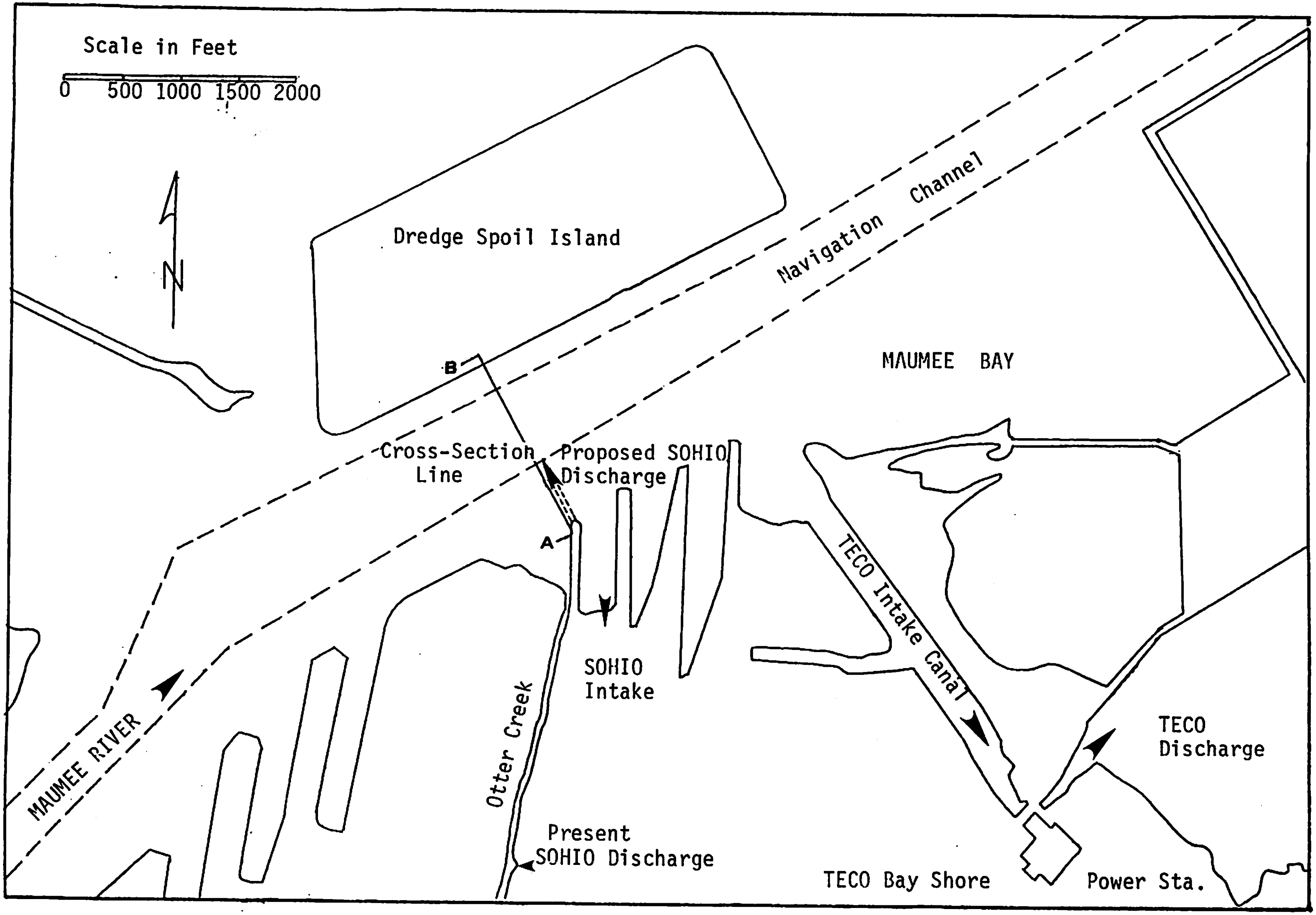


Figure 2. Location Map of Proposed SOHIO Water Discharge

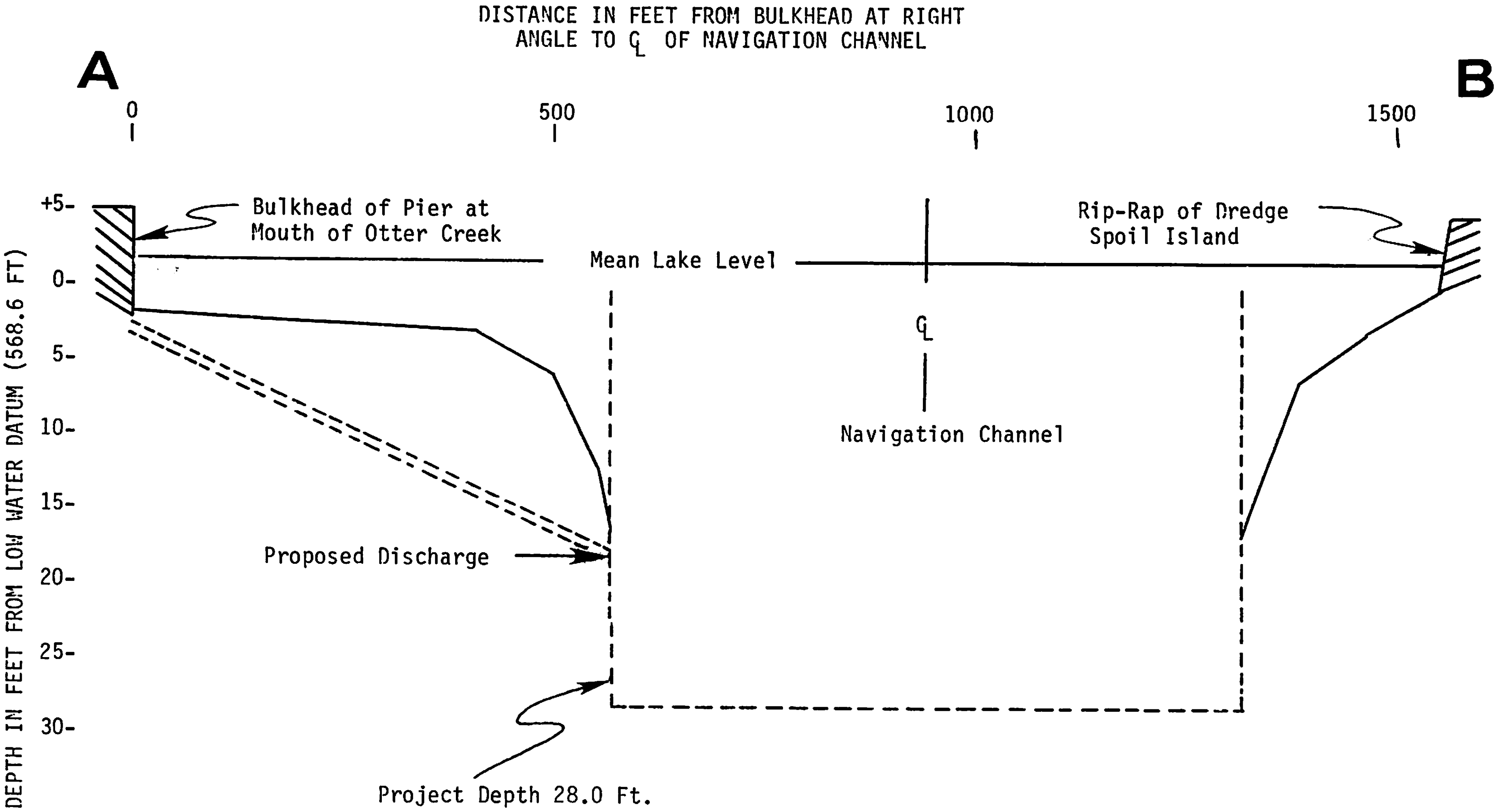


Figure 3. Cross-Section A-B of Maumee Bay in the Vicinity of Proposed SOHIO Water Discharge

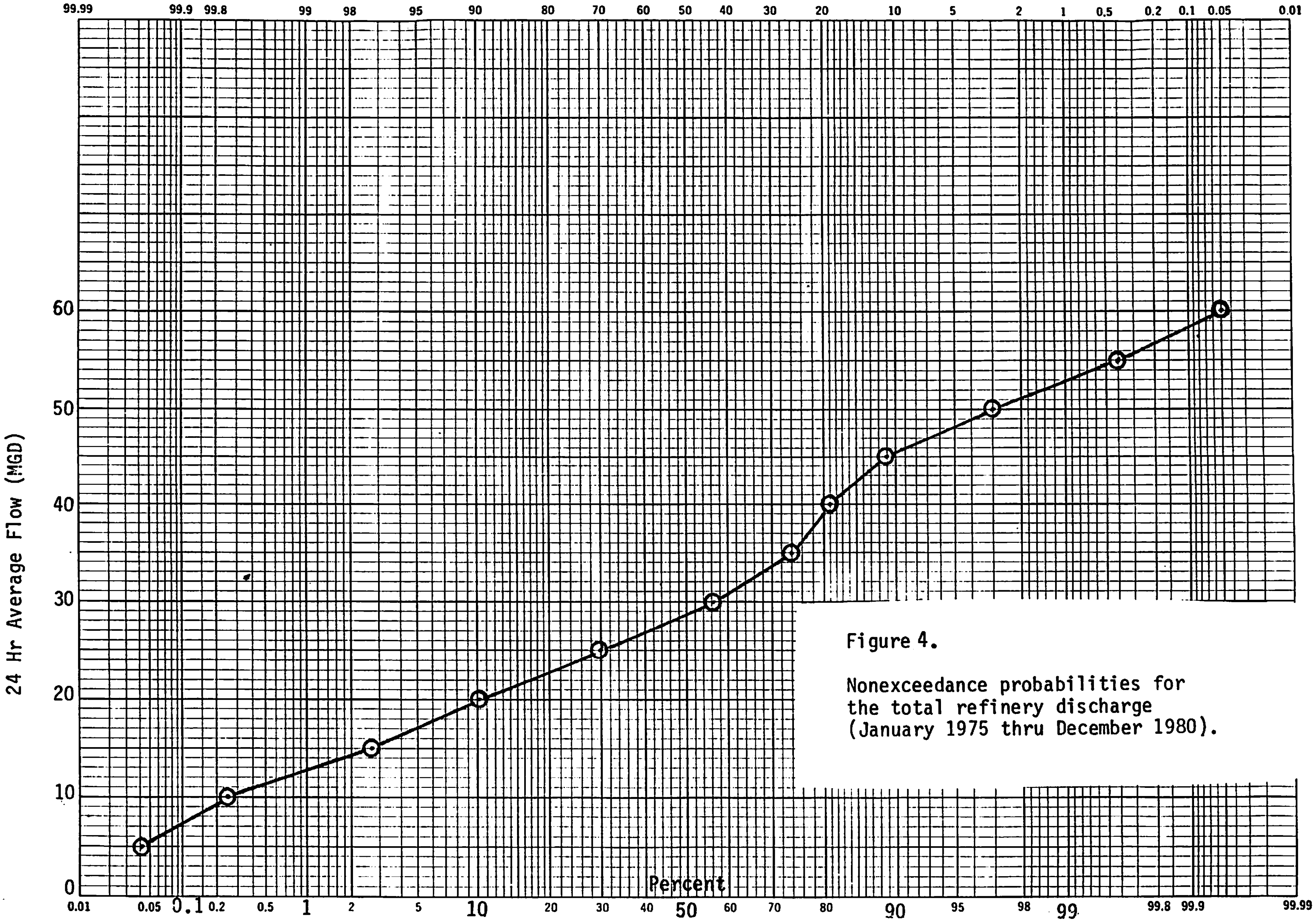


Figure 4.

Nonexceedance probabilities for the total refinery discharge (January 1975 thru December 1980).

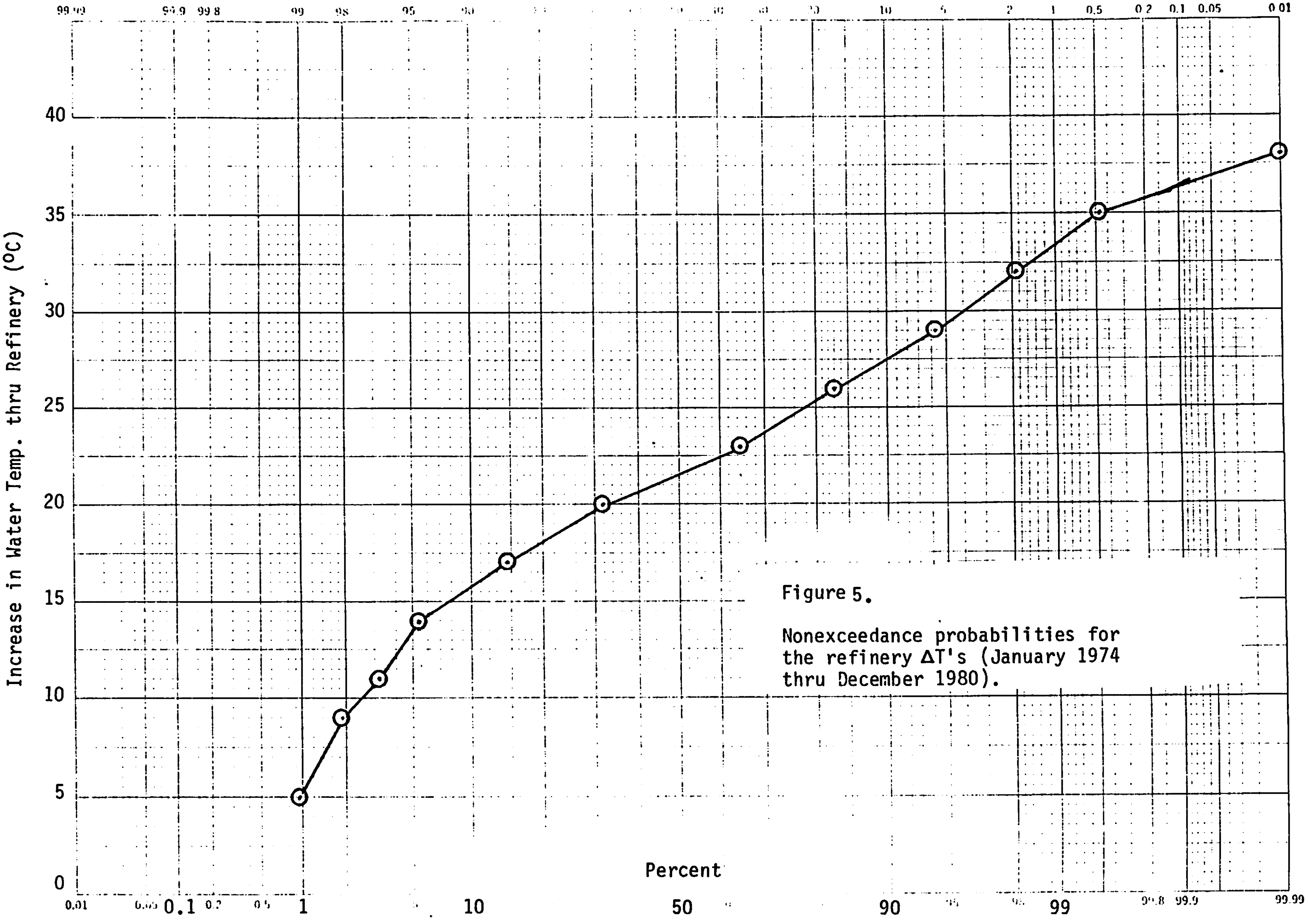


Figure 5.

Nonexceedance probabilities for the refinery ΔT's (January 1974 thru December 1980).

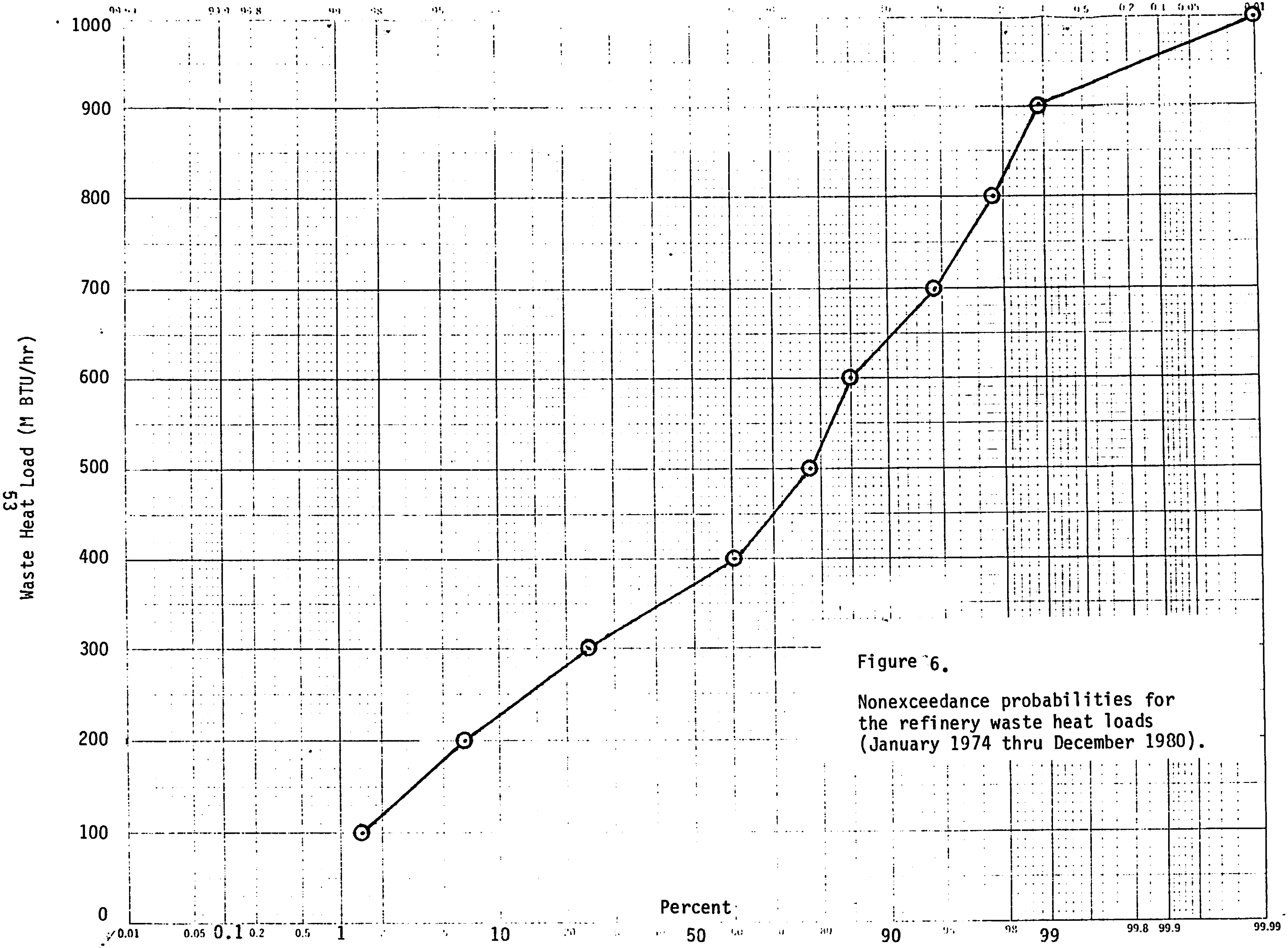
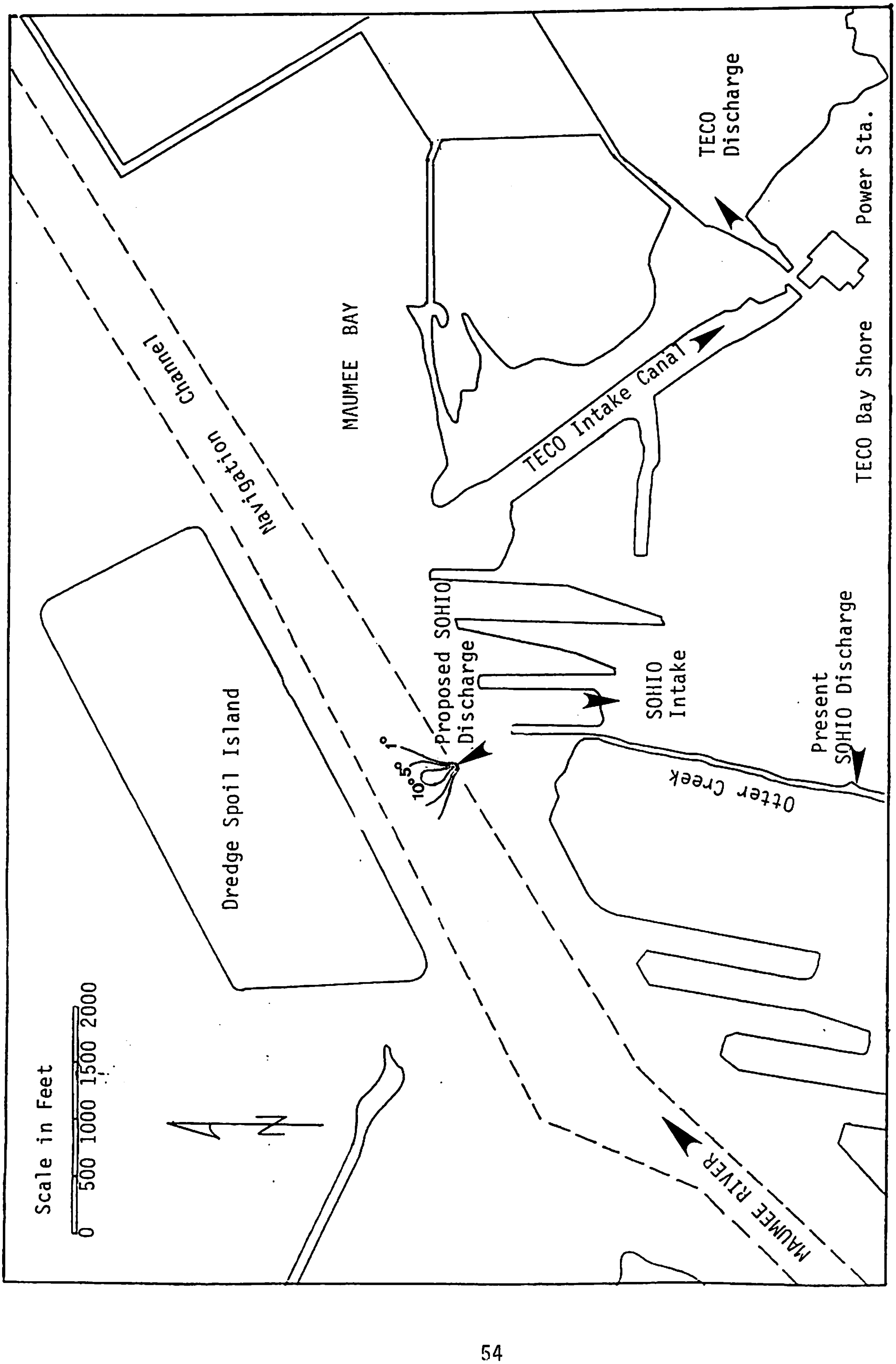


Figure 6.

Nonexceedance probabilities for the refinery waste heat loads (January 1974 thru December 1980).


MAUMEE BAY
Navigation Channel
TECO Discharge
Power Sta.
TECO Intake Canal
TECO Bay Shore
Dredge Spoil Island
Proposed SOHIO Discharge
10°
5°
1°
SOHIO Intake
Present SOHIO Discharge
Otter Creek
MAUMEE RIVER
Scale in Feet
0
500
1000
1500
2000

APPENDIX A

REFINERY DISCHARGE CHARACTERISTICS

MONTHLY AVERAGE TOTAL REFINERY DISCHARGE (MGD)

Month	1974	1975	1976	1977	1978	1979	1980
January	25.6	23.4	20.0	--	38.2	23.6	21.9
February	26.4	18.7	28.5	43.2	37.9	20.9	23.0
March	27.7	23.6	33.4	45.4	28.9	26.2	24.3
April	28.0	27.6	33.8	47.5	--	30.1	25.5
May	29.4	32.2	33.3	48.2	28.4	34.0	27.6
June	31.5	36.9	21.6	49.5	28.4	33.6	28.2
July	32.8	29.7	19.9	52.6	27.9	34.7	27.9
August	33.1	27.6	--	50.3	26.9	32.4	30.2
September	28.0	25.9	39.8	48.7	26.8	30.4	22.2
October	24.1	26.9	42.9	46.2	24.2	25.1	18.0
November	20.0	26.0	45.6	42.6	23.5	21.3	17.4
December	22.8	24.1	43.4	43.1	24.2	22.2	13.5

Note: These data are synoptic with the data in other tables of Appendix A.

MONTHLY AVERAGE REFINERY DISCHARGE TEMPERATURES (^{o}C)

Month	1974	1975	1976	1977	1978	1979	1980
January	21.4	23.3	23.1	--	29.2	24.9	32.0
February	22.2	27.4	24.8	36.5	30.6	28.2	31.4
March	27.2	29.9	29.1	33.6	31.1	32.1	31.4
April	30.5	31.2	34.9	34.9	--	31.0	34.5
May	33.3	36.7	38.3	40.3	35.0	38.6	38.3
June	34.3	38.4	39.1	40.6	43.5	42.0	41.5
July	38.5	42.1	39.9	39.4	43.8	43.3	43.9
August	41.6	41.8	41.2	42.1	44.2	41.1	44.4
September	33.0	35.3	33.6	41.6	43.3	40.7	30.0
October	28.6	32.8	25.2	32.8	36.6	35.1	31.4
November	29.7	32.9	26.0	33.5	31.3	35.7	32.8
December	20.3	26.8	25.6	28.1	26.1	33.9	32.7

Note: These data are synoptic with the data in other tables of Appendix A.

MONTHLY AVERAGE INTAKE TEMPERATURES (^oC)

Month	1974	1975	1976	1977	1978	1979	1980
January	2.0	3.5	1.8	--	1.9	0.1	2.9
February	1.5	5.7	1.8	3.6	1.8	0.7	5.9
March	5.8	5.0	5.9	5.8	3.3	3.4	7.7
April	9.9	7.8	11.7	12.9	--	10.0	7.5
May	19.4	17.8	15.1	17.7	14.1	17.0	15.6
June	20.4	21.8	21.5	21.3	22.2	19.8	20.3
July	23.8	24.6	23.8	25.4	23.9	23.3	24.1
August	24.0	25.0	22.4	23.4	22.6	21.8	23.8
September	19.0	18.9	17.9	21.1	21.3	19.3	22.2
October	12.8	--	--	13.2	13.2	14.6	12.4
November	8.7	9.7	--	9.6	7.9	8.1	8.0
December	2.6	3.5	--	2.3	2.4	2.8	3.8

Note: These data are synoptic with the data in other tables of Appendix A.

MONTHLY AVERAGE WASTE HEAT LOAD
(million BTU/hr)

Month	1974	1975	1976	1977	1978	1979	1980
January	306.	291.	268.	--	648.	364.	398.
February	341.	256.	414.	890.	671.	408.	367.
March	371.	363.	485.	785.	509.	468.	360.
April	365.	404.	479.	655.	--	393.	424.
May	322.	377.	467.	693.	368.	456.	391.
June	270.	387.	238.	603.	379.	466.	374.
July	301.	325.	200.	461.	348.	432.	348.
August	361.	291.	--	587.	323.	391.	388.
September	259.	281.	419.	624.	372.	407.	117.
October	240.	--	--	565.	353.	322.	208.
November	252.	379.	--	626.	342.	367.	269.
December	255.	354.	--	702.	355.	432.	240.

Note: These data are synoptic with the data in other tables of Appendix A.

APPENDIX B

THERMAL PLUME PATTERNS

APPENDIX B

SOHIO OUTFALL THERMAL DESIGN PARAMETERS

Month	Run No.	10 yr Avg Flow (a)	Site Flow (1.046a + 124)	Water Level[1] (b)	Cross Sect Area 700(28 + b)	Velocity (fps)	Outfall Flow 24 hr 10 yr	Proposed Design Outfall Area	Proposed Outfall Velocity	Proposed Outfall Temp (°F)	River Temp (°F)	Densimetric Fr
MONTHLY FLOWS												
Jan	1	4351 (cfs)	4675 (cfs)	1.2 (ft)	20440 (ft^2)	0.22	58 Mgd;90cfs	5x2 = 10 (ft^2)	9 (ft/sec)	82.4[2]	34.7[3]	18
Feb	2	7120	7571	1.2	20440	0.37	90[6]cfs	10	9	83.66	37.4	17.5
March	3	9546	10110	1.4	20580	0.49	90	10	9	87.1	41.5	16.4
April	4	9774	10347	2.0	21000	0.49	90	10	9	91.0	50.0	15.8
May	5	6048	6450	2.2	21140	0.3	90	10	9	99.0	62.0	14.9
June	6	2630	2875	2.4	21280	0.13	90	10	9	103.8	69.8	14.8
July	7	1857	2066	2.4	21280	0.09	90	10	9	106.9	75.4	14.9
August	8	713	870	2.2	21140	0.04	90	10	9	108.1	73.9	14.3
Sept	9	1250	1431	2.0	21000	0.07	90	10	9	98.2	68.0	16.1
Oct	10	1254	1436	1.5	20650	0.07	90	10	9	89.2	55.8	17.1
Nov	11	3918	4222	1.3	20510	0.2	90	10	9	89.1	47.7	16.2
Dec	12	7858	8343	1.2	20440	0.4	90	10	9	81.7	37.2	18.2
EXTREME CONDITION												
7 day 10 yr #1	13	95[8]	223	2.0	21140	0.01	43[7]	10	4.3	106.7[4]	68.0[4]	6.6
7 day 10 yr #2	14	4696[9]	5033	2.0	21140	0.23	43	10	4.3	101.1[5]	37.2[5]	6.2
7 day 10 yr #3	15	4696[9]	5033	2.0	21140	0.23	90	10	9	106.7[4]	68.0[4]	13.8

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[1] Monthly average height above International Great Lakes Datum

[2] Monthly average

[3] Monthly average

[4] Yearly average ΔT = 38.7° F

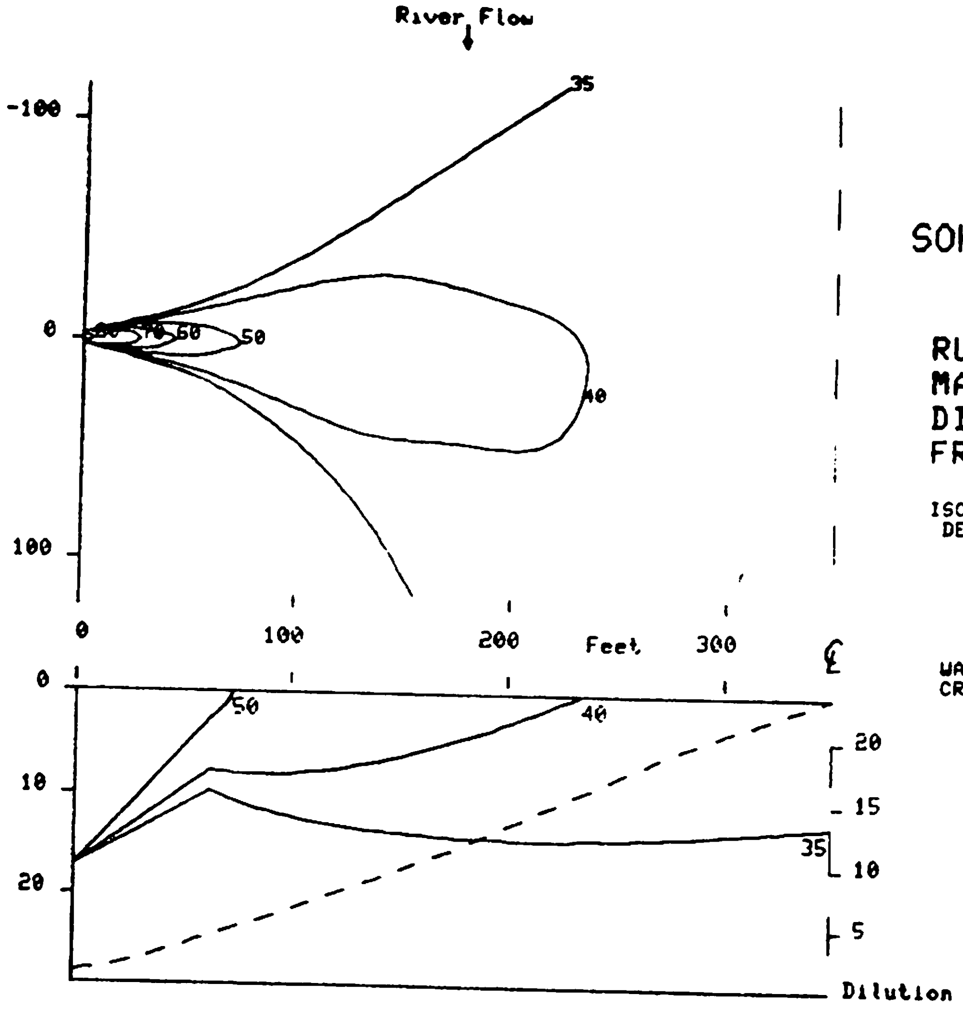
[5] 10 year ΔT maximum

[6] 10 yr maximum outfall flow

[7] Median outfall flow

[8] 10 yr 7 day low river flow

[9] Yearly average river flow



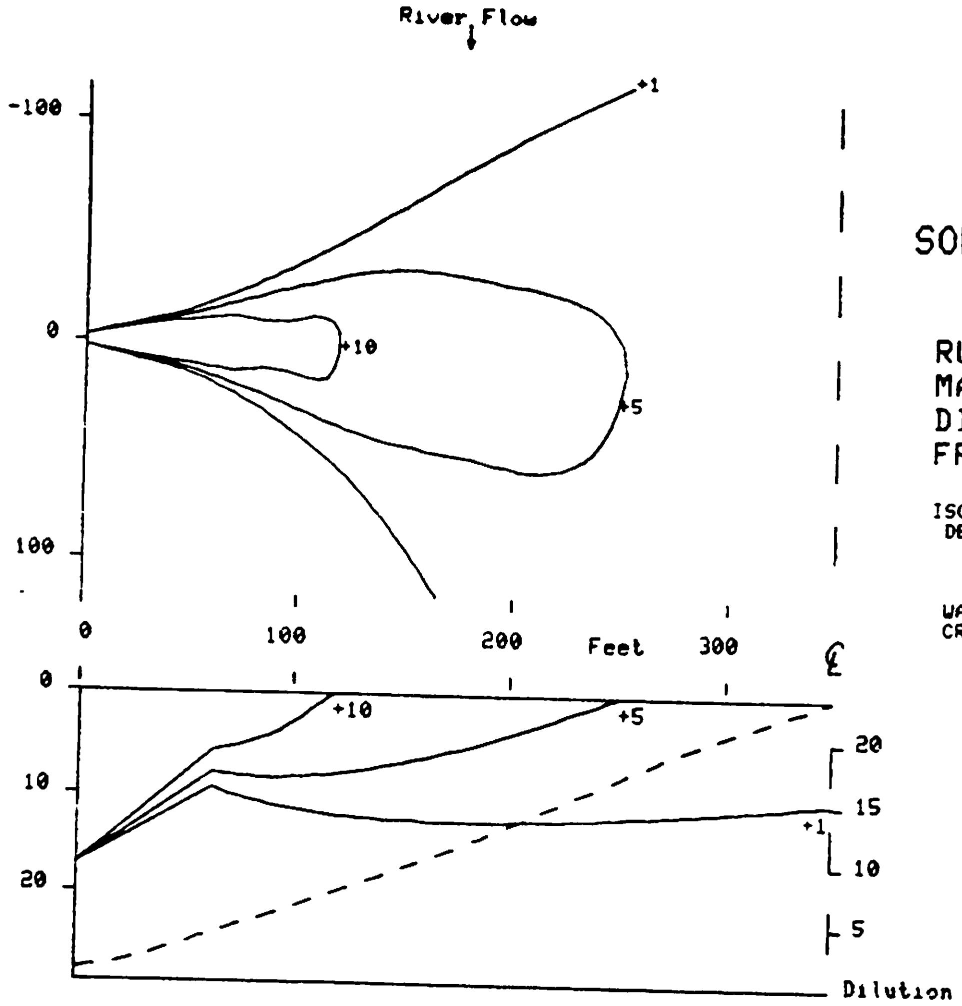
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 1
MAUMEE TEMP. 34.7 DEG. F
DISCHARGE TEMP. 82.4 DEG. F
FROUDE NUMBER 18.0

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
40.	1771.	15989.
50.	554.	916.
60.	516.	312.
70.	516.	165.
80.	516.	15.

WATER LEVEL = IGLD+1.2
CROSS-SECTIONAL AREA = 20440. SQ. FT.

Plume Pattern 1A



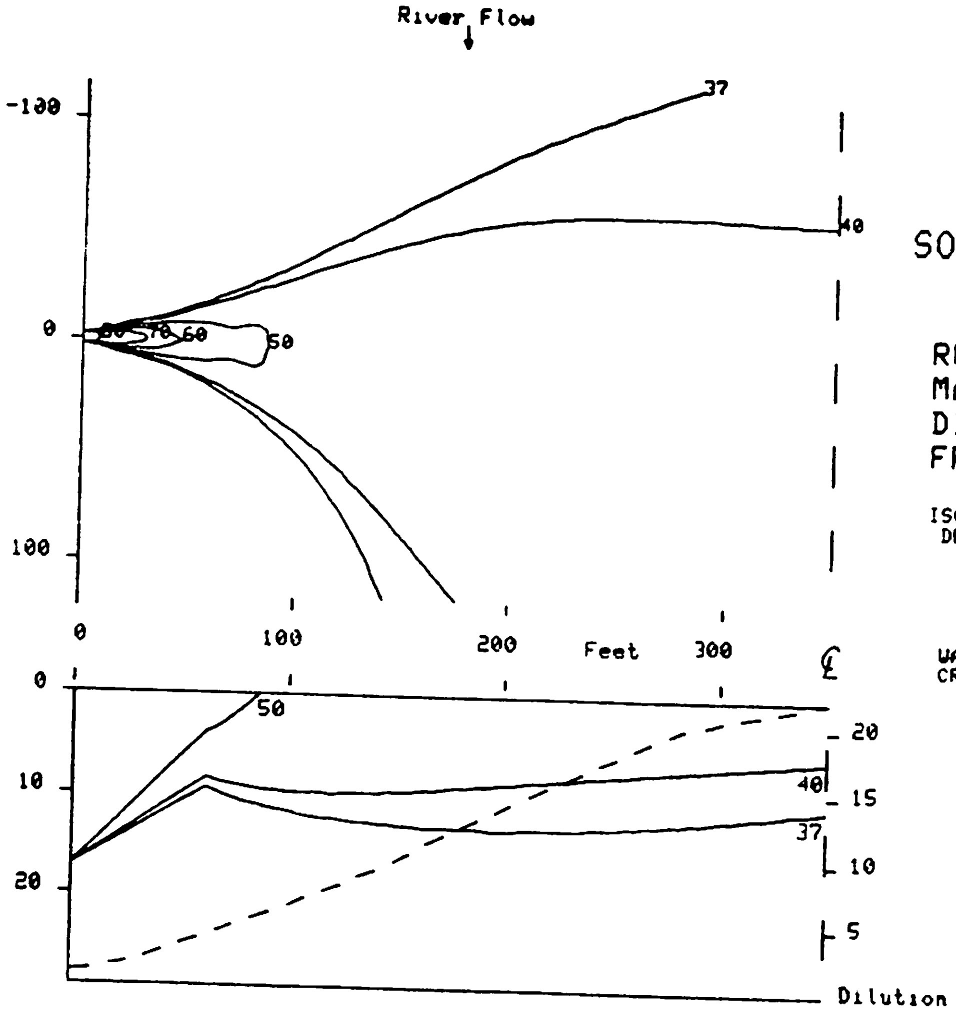
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 1
MAUMEE TEMP. 34.7 DEG. F
DISCHARGE TEMP. 82.4 DEG. F
FROUDE NUMBER 18.0

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
40.	1943.	18713.
45.	867.	3011.

WATER LEVEL = IGLD+1.2
CROSS-SECTIONAL AREA = 20440. SQ. FT.

Plume Pattern 1B



SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 2
MAUMEE TEMP. 37.4 DEG. F
DISCHARGE TEMP. 83.7 DEG. F
FROUDE NUMBER 17.5

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
50.	654.	1490.
60.	516.	348.
70.	516.	161.
80.	516.	56.

WATER LEVEL = IGLD+1.2
CROSS-SECTIONAL AREA = 20440. SQ. FT.

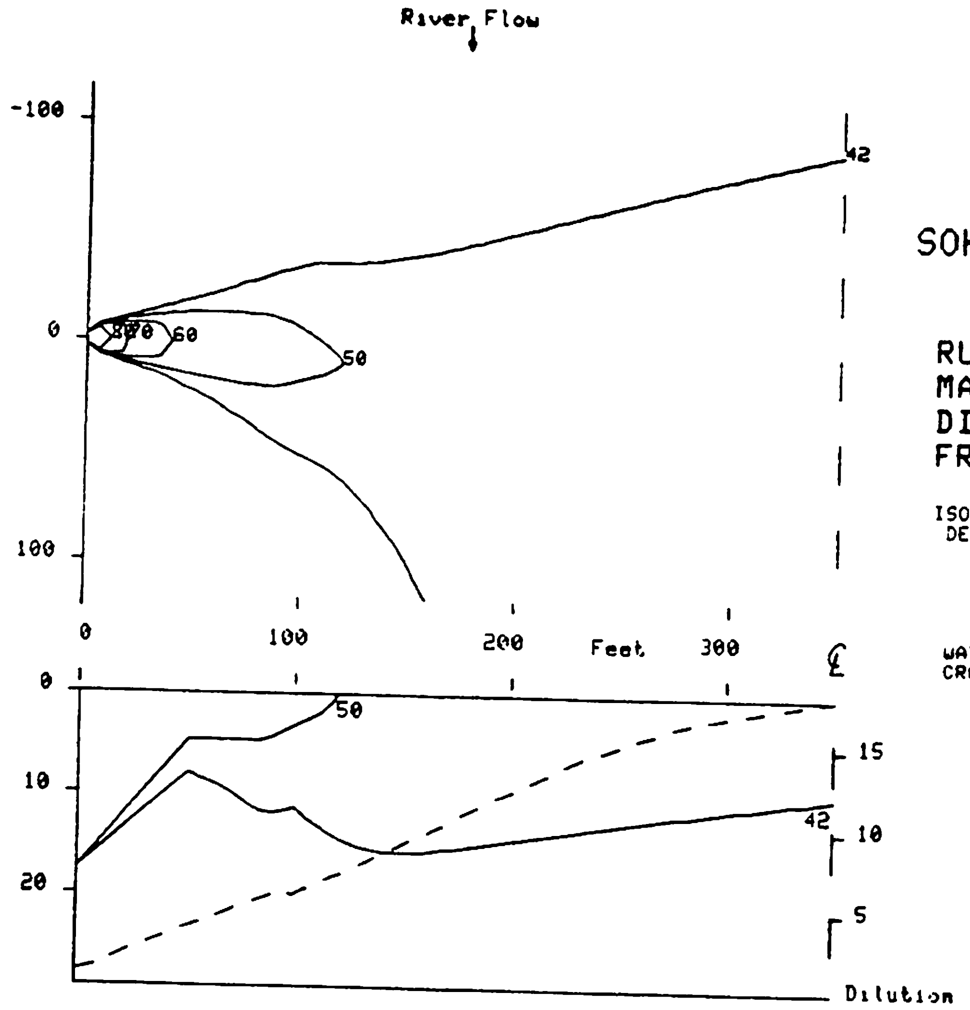
Plume Pattern 2

SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

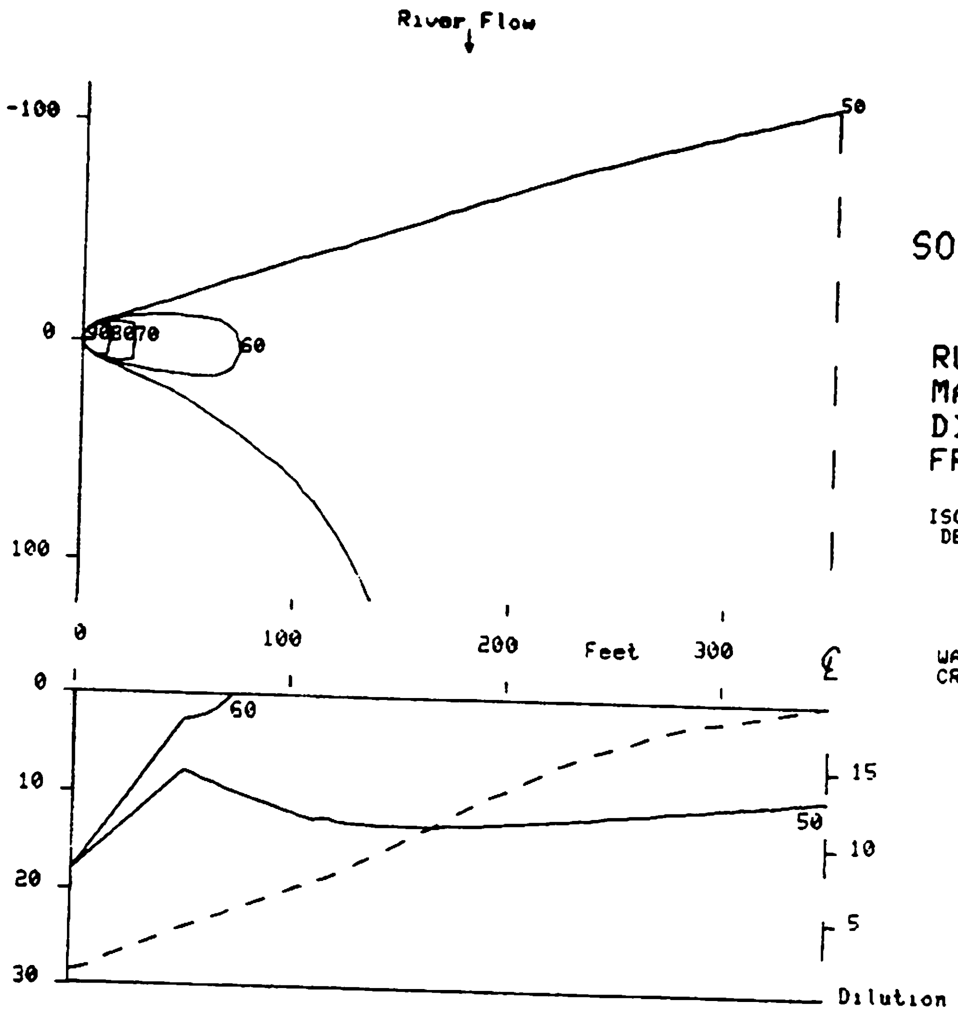
RUN # 3
MAUMEE TEMP. 41.5 DEG. F
DISCHARGE TEMP. 87.1 DEG. F
FROUDE NUMBER 16.4

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL APEA (SQ. FT.)
50.	750.	2817.
60.	522.	711.
70.	522.	293.
80.	522.	141.

WATER LEVEL • IGLD+1.4
CROSS-SECTIONAL AREA • 20580. SQ. FT.



Plume Pattern 3



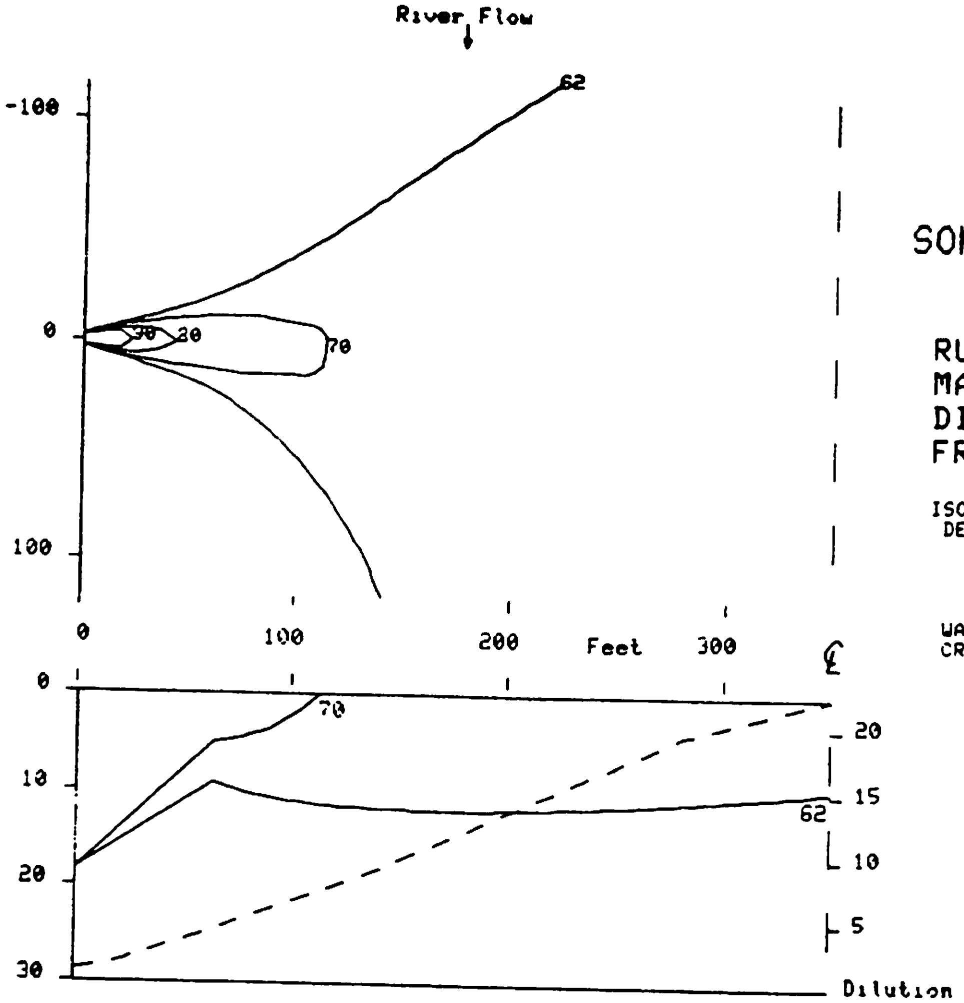
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 4
MAUMEE TEMP. 50.0 DEG. F
DISCHARGE TEMP. 91.0 DEG. F
FROUDE NUMBER 15.8

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
60.	566.	1864.
70.	540.	522.
80.	540.	217.
90.	540.	15.

WATER LEVEL - IGLD+2.0
CROSS-SECTIONAL AREA - 21000. SQ. FT.

Plume Pattern 4



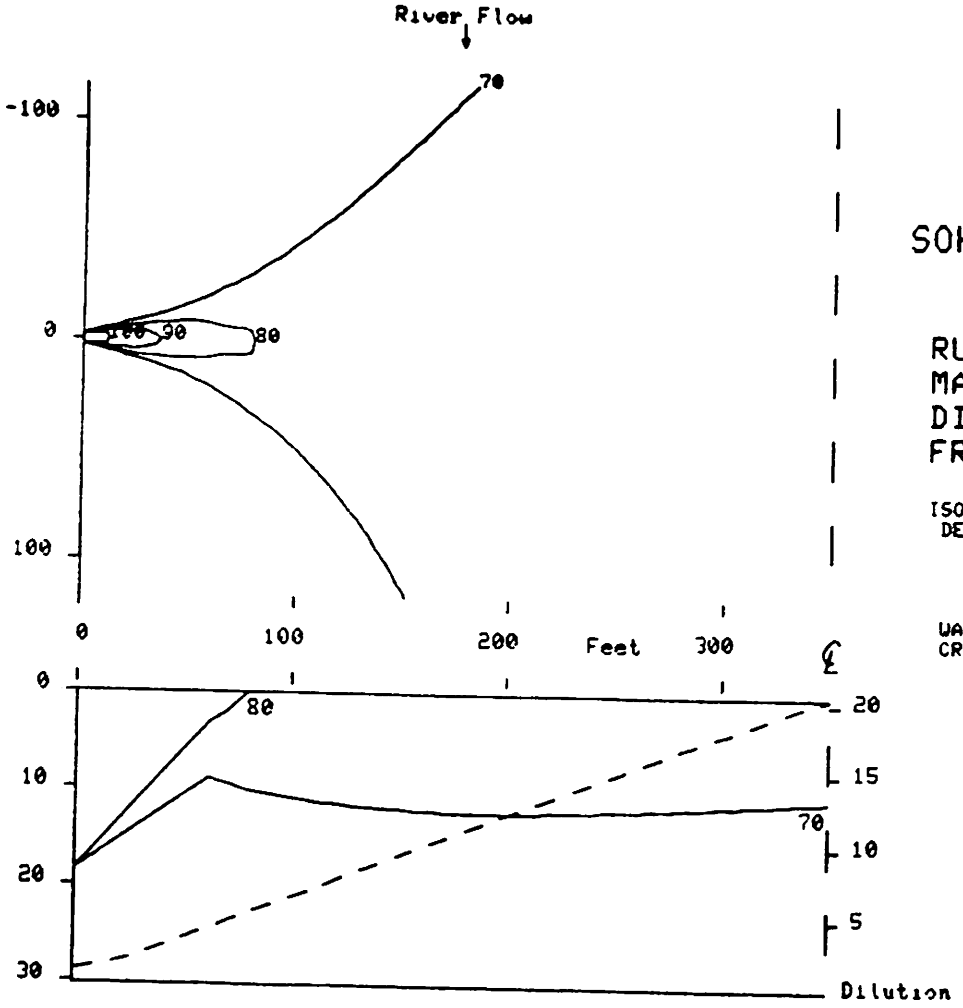
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 5
MAUMEE TEMP. 62.1 DEG. F
DISCHARGE TEMP. 99.0 DEG. F
FROUDE NUMBER 14.9

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
70.	791.	2668.
80.	546.	462.
90.	546.	173.

WATER LEVEL = IGLD+2.2
CROSS-SECTIONAL AREA = 21140. SQ. FT.

Plume Pattern 5



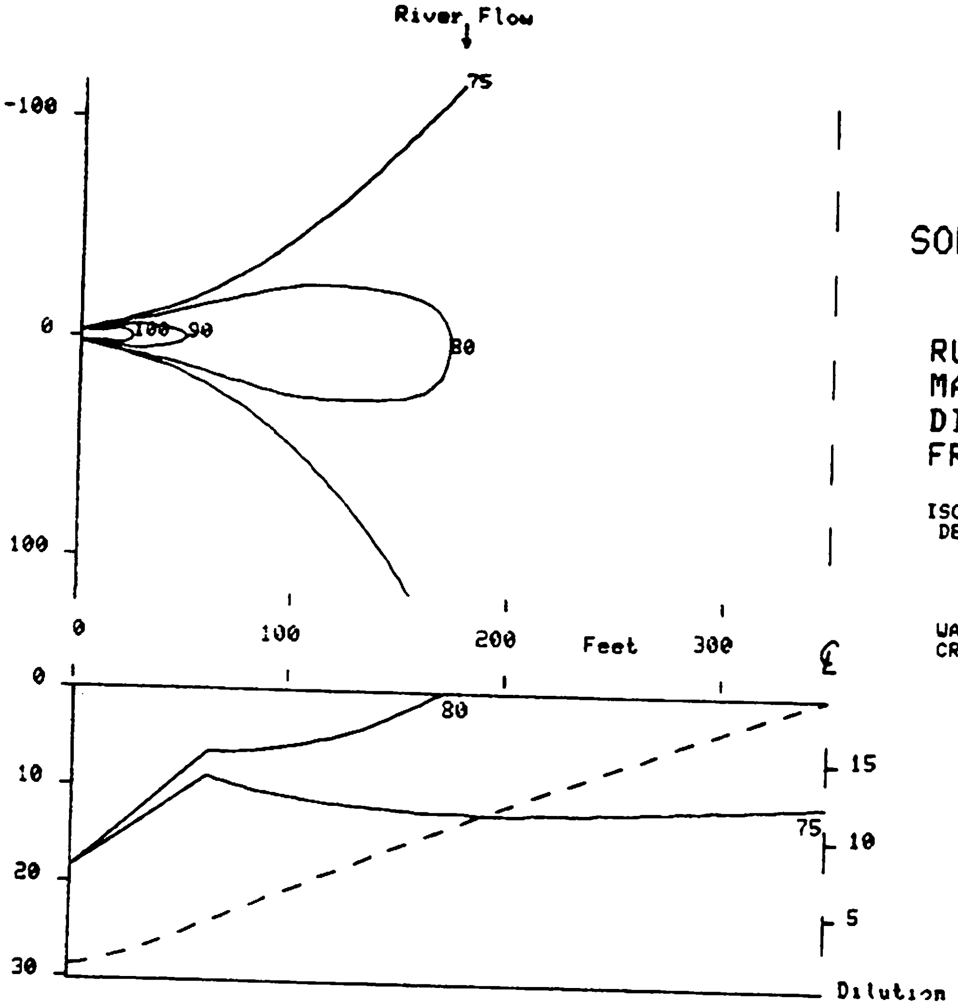
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 6
MAUMEE TEMP. 69.8 DEG. F
DISCHARGE TEMP. 103.8 DEG. F
FROUDE NUMBER 14.8

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
80.	635.	1307.
90.	552.	260.
100.	552.	97.

WATER LEVEL • IGLD+2.4
CROSS-SECTIONAL AREA • 21280. SQ. FT.

Plume Pattern 6



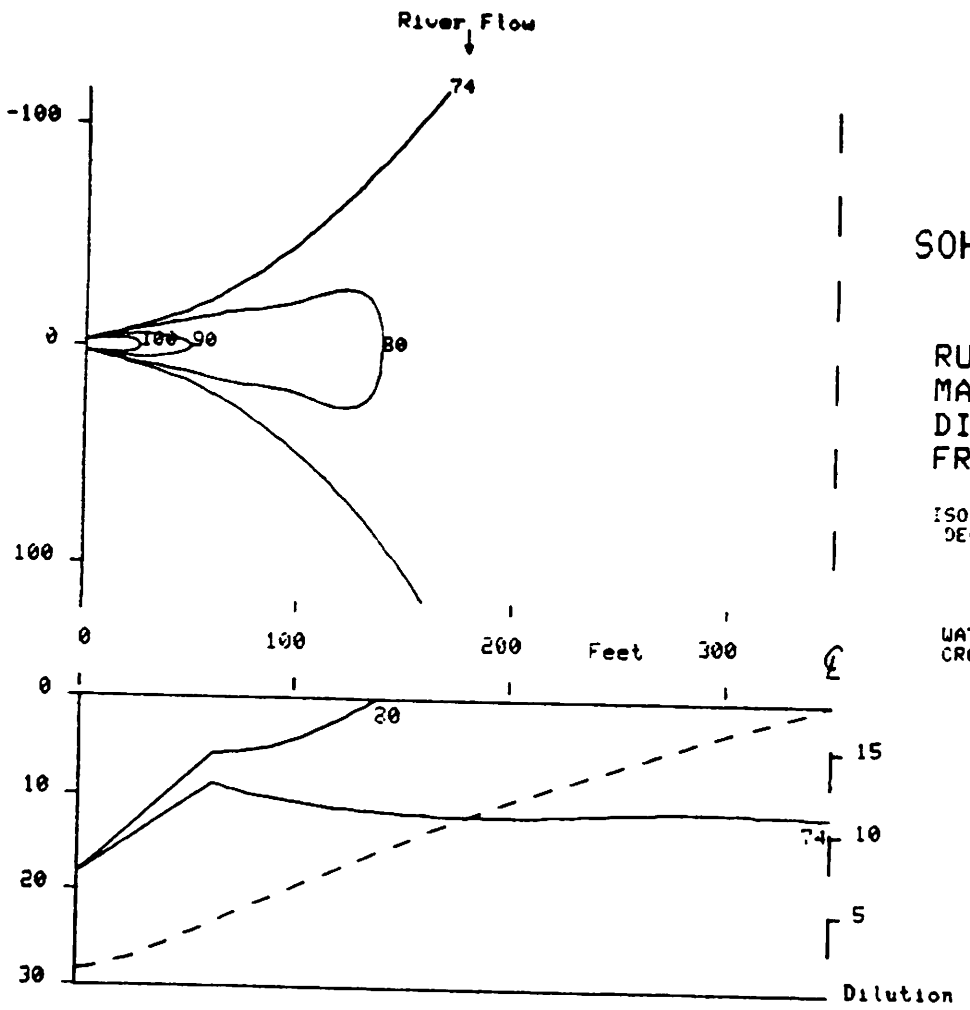
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 7
MAUMEE TEMP. 75.4 DEG. F
DISCHARGE TEMP. 106.9 DEG. F
FROUDE NUMBER 14.9

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
80.	1218.	8461.
90.	552.	417.
100.	552.	128.

WATER LEVEL • IGLD+2.4
CROSS-SECTIONAL AREA • 21280. SQ. FT.

Plume Pattern 7



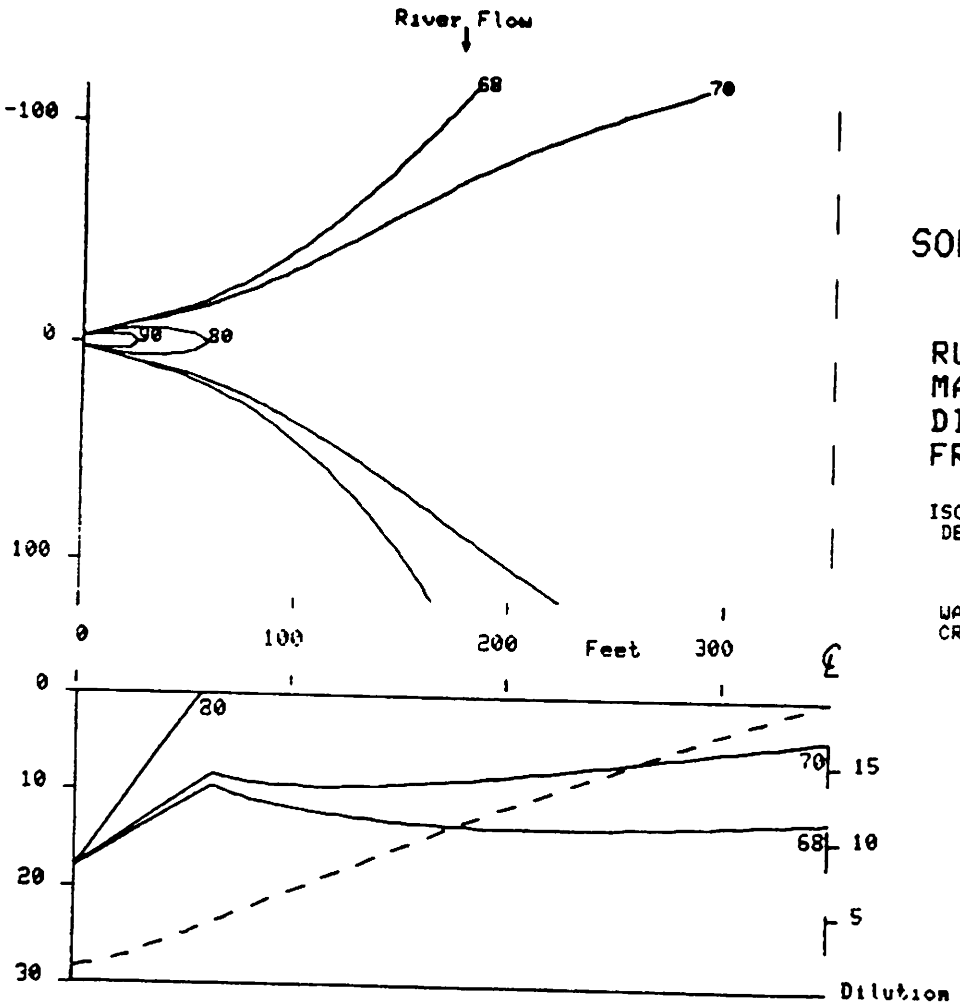
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 8
MAUMEE TEMP. 73.9 DEG. F
DISCHARGE TEMP. 108.1 DEG. F
FROUDE NUMBER 14.3

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
80.	1025.	4835.
90.	546.	423.
100.	546.	149.

WATER LEVEL = IGLD+2.2
CROSS-SECTIONAL AREA = 21140. SQ. FT.

Plume Pattern 8



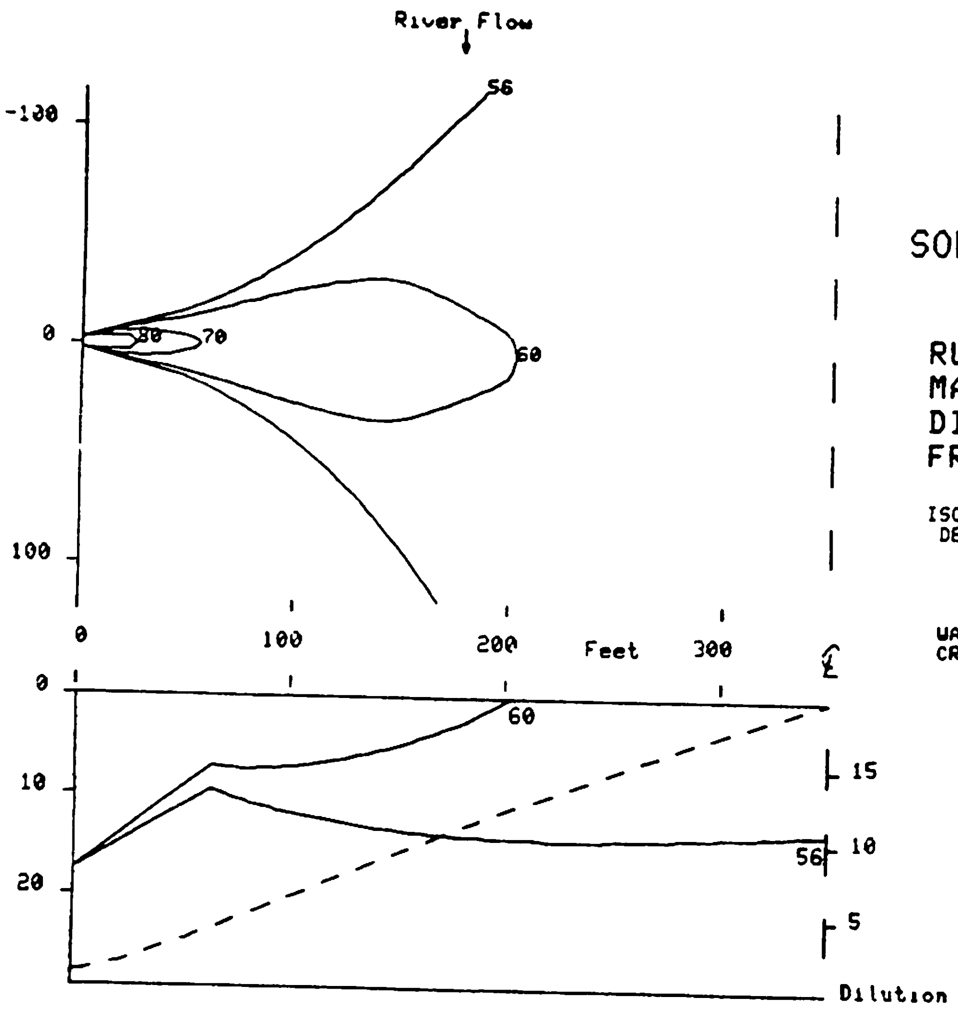
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN # 9
MAUMEE TEMP. 68.0 DEG. F
DISCHARGE TEMP. 98.2 DEG. F
FROUDE NUMBER 16.1

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
80.	541.	567.
90.	540.	191.

WATER LEVEL • IGLD+2.0
CROSS-SECTIONAL AREA • 21000. SQ. FT.

Plume Pattern 9



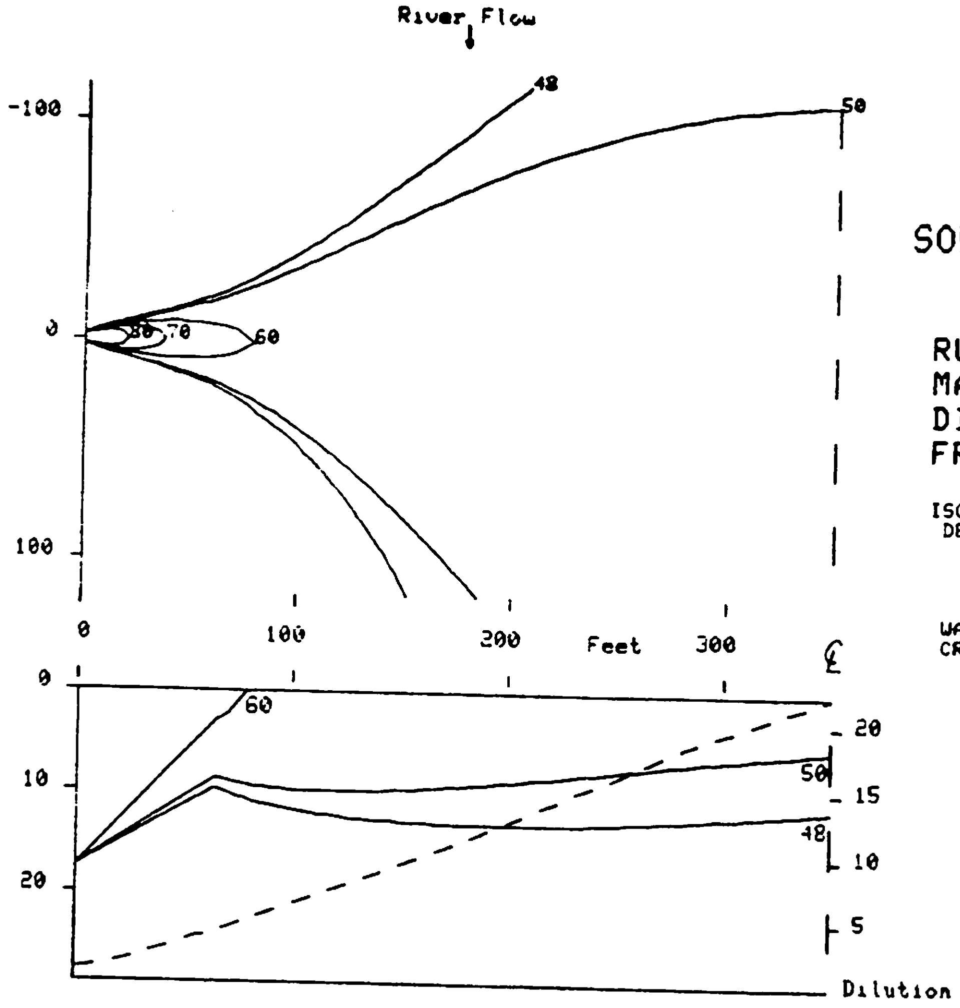
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN #10
MAUMEE TEMP. 55.8 DEG. F
DISCHARGE TEMP. 89.2 DEG. F
FROUDE NUMBER 17.1

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
60.	1409.	10628.
70.	525.	509.
80.	525.	187.

WATER LEVEL • IGLD+1.5
CROSS-SECTIONAL AREA • 20650. SQ. FT.

Plume Pattern 10



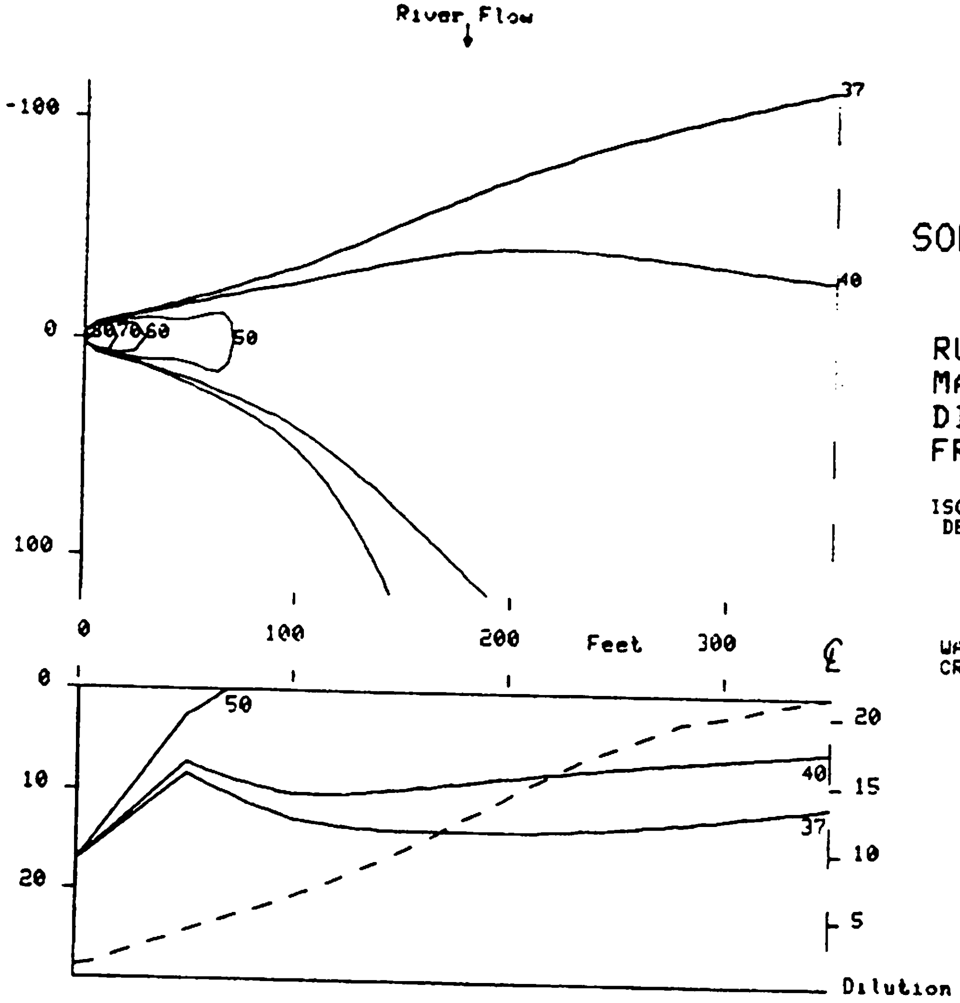
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN #11
MAUMEE TEMP. 47.7 DEG. F
DISCHARGE TEMP. 89.1 DEG. F
FROUDE NUMBER 16.2

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
60.	579.	1123.
70.	519.	365.
80.	519.	159.

WATER LEVEL = IGLD+1.3
CROSS-SECTIONAL AREA = 20510. SQ. FT.

Plume Pattern 11



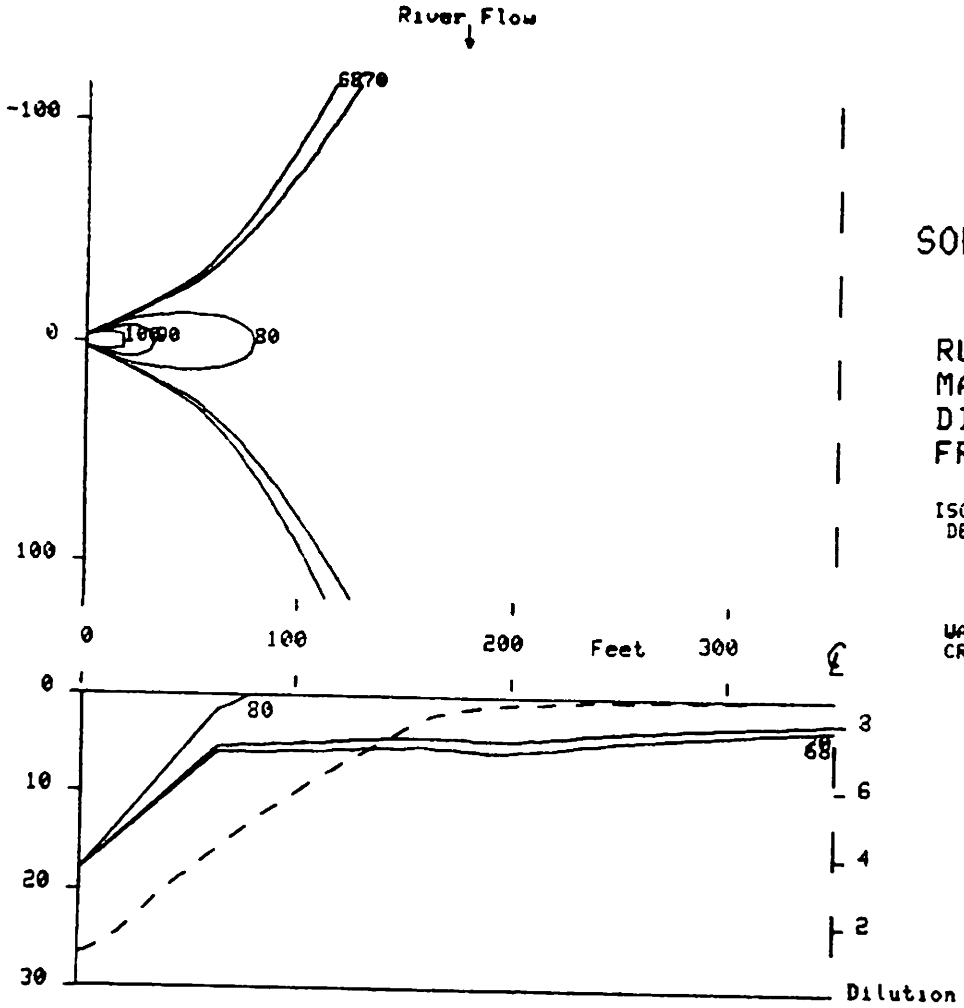
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN #12
MAUMEE TEMP. 37.2 DEG. F
DISCHARGE TEMP. 81.7 DEG. F
FROUDE NUMBER 18.2

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
50.	582.	1396.
60.	516.	453.
70.	516.	201.
80.	516.	15.

WATER LEVEL = IGLD+1.2
CROSS-SECTIONAL AREA = 20440. SQ. FT.

Plume Pattern 12



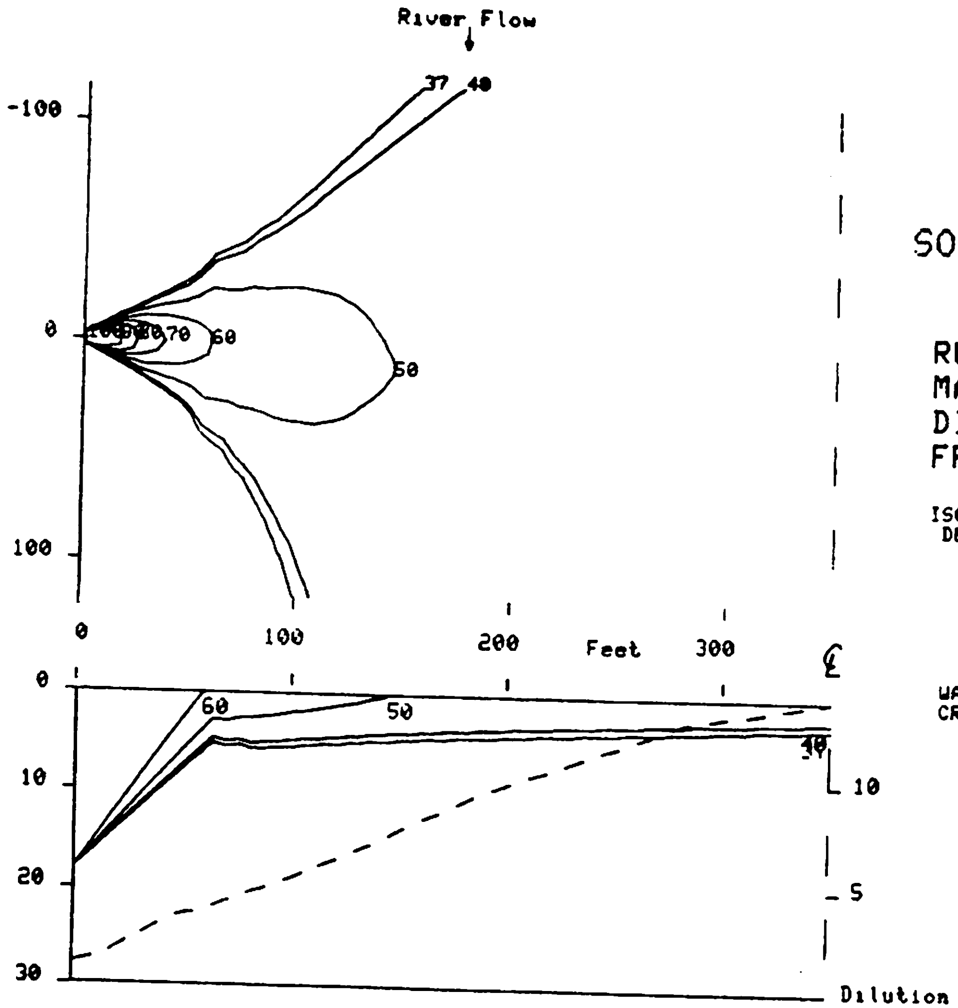
SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN #13
MAUMEE TEMP. 68.0 DEG. F
DISCHARGE TEMP. 106.7 DEG. F
FROUDE NUMBER 6.6

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
80.	570.	1697.
90.	540.	397.
100.	540.	156.

WATER LEVEL = IGLD+2.0
CROSS-SECTIONAL AREA = 21000. SQ. FT.

Plume Pattern 13



SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN #14
MAUMEE TEMP. 37.2 DEG. F
DISCHARGE TEMP. 101.1 DEG. F
FROUDE NUMBER 6.2

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
50.	706.	6789.
60.	541.	1069.
70.	540.	531.
80.	540.	275.
90.	540.	157.
100.	540.	15.

WATER LEVEL = IGLD+2.0
CROSS-SECTIONAL AREA = 21000. SQ. FT.

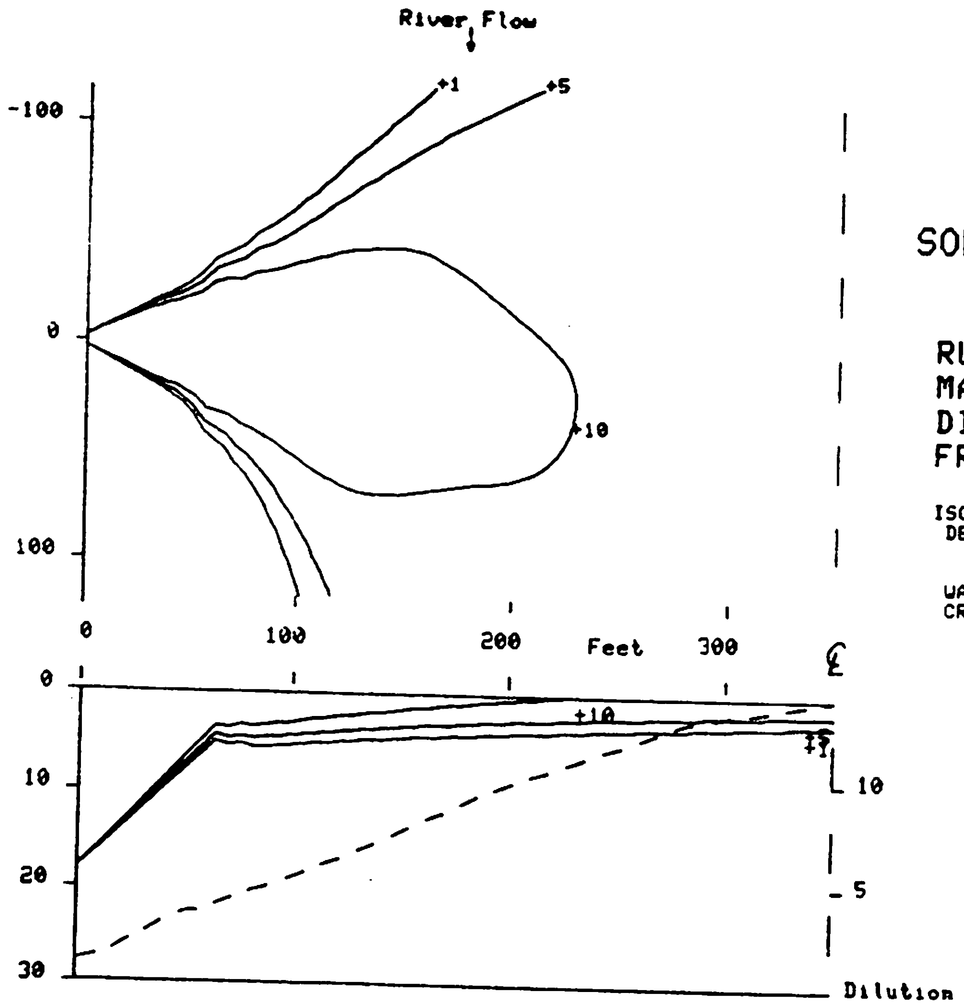
Plume Pattern 14A

SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

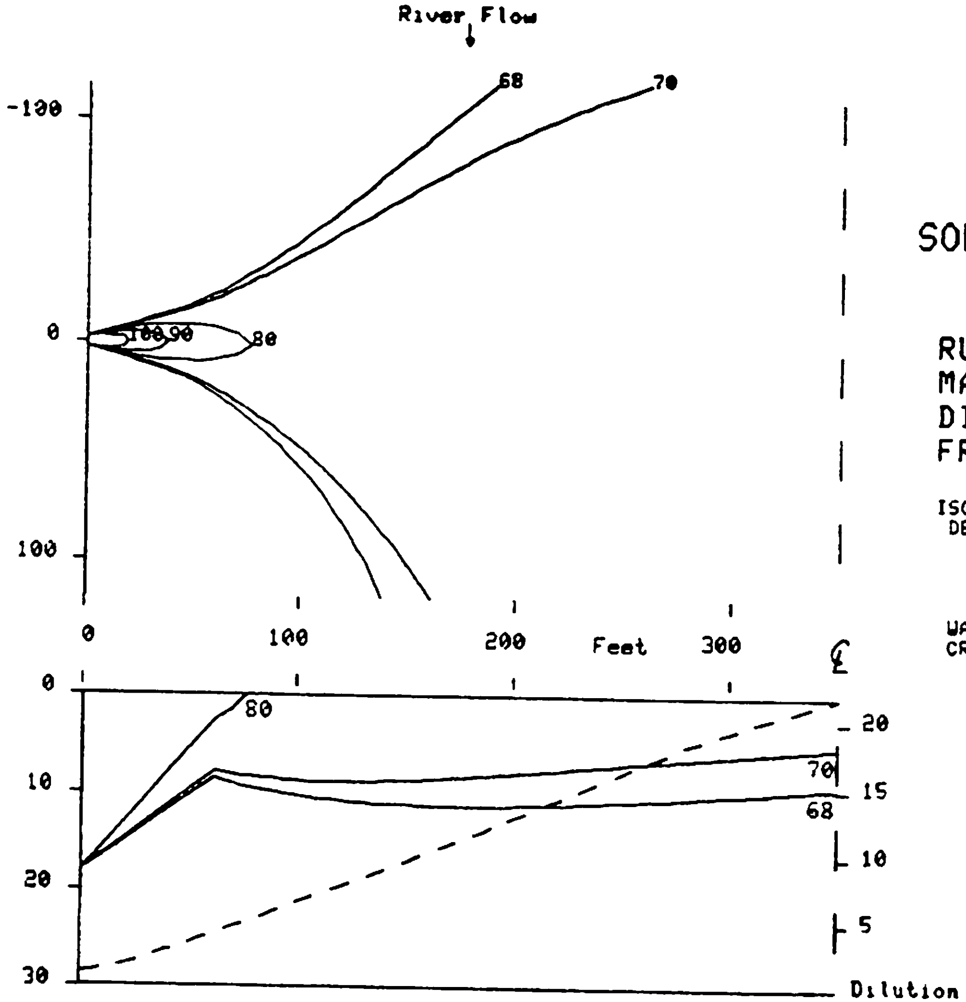
RUN $14
MAUMEE TEMP. 37.2 DEG. F
DISCHARGE TEMP. 101.1 DEG. F
FROUDE NUMBER 6.2

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
47.	907.	22465.

WATER LEVEL • IGLD+2.0
CROSS-SECTIONAL AREA • 21000. SQ. FT.



Plume Pattern 14B



SOHIO OUTFALL DISCHARGE
(TOLEDO REFINERY)

RUN #15
MAUMEE TEMP. 68.0 DEG. F
DISCHARGE TEMP. 106.7 DEG. F
FROUDE NUMBER 13.8

ISOTHERM DEG. F	VERTICAL AREA (SQ. FT.)	HORIZONTAL AREA (SQ. FT.)
80.	594.	1200.
90.	540.	301.
100.	540.	118.

WATER LEVEL • IGLD+2.0
CROSS-SECTIONAL AREA • 21000. SQ. FT.

Plume Pattern 15

APPENDIX C

REPRESENTATIVE AQUATIC SPECIES

Alewife (Alosa pseudoharengus)

This marine species was first recorded in Lake Erie in 1931. It has been present in only moderate-size populations and has never approached the overwhelming abundance found in the upper Great Lakes. Alewives remain in the deeper waters of Lake Erie throughout much of the year, coming into shallower water or ascending streams such as the Maumee River to spawn in June or July. Alewives are basically zooplankton feeders, both as adults and young. In Lake Erie the principle food organisms are copepods and cladocerans.

In the Great Lakes the alewife has long been considered a nuisance. They are particularly obnoxious during periods of mass die-offs in spring and summer. Populations in Lake Erie have not been seriously exploited by commercial fishermen, largely because these landlocked fish are small, thin and bony. The alewife serves as a forage fish for larger predators.

Carp (Cyprinus carpio)

Carp thrive in a wide variety of conditions. They are most abundant in the warm nearshore regions of Lake Erie having much organic matter; they tolerate all types of bottom and clear or turbid water. Compared to other species found in Maumee Bay, carp is not abundant, amounting to less than 0.05 percent of the total fish population.

Carp usually spawn from May to July. They do not build a nest but deposit their eggs among vegetation, debris and roots in rather shallow water from one to four feet.

This species was introduced into Ohio waters in 1879. In 1980, approximately 551,000 pounds of carp were taken in by commercial fishermen in the Ohio waters of Maumee Bay and western Lake Erie with an estimated market value of $44,000. They are of minimal value as a game fish. Carp are often considered detrimental to native fish populations because they increase the turbidity of the water and uproot submerged aquatic vegetation.

Channel Catfish (Ictalurus punctatus)

This fish prefers deep water having a gravel or sand bottom and not the shallower, more turbid, vegetated areas frequented by other ictalurids such as bullheads. Channel catfish also prefer a current rather than sluggish water. This species feeds on a wide variety of plant and animal material, both during the day and night. Bottom feeding is most characteristic of these largely sedentary animals.

This species is an excellent food fish of commerical importance in Lake Erie. In western Lake Erie, including Maumee Bay, Ohio commercial fishermen harvested 158,000 pounds in 1980 at a value of $83,000. Sport harvest of channel catfish in the same area amounted to approximately 220,000 fish in 1980 (Ohio Division of Wildlife, 1981).

Channel Darter (Percina copelandi)

This species was formerly present in goodly numbers on sand and gravel beaches of western Lake Erie and on bars in the large tributaries. Populations have been reduced to the point where the Ohio Department of Natural Resources has included this fish on the state endangered species list. This species was observed in low numbers at the mouth of the Maumee River in 1977.

Spawning takes place in the spring, on sand and gravel beaches or bars where the current is slow or sluggish. All ages are strongly benthic feeders. This species fed primarily upon mayfly and midge larvae prior to the decline of the mayfly in Lake Erie.

Algae and bottom debris are also important components of the diet. The role of this fish in the aquatic environment is not well known, and no direct economic importance has been established, but indirectly it is significant because of its benthic food habits and ingestion of algae.

Emerald Shiner (Notropis atherinoides)

This minnow prefers clear water and is most abundant in central Lake Erie, but a sizable population exists in Maumee Bay where it accounts for over 18 percent of the total fish population. It spends most of its time in mid-water and near the surface, hardly ever moving to the bottom. Because of the turbid nature of the Maumee River, the population of this species is reduced in this tributary. In Maumee Bay, it spawns from late June into August near the surface of open water.

The emerald shiner is an important forage fish in Lake Erie. Schooling fish such as white bass feed heavily on this species. Emerald shiners are probably used more often as bait, largely because of availability, than any other single species on Lake Erie.

Freshwater Drum (Aplodinotus grunniens)

In Lake Erie this fish frequents waters between 5 and 60 feet in depth. At twilight during the warmer months, they come into water less than five feet in depth where they feed by moving rocks and stones with their snouts, capturing crayfish, aquatic insects and darters. Although drum can tolerate turbid water, it prefers clean, clear water with a clean bottom.

The freshwater drum are pelagic spawners in summer in the open waters of Lake Erie. They spawn by scattering their eggs rather than building a nest or searching for a suitable substrate. Larger females normally release from 100,000 to 500,000 eggs.

Freshwater drum is a commercial species rather than a sport fish, although it is taken incidentally by anglers fishing for other species. Ohio commercial fishermen landed 160,000 pounds of freshwater drum in western Lake Erie in 1980, with a value of only $5,000. Approximately 2.1 percent of the total fish population in the study area is composed of this species.

Gizzard Shad (*Dorosoma cepedianum*)

This species is near the northern extremity of its range in Lake Erie. Gizzard shad is perhaps the most abundant fish in western Lake Erie. It is tolerant of turbid waters if phytoplankton productivity is high, but it is winter-killed readily, especially the young. Spawning takes place in shallow water on sand and gravel during the period June through July. Fish return to deeper water after spawning. Large accumulations of this species are common in the fall and winter in the vicinity of thermal discharges to Lake Erie.

Young gizzard shad are an important forage fish for predaceous game and commercial fishes before their rapid growth makes them less utilizable as food items. The abundance of this species creates problems at water intake facilities, particularly in the cold months. The flesh is soft and generally considered to be unappetizing and bony, making it an undesirable item for human consumption.

Goldfish (*Carassius auratus*)

The Eurasian goldfish were imported to North America for ornamental purposes and were introduced into Lake Erie during the late 1800's. This species reproduced prolifically and are now abundant, especially in the western basin. Goldfish are largely nearshore and inland water species, reaching greatest abundance in warm, silty, low-gradient waters of bays, marshes and estuaries of western Lake Erie. Spawning also occurs in these areas in late May to early June. Hybridization between goldfish and carp is common.

The diet of the goldfish consists primarily of chironomid (midge) larvae, oligochaete worms and diatoms. This species can be very disruptive of wetland vegetation and *Cladophora* beds, particularly during the spawning season. Goldfish have little commercial or recreational importance in Maumee Bay.

Green Sunfish (*Lepomis cyanellus*)

This fish is more widely distributed than any other sunfish because of its ability to adapt to a greater variety of habitats. Green sunfish are essentially the inhabitants of small streams and lakes with only isolated populations or strays present in Lake Erie. It is tolerant of turbidity and silt and is often found among vegetation and sunken logs.

Spawning occurs in late spring to mid-summer. Males build shallow nests in sunlit water and after spawning guard and fan the eggs until they are hatched. Food for this species includes insects, molluscs and small fish. They fall prey to a wide variety of warmwater fishes, particularly the basses.

In Maumee Bay, the green sunfish bears little relation to man, amounting to only 0.05 percent of the fish population. They are good eating and constitute a minor game fish in the area.

Log-perch (Percina caprodes)

Log-perch inhabit sand, gravel or rocky nearshore reaches in western Lake Erie and the more sluggish sand and gravel riffles of the Maumee River. It is frequently found in moderately dense beds of submerged aquatic vegetation, especially young-of-the-year. They have also been observed offshore, to depths of over 100 feet.

Log-perch spawn in late spring on sandy inshore shallows. The young feed on a variety of zooplankters, primarily cladocerans and copepods, and as they grow they feed on aquatic insect larvae, particularly midges. Log-perch eggs are preyed upon by white suckers, and juveniles and adults are eaten by a wide variety of piscivorous fish, including walleye.

The log-perch is occasionally used as live bait by anglers but cannot be held alive for long. It is chiefly a forage species, eaten by game and commercial fishes.

Mooneye (Hiodon tergisus)

This species is on the Ohio endangered species list. It was formerly abundant along the Lake Erie shore from Toledo, Ohio to Erie, Pennsylvania. The mooneye prefers clear water with an ample supply of small fish to feed upon. Food items also include a variety of planktonic and benthic invertebrates.

Spring is the principle spawning season for the mooneye with average adult females producing 10,000 to 20,000 eggs. Although detailed information of the mooneye's life history in Lake Erie is lacking, the nearshore zone is a probable spawning, nursery and feeding area for this species.

The mooneye once constituted a minor portion of commercial catches, but is now greatly diminished in population. Only five individuals were collected during the 1976-1977 impingement study at the Bay Shore Power Station. Therefore, the mooneye is not an important food or game fish. A few are caught annually in Maumee Bay, mostly when fishing for other species. They are probably a minor forage species for other fish.

Rainbow Smelt (Osmerus mordax)

The smelt is an anadromous species, leaving Lake Erie in the spring and ascending tributary streams to spawn. Smelt may also spawn on offshore rock and gravel shoals. Adults prefer the deeper portions of Lake Erie, where they apparently remain except during spawning season. The Maumee River is not shown as a spawning tributary for smelt by Trautman (1957).

Smelt are carnivorous fishes, feeding on a wide variety of organisms, including crustaceans, insect larvae, aquatic worms and some fish. In turn, smelt are preyed upon by walleye, perch and gulls. Large commercial catches of smelt are taken from the Ontario waters of Lake Erie, but in 1980 none were reported by Ohio commercial fishermen in the western basin.

Silver Chub (Hybopsis storeriana)

Although on the Ohio endangered species list, 123 individuals of this species were collected during the 1976-1977 fish impingement study at the Bay Shore Power Station. Lake Erie is at the northern limit of this species range.

Silver chub occurs in greatest abundance at water depths of 3 to 60 feet. Spawning is thought to occur in open water during June and July. Young silver chubs consume cladocerans, amphipods, copepods and chironomids, but formerly the major food supply for adults was the mayfly (genus Hexagenia) until this insect larvae disappeared in the mid-1950's.

Because of its small numbers in Maumee Bay, its contribution to the economy of the bay is small. It likely served as a forage species for larger fish in the past.

Silver Lamprey (Ichthyomyzon unicuspis)

This lamprey is much less numerous now than it was in the first half of the century and is presently on the Ohio endangered species list. However, the 1976-1977 fish impingement study at the Bay Shore Power Station yielded 184 specimens of this species.

The silver lamprey is parasitic on other fishes such as freshwater drum or other abundant larger species. In spring, adults migrate up tributary streams to spawn in nests built in sand and gravel bottoms. After hatching, the young dig into the stream bed leaving their heads out to feed on drifting microscopic food. Eventually the ammocoetes are transformed to adults and drift downstream to the lake. Such a life history requires rather clear waters in order to capture prey and clean bottoms to support the young. The loss of these conditions and the construction of dams have reduced the population of this species.

This parasitic species is of little benefit to man, although it was formerly marketed at Lake Erie ports. The adverse effect of this species on host populations is thought to have been minimal in the past and all but nonexistent today.

Spottail Shiner (Notropis hudsonius)

The spottail shiner is benthipelagic, preferring shallower waters. As such it is essentially shore-oriented and common in the nearshore zone throughout Lake Erie. Spawning areas and behavior in Lake Erie are not recorded, but spawning activity apparently occurs in shallow water on sandy bottoms in June and July.

Spottail shiners are opportunistic predators and feed on a variety of plant and animal material. In turn the species prey for walleye, white bass and other large predator species.

The spottail shiner is not of sport or commercial importance in Lake Erie except as a minor bait fish. It is, however, the fourth most important forage species in Maumee Bay, after gizzard shad, emerald shiner and alewife.

Trout-perch (Percopsis omiscomaycus)

Spawning for these fish has been reported to occur over a sand and gravel bottom in Lake Erie. These lake-spawning populations seem unique in that spawning is prolonged, extending from May to August.

A characteristic inshore movement of this species after dark is probably for the purpose of getting food. Food items include insect larvae, particularly midges, mayflies, darters and minnows. Trout-perch are regarded as an important forage fish for walleye, yellow perch and freshwater drum.

The trout-perch is probably of little direct importance except as occasional bait. It is an important forage fish, but its population is low (about 0.1 percent of the total fish population) in Maumee Bay as indicated by the Bay Shore Power Station fish impingement study.

Walleye (Stizostedion v. vitreum)

Walleye is distributed throughout Lake Erie, but it is most abundant in the western basin. Major spawning areas presently include offshore reefs and riffles on the Maumee and Sandusky Rivers. Spawning areas consist of rock and rubble, and the spawning season begins in March or April, depending on the water temperature. In 1977, the estimated Maumee River brood stock which migrated upstream from Lake Erie was 540,000, whereas the western basin brood stock was estimated at 8,610,000 for the same year.

Walleye has long been an important commercial and game species in Lake Erie. It began to assume major commercial importance after 1900, when declining production of salmoids forced consideration of alternative fish stocks. By 1960, the commercial walleye fishery also collapsed due to overfishing, siltation on spawning areas and other environmental alterations. Commercial fishing for walleye is now banned in Ohio and Michigan. The species has recovered to the point where the western basin supports a fine recreational fishery. Approximately 2.1 million walleyes were taken by Ohio sportsmen in western Lake Erie in 1980.

White Bass (Morone chrysops)

White bass is a highly mobile, benthipelagic species ranging from inshore to far offshore in Lake Erie. It is particularly abundant throughout the western basin. This species spawns in rocky areas in tributaries, particularly the Maumee and Sandusky Rivers and probably in similar habitats in bays and/or reefs. Fish, primarily minnows, is the major dietary item of white bass, with dipteran larvae and cladocerans also constituting important food sources.

White bass is a major sport fish in Lake Erie and has increased substantially in commercial importance since the decline of commercial walleye fishing. Although this species has been highly exploited, no progressive decline in the stock is evident. In 1980, Ohio commercial fishermen harvested 1,284,000 pounds in the western basin, at a value of $450,000. Sport harvest in the western basin was approximately 100,000 fish in 1980. White bass accounts for about 3.5 percent of the total fish population.

White Crappie (Pomoxis annularis)

This fish can tolerate a wide variety of conditions. It prefers turbid and silty water. White crappie is found over hard and soft bottoms; sometimes it inhabits vegetated areas and will often accumulate around underwater logs and stumps. Spawning normally occurs in May and June; nests are made in bare spots among aquatic vegetation in water up to five feet deep. Moderate populations occur in the bays, marshes, harbors and shallow waters of western Lake Erie. Smaller populations are found in sluggish streams such as the Maumee River.

Food items for the white crappie include planktonic crustaceans, aquatic insects and small fish. Young white crappie fall prey to a variety of predaceous fish, including largemouth bass and larger white and black crappie. Larger individuals, with their deep bodies, may be fairly free of predation.

Crappies are among the most popular fishes for anglers in Ohio, but it is not a target species for most Lake Erie sportsmen. The flesh is white, flaky and highly suitable as food, but their heavy, compressed long bodies make preparation somewhat difficult.

White Sucker (Catostomus commersoni)

A large population of white sucker exists in Lake Erie and the adjoining bays. This species is tolerant of a great variety of habitats and conditions. It withstands turbidity, silt and low oxygen content. At spawning time, spring, white suckers move into riffle areas of streams and over gravel beds in lakes.

They are bottom feeders, browsing on midge larvae, molluscs, caddis fly larvae and cladocerans. White sucker has also been reported as a fish egg predator. They may form a major food item for a wide variety of predatory fishes, including basses and walleye.

Suckers are of minor commercial importance in western Lake Erie. The Ohio commercial harvest in this part of the lake in 1980 was 26,000 pounds at a value of $2,300. It is rarely angled for on Lake Erie, but anglers fish for white sucker inland in the Maumee River basin.

Yellow Perch (Perca flavescens)

This important species is most abundant in the clearer, shallower waters of Lake Erie, although it occurs at a variety of depths and in turbid waters such as Maumee Bay. Yellow perch spawns in late April to late May, attaching gelatinous, adhesive ribbons of eggs to submerged vegetation and artificial structures in sheltered nearshore waters.

Perch feed primarily on dipteran larvae, oligochaetes, zooplankton and forage fish such as emerald and spottail shiners. It is preyed upon by many warm and cool-water predatory fish such as basses, crappies and walleyes.

Yellow perch has long been an important commercial and sport fish in Lake Erie. It is widely-distributed and abundant throughout the lake. It is a schooling fish and congregates near shore in spring. In 1980, Ohio commercial fishermen landed 267,000 pounds of yellow perch in western Lake Erie at a value of $150,000. Sport harvest of this species in western Lake Erie was 10,000,000 fish in 1980. Yellow perch accounts for about 2.5 percent of the total fish population in Maumee Bay.

APPENDIX D

THERMAL DATA FOR COMMON FISH SPECIES

ADDITIONAL THERMAL DATA FOR SOME OF THE MORE COMMON FISH SPECIES ON THE RAS LIST

ALEWIFE (Alosa pseudoharengus)

Activity	Temperature, F(C) Critical	 Acclimation	Reference and Comment
Max. for survival of parent	76.1 (24.5)	68 (20)	Otto 1973:49. Incipient upper TL50.
Max. for summer survival	73 (22.8)	68 (20)	Graham 1956. Estimation of upper TL50 based on studies of resistance times of adults to gradually increasing temperatures.
	94.1-95 (34.5-35)		Dorfman and Westman 1970:56. Upper limit for survival and feeding; 20% of alewife juveniles survived for 24 hours.
	89.8 (32.1)	77 (25)	Otto 1973:49. Incipient upper TL50, juveniles.
	72.7 (22.6)	48.2 (9)	Graham 1956. Estimated upper TL50 (see comment above).
Optimum for growth	—	—	
Min. avoidance temp.	60.9-64.4 (16-18)	51.1-54.5 (10.6-12.5)	Texas Instruments 1973:IV-24. Juveniles.
	78.8-86 (26-30)	62.6-80.6 (17-27)	Meldrim et al. 1974:41.
	86 (30)	77 (25)	Meldrim and Gift 1971:34.
Max. for development	70.0 (17.2)		Edsall 1970:378. Optimum.
	48.2-82.4 (9-28)		Edsall 1970:378. Range over which 50% of optimal hatching rate occurs.
Cold shock	39.2 (4)	50 (10)	Otto 1973:59. Lower incipient TL50.
	41.7 (5.4)	59 (15)	
	46.0 (7.8)	68 (20)	
	37.0 (2.8)	60 (15.6)	Colby 1973:170. Drop in temp. over 15 days; 92% loss.
	36.0 (2.2)	55 (12.8)	Drop in temp. over 22 weeks, 50% loss.
	36.0 (2.2)	54 (12.2)	Drop in temp. over 17 weeks, 75% loss.
	37.4 (3.0)	65.1 (18.4)	Drop in temp. over 130 days, 100% loss.

ALEWIFE (Alosa pseudoharengus)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	76.1 (24.5)	68 (20)	Otto 1973:49. Incipient upper TL50.
Max. for summer survival	73 (22.8)	68 (20)	Graham 1956. Estimation of upper TL50 based on studies of resistance times of adults to gradually increasing temperatures.
	94.1-95 (34.5-35)		Dorfman and Westman 1970:56. Upper limit for survival and feeding; 20% of alewife juveniles survived for 24 hours.
	89.8 (32.1)	77 (25)	Otto 1973:49. Incipient upper TL50, juveniles.
	72.7 (22.6)	48.2 (9)	Graham 1956. Estimated upper TL50 (see comment above).
Optimum for growth	—	—	
Min. avoidance temp.	60.9-64.4 (16-18)	51.1-54.5 (10.6-12.5)	Texas Instruments 1973:IV-24. Juveniles.
	78.8-86 (26-30)	62.6-80.6 (17-27)	Meldrim et al. 1974:41.
	86 (30)	77 (25)	Meldrim and Gift 1971:34.
Max. for development	70.0 (17.2)		Edsall 1970:378. Optimum.
	48.2-82.4 (9-28)		Edsall 1970:378. Range over which 50% of optimal hatching rate occurs.
Cold shock	39.2 (4)	50 (10)	Otto 1973:59. Lower incipient TL50.
	41.7 (5.4)	59 (15)	
	46.0 (7.8)	68 (20)	
	37.0 (2.8)	60 (15.6)	Colby 1973:170. Drop in temp. over 15 days; 92% loss.
	36.0 (2.2)	55 (12.8)	Drop in temp. over 22 weeks, 50% loss.
	36.0 (2.2)	54 (12.2)	Drop in temp. over 17 weeks, 75% loss.
	37.4 (3.0)	65.1 (18.4)	Drop in temp. over 130 days, 100% loss.

GIZZARD SHAD (*Dorosoma cepedianum*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	—	—	
Max. for summer survival	86.4-89.1 (30.2-31.7)	60.6 (15.9)	Reutter and Herdendorf 1975:25. Critical thermal maximum, juveniles.
	93.2-97.7 (34-36.5)	77-95 (25-35)	Hart 1952:67. Incipient lethal temp.
Optimum for growth	—	—	
Min. avoidance temp.	—	—	
Max. for development	—	—	
Cold shock	32.2-38.1 (0.1-3.4)	53.8-58.3 (12.1-14.6)	Reutter and Herdendorf 1975:41. Shock resulted in stress or death.

GOLDFISH (*Carassius auratus*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	95 (35)	75 (23.9)	Reutter and Herdendorf 1975:28. From hot shock survival experiments. Survived 1-hr exposure.
Max. for summer survival	97.9 (36.6)	78.8 (26)	Fry et al. 1942. Upper lethal temp. For juveniles.
Optimum for growth	—	—	
Min. avoidance temp.	—	—	
Max. for development	—	—	
Cold shock	37.4 (3)	75.2 (24)	Reutter and Herdendorf 1975:40. Shock caused 100% mortality.
	34.7 (1.5)	53.6 (12)	Reutter and Herdendorf 1975:40. Shock caused no mortality.

RAINBOW SMELT (*Osmerus mordax*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	75.9 (24.4)	50 (10)	Otto 1973:41. Critical thermal maximum.
Max. for summer survival	—	—	
Optimum for growth	—	—	
Min. avoidance temp.	60.8 (16)	50 (10)	Otto 1973:62.
Max. for development	—	—	

EMERALD SHINER (*Notropis atherinoides*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	—	—	
Max. for summer survival	90.7 (32.6)	68-77 (20-25)	McCormick and Kleiner 1970:10. 24-hr TL50 for juveniles.
	87.3 (30.7)	77 (25)	Hart 1947. 7-day TL50 for juveniles.
Optimum for growth	75.2-84.2 (24-29)	68 (20)	McCormick and Kleiner 1970:9. Juveniles tested for 6 weeks after 2-week acclimation period.
Min. avoidance temp.	80.6 (27)		Barans 1972. Adults tested.
	86 (30)		Barans 1972. Juveniles tested.
Max. for development	—	—	
Cold shock	33.6-45.9 (0.9-7.7)	54.5-66.0 (12.5-18.9)	Reutter and Herdendorf 1975:42. Adults; shock resulted in no mortality.

FRESHWATER DRUM (*Aplodinotus grunniens*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	—	—	
Max. for summer survival	93.2 (34)	70.2 (21.2)	Reutter and Herdendorf 1975:22. Critical thermal maximum for juveniles.
Optimum for growth	—	—	
Min. avoidance temp.	—	—	
Max. for development	69.8-77 (21-25)		Swedberg and Walburg 1970:563. Hatching took 36 hrs. at 69.8 F and 22 hrs. at 77 F.
Cold Shock	33.1 (0.6)	53.2 (11.8)	Reutter and Herdendorf 1975:40. 1 of 2 died.
	66.4 (19.1)	84.7 (29.3)	1 of 1 survived.

WHITE BASS (*Morone chrysops*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	—	—	
Max. for summer survival	—	—	
Optimum for growth	—	—	
Min. avoidance temp.	—	—	
Max. for development	60.8-62.6 (16-17)		Yellayi 1972. Range is optimum for hatching.
Cold shock	33.4-43.3 (0.8-6.3)	55-63.5 (12.8-17.5)	Reutter and Herdendorf 1975:42. Shock caused 15% mortality.

WHITE SUCKER (*Catostomus commersoni*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	—	—	
Max. for summer survival	91.2 (32.9)	68 (20)	Otto 1973:41. Critical thermal max. for juveniles. Temp. increased at rate 0.3°C/minute.
	86-89.6 (30-32)	59-69.8 (15-21)	McCormick et al. 1972:12. 1-, 2-, and 7-day TL50s for both newly hatched and swim-up larvae.
Optimum for growth	80.4 (26.9)		McCormick et al. 1972:11. Larvae.
Min. avoidance temp.	88.2 (31.2)		McCormick et al. 1972:12. Larvae.
Max. for development	48.2-63.0 (9-17.2)		McCormick et al. 1972:11. Optimum range for normal hatching.

YELLOW PERCH (*Perca flavescens*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	85.5 (29.7)	77 (25)	Hart 1947.
Max. for summer survival	89.6 (32)	75.2 (24)	McCormick (MS):10. Juveniles, 7-day TL50.
	84.6 (29.2)	71.6-75.2 (22-24)	Black 1953:204. Juveniles, 24-hr TL50.
Optimum for growth	78.8-86 (26-30)		McCormick (MS):10. 8-week test with juveniles.
Min. avoidance temp.	91.9-93.9 (33.3-34.4)	77 (25)	Meldrim and Gift 1971:36.
Max. for development	50.2-64.8 (10.1-18.2)		Hokanson and Kleiner 1974:443. Optimum for normal hatching; embryos reared at selected test temperatures from fertilization.
	55.6-64.8 (13.1-18.2)		Hokanson and Kleiner 1974:443. Optimum for normal hatching; embryos reared at 12 C from fertilization to formation of neural keel, then exposed to test temperatures.
Cold shock	33.8-41 (1-5)	53.8-70.2 (12.1-21.2)	Reutter and Herdendorf 1975:43. Shock resulted in no mortality.

CARP (*Cyprinus carpio*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival of parent	99.9 (37.7)	68.4 (20.2)	Reutter and Herdendorf 1975:24. Critical thermal maximum.
Max. for summer survival	96.3 (35.7)	78.8 (26)	Black 1953:204. 24-hr TL50, juveniles.
	100.0 (37.8)	64.4 (18)	Otto 1973:42. Critical thermal max., juveniles.
Optimum for growth	68-77 (20-25)		Meuwis and Heuts 1957. Larvae.
Min. avoidance temp.	—	—	
Max. for development	62.6-71.6 (17-22)		Burns 1966:513. Hatching takes 4-8 days at 17 C, less than 4 days at 22 C.
Cold shock	33.4-44.6 (0.8-7.0)	53.6-65.8 (12-18.8)	Reutter and Herdendorf 1975:40. Shock resulted in no mortality.

CHANNEL CATFISH (*Ictalurus punctatus*)

Activity	Temperature, F(C)		Reference and Comment
	Critical	Acclimation	
Max. for survival	86 (30)	59 (15)	Hart 1952. Upper TL50.
	92.3 (33.5)	77 (25)	Hart 1952. Ultimate upper TL50.
Max. for summer survival	97.9-100 (36.6-37.8)	78.8-93.2 (26-34)	Allen and Strawn 1968:399. Upper incipient TL50.
Optimum for growth	84.2-87.8 (29-31)		West 1966. Larvae.
	82.4-86 (28-30)		Andrews et al. 1972:240. Juveniles.
Min. avoidance temp.	91.4-95 (33-35)	75.2-86 (24-30)	Cherry et al. 1974:28.
Max. for development	84.2 (29)		Clemens and Sneed 1957.
Cold shock	33.6-33.8 (0.9-1.0)	53.6 (12)	Reutter and Herdendorf 1975:42. Shock resulted in no mortality.
	32 (0)	59-77 (15-25)	Hart 1952. Lower TL50.