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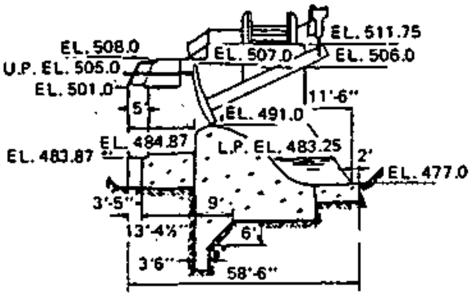
THE EFFECTS OF HYDROPOWER DEVELOPMENT AT THE DRESDEN ISLAND DAM ON DOWNSTREAM DISSOLVED OXYGEN RESOURCES

by
Thomas A. Butts, Harvey R. Adkins, and Donald H. Schnepper



CROSS SECTION OF
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Prepared for the Village of Channahon
in cooperation with Beling Consultants, Joliet, Illinois

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Illinois Department of Energy and Natural Resources

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INTRODUCTION

The Illinois Pollution Control Board (IPCB) dissolved oxygen (DO) standards, as administered by the Illinois Environmental Protection Agency (IEPA), are not being consistently met along several major reaches of the Illinois Waterway. Undesirably low DO levels still occur routinely, particularly during low summer flows, in spite of the fact that hundreds of millions of dollars have been expended over the last 20 years to reduce point source waste loads. General use water quality standards are applicable to the Illinois Waterway below the I-55 bridge, which is approximately 6.5 miles above the Dresden Island dam. Section 302.206 of Subpart B of the IPCB Rules and Regulations (1986) states:

> Dissolved oxygen (STORET number 00300) shall not be less than 6.0 mg/l during at least 16 hours of any 24 hour period, nor less than 5.0 mg/l at any time.

Dissolved oxygen surveys conducted in the Peoria pool by the Water Quality Section (WQS) of the State Water Survey (SWS) during the summers of 1982, 1983, and 1986 show that DO concentrations often drop below 5.0 mg/1 even during relatively high summer flows. In the LaGrange pool below Peoria, concentrations as low as 3.5 mg/l were observed during 1983 summer low flow conditions. Computer biochemical oxygen demand (BOD) - DO model simulations have clearly demonstrated that significant improvements in DO levels cannot be achieved by requiring additional organic waste load (BOD) reductions at the point sources. Most treatment plants along the waterway are presently achieving 90 to 95 percent BOD reductions. In addition, since 1971 ammonia input to the waterway (another cause of oxygen depletion) has been reduced over 50 percent. Additional treatment would not produce a commensurate improvement in DO levels. The only plant along the waterway amenable to a large-scale upgrading is the Metropolitan Sanitary District of Greater Chicago Calumet plant. Butts et al. (1983) have shown that upgrading the effluent of this plant to 7 mg/l BOD and 2 mg/l ammonia would improve the DO level in the critical reach of the Peoria pool by only 0.6 mg/l during low flow conditions.

Cause of the Problem

The reason the improvement in DO has not been commensurate with the reduction of waste inputs is that the waste assimilative capacity of the waterway has been drastically reduced due to the physical alterations of the natural stream channel over the last 50 years. Dam construction, dredging, and channelization have slowed flows and increased water depths, thereby reducing the natural reaeration capacity, i.e., the ability of the water to replenish oxygen from the air that has been lost to biological oxidation. Also, the pools and deepened channels have created sediment traps. These trapped sediments often exert a significant sediment oxygen demand (SOD) (Butts, 1974). In some pools, the reaeration capacity is barely adequate to supply the oxygen needed to stabilize the SOD.

General Effects of Dams

Dams are built across streams for reasons such as aesthetics (as exemplified by small channel dams in parks), flow and navigation control, and hydroelectric power generation. Regardless of the purpose of the dam, all affect water quality to some degree. The manifestations can be both positive and negative, and some effects may be subtle and indirect while others may be obvious and direct.

One of the most obvious and direct effects dams have on water quality is the creation of abrupt changes in dissolved oxygen concentrations. When DO problems are likely to appear at a new dam, consideration should be given in the design for maximizing aeration efficiency. At established sites, operating procedures should be geared (when feasible) to maximizing reaeration in a practical manner.

To fully appreciate the need for an efficient aeration design or operating procedure at a dam site, an understanding is needed of the basic ecological and environmental consequences dams have on aquatic systems. Weirs and dams create pools which have DO levels inherently above or below those normally expected in a free-flowing stream of similar water quality. If the water is nutrient-rich but not grossly polluted, excessive algal growths can be expected to occur in the pools, resulting in wide fluctuations of diurnal DO levels. During the day, supersaturation may occur because of algal cell photosynthesis, whereas during the night almost total depletion may occur because of the respiratory needs of the algae. Essentially the pools act as biological incubators for plankton. However, in the absence of sustained photosynthetic oxygen production, DO concentrations may often fall below desired levels since the waste assimilative capacities of the pools are often much lower than those of free-flowing reaches of the same stream. Several factors account for this.

One is that the physical reaeration capability of a pool is much lower than that of a free-flowing reach of similar length. Reaeration is directly related to stream velocity and inversely related to depth. Consequently, since pooling decreases velocity and increases depth, natural physical aeration in a pool proceeds at a much slower rate. Butts et al. (1973) showed that for the Rock River in Illinois the average reaeration constant for an 11-mile pool was only 11 percent of the average of the one calculated for the preceding 11-mile upstream free-flowing reach.

The problem of low aeration rates in pools is compounded by the fact that more oxygen is used in the pool than in a free-flowing reach since the detention time is increased as a result of lower velocities. This enables microorganisms suspended in the water and micro- and macroorganisms indigenous to the bottom sediments in the pools to use more of the DO resources in a given area to satisfy respiratory needs. The detention time in the afore-mentioned Rock River pool was 2.23 days compared with the free-flowing reach time of travel of only 0.68 days.

Also, dams promote the accumulation of sediments upstream. If these sediments are polluted or laden with organic material, additional strain is put on the DO resources since the quantity of oxygen needed to satisfy sediment oxygen demand is directly related to the detention time and inversely related to depth, as shown by Butts et al. (1974). Depths behind navigation dams at intermediate to low flow fluctuations change at a lower rate than do corresponding detention times because flat pool elevations need to be maintained for navigational interests. Essentially, a fixed volume of water is preserved, allowing more time for benthic organisms to deoxygenize the water as flow rates decrease.

The reduction in oxygen levels behind the dams can be partially compensated for by aeration at the dam site. This localized aeration cannot make up for the overall damage rendered in the pools, but it can establish or control conditions in the next succeeding downstream reach. Unfortunately, dam aeration theory dictates that head loss structures deaerate water with supersaturated levels of DO at the same rate at which they would aerate water at equivalent subsaturated levels.

For example, water with a DO level 2 mg/l above saturation is deoxygenated at the same rate that it would be reaerated at 2 mg/l below saturation with all other physical conditions remaining unchanged.

Butts and Evans (1978) found that for highly productive streams such as the Fox River in Illinois, any DO above 200 percent saturation is lost instantaneously to the air as the flow makes contact with a weir or spillway crest. Dams in essence "blow out" supersaturated oxygen which may be needed as a reserve for algal respiration at some future time downstream.

Purpose of Study

The purpose of this study was to evaluate the possible effects of hydroelectric power development at the Dresden Island lock and dam on the Illinois River (figure 1) on downstream dissolved oxygen resources. Water passing through penstocks and turbines receives very little aeration, whereas flow released through Tainter gates, such as those at Dresden Island which are perched on top of a spillway, can be highly aerated depending upon gate manipulation and management.

Comprehensive evaluations were made by using Illinois River hydraulic and water quality models developed and verified by the WQS of the SWS over the last 15 years. Data inputs to the models and model coefficients were derived and developed from the results of recent water quality sampling conducted along the whole of the waterway and at the Dresden Island dam by the SWS as part of this study, and from the most current U.S. Army Corps of Engineers river cross-sectional soundings. Statistical procedures were used to reduce the raw river data to meaningful form for use in the models.

Specific questions addressed and answered in this study are:

1. Will hydropower development at Dresden Island have negative effects on the already strained DO resources downstream of the dam?

2. If negative effects appear (as reflected by the results of the model study), what is their frequency of occurrence?

3. Can predicted negative effects be reduced or eliminated by managing and controlling water released through the potential power plant and/or dam flow release gates?

4. If flow release control is not a viable alternative, is artifical reaeration practical?

Illinois Waterway Background Information

The Illinois Waterway (figure 1) is special among the many streams and rivers within Illinois: it drains 43 percent of the state and small portions of Wisconsin and Indiana. During dry weather, its headwaters consist principally of treated Chicago area wastewaters diluted with flow diverted from Lake Michigan. The waterway is not a free-flowing stream; it consists of eight navigational pools extending over 327 miles between the Mississippi River and Lake Michigan (figure 2). Locks and dams are located at Lockport (mile 291.1), Brandon Road (286.0), Dresden Island (271.5), Marseilles (247.0), Starved Rock (231.0), Peoria (157.7), and LaGrange (80.2). Flow control at Brandon Road, Dresden Island, Marseilles, and Starved Rock is exercised by using Tainter gates. The Peoria and LaGrange dams are unique in that bottom hinged rectangular plates, known as Chanoine wickets, are lowered to lie flat on the river bottom during high flows for river traffic to pass. During low flows, desired upstream head is achieved by raising the wickets and inserting timbers called needles between each wicket, thereby creating a sharp-crested, low-head channel dam or spillway. All the flow at Lockport is passed through penstocks for power.

Although the dams are principally responsible for the overall reduction in the ability of the waterway to assimilate wastes, some of the natural aeration capacity lost through pooling can be partially made up at the dam. As water is passed either under or over flow release control structures at the dams, it is instantaneously reaerated due to the great turbulence and head loss factors associated with these releases. Historically, these flow release structures have been operated only to meet flow needs. No consideration has been given to optimizing and coordinating flow control adjustments with downstream water quality needs. If slightly more than one part per million of DO could be added by reaeration at the Starved Rock dam by better management relative to reaeration, the DO standards could probably be achieved in the Peoria pool when or if improvements are made to the Calumet treatment plant. The purpose of this study was to define the aeration characteristics of the Dresden Island flow release control structures so that a practical operating scheme could be developed and employed to enhance the dissolved oxygen resources in the Marseilles and Starved Rock pools below the dam.

Acknowledgments

This study was funded by a research grant from the Village of Channahon. The research was conducted as part of the work of the Water Quality Section of the Illinois State Water Survey (Richard G. Semonin, Chief). Robert Rogina of Beling Consultants in Joliet, Illinois, provided considerable valuable assistance and guidance. Field crews consisting at various times of Dave Beuscher, Jud Williams, Dave Green, Jim Kelton, Pete Berg, John Mathis, and Eric Von Hoven made this study possible by spending long days and nights in the field collecting data. Dave Hullinger and Dana Shackleford ran the laboratory analyses. Special recognition is given to Harvey Adkins, who supervised the field crews and was responsible for designing the computer programs needed to handle the massive amounts of data generated by this study. Harvey died unexpectedly at the age of 31 before the completion of this report, and this report is therefore dedicated in memory of him and his truly great concern for the environment.

DAM AERATION THEORY

As previously noted, water flowing over weirs and spillways or through head-loss control structures such as Tainter and sluice gates can be aerated or deaerated depending upon the ambient upstream DO concentration. This relatively instantaneous DO change at a dam site may be dramatic and may have a more lasting effect on water quality and overall aquatic biology than any other single physical factor. This is especially true where deep pools are created behind navigation dams which limit the natural physical reaeration capacity of a stream. The effects of these structures on water quality cannot be ignored; any water quality model dealing with DO as a parameter must take into consideration the influence of all types of dams, and this must be done with accuracy and confidence.

Unfortunately, however, little work has been done to develop universally applicable techniques for predicting DO changes at dams. The lack of information and methodologies applicable to navigation dams where flow releases are usually gate-controlled is especially noticeable when searching for information. Most of the limited work on developing a dam reaeration model has been done by studying channel dams, weirs, and head loss structures on small streams and rivers. Usually when dam aeration is incorporated into a water quality model, it is handled with a simplistic "black box" approach whereby the change in DO concentration is correlated to a single factor, the water fall height.

Typical examples of this approach are the simple models developed by Crevensten and Stoddard (1974) and by Foree (1976). From field observations, Crevensten and Stoddard derived an empirical expression in which dam aeration is expressed as a direct function of the water fall and a variable numerical coefficient. Foree derived an empirical expression from field data, in which dam aeration is a direct function of the natural logarithm base (e) raised to the power of 0.16 times the water fall. The specificity of these equations limits their usage to the conditions for which they were developed.

Only two references were found related to evaluating the aeration capacity of flow-controlling works at navigation dams. One was the work reported by Susag et al. (1967) for the Hastings Dam on the Mississippi River below Minneapolis, Minnesota, and the other was the work reported by Preul and Holler (1969) for two dams in the vicinity of Cincinnati on the Ohio River. Of particular note is the fact that both published papers were void of references to previous works on the subject, indicating an historical lack of interest in the subject. In addition to studying the two Ohio River Dams in situ, Preul and Holler evaluated a laboratory-scale model of a Tainter gate of one of the dams.

Both the Mississippi and Ohio River dam studies were interesting and informative, and management techniques were developed to increase aeration efficiencies in a manner compatible with navigation interests. However, these management techniques were basically site-specific and not directly transferable to other locations, although an attempt was made by Preul and Holler (1969) to develop a more universally applicable mathematical model using dimensional analysis. Aeration efficiencies were equated to the Froude number. A good relationship was found to occur within the range of conditions encountered during sampling of the two Ohio River dams. However, this relationship, along with the operational procedures proposed, is dependent upon an intimate knowledge of hydraulic parameters relative to energy dissipation and to the discharge characteristics of the gates and attendant receiving basins. Essentially, the application of this approach requires discharge rating information on flow releases through gates.

The Hastings Dam study was designed to evaluate the aeration efficiencies of navigational dam flow releases for three conditions: 1) Tainter gates unsubmerged in the downstream direction (tailwater area), 2) Tainter gates submerged by tailwater, and 3) replacement of Tainter gates with bulkheads (fixed walls) which create sharp - crested weir overflows. Unsubmerged Tainter gate discharges were found to be three times more efficient than submerged discharges relative to reaeration when the upstream DO was 0 mg/l. Under similar DO and head conditions, the bulkhead overflow-weirs exhibited aeration efficiencies 2.5 times as great as the submerged Tainter gate discharges.

Preul and Holler also explored the possibility of increasing the aeration by overflow rather than underflow. Instead of using bulkheads in the gate openings, the gates were fully closed, letting water spill over the top. This operational procedure was found to be the least efficient method; both submerged and unsubmerged tailwater releases exhibited higher efficiencies.

In addition to differential water levels around which simplistic statistical formulations have been developed, other factors such as water film thickness, water quality, structural design and/or configuration, and flow rate all influence aeration to some degree.

Gameson (1957) has shown experimentally that the largest percentage of DO changes occurs at the foot or on the aprons of spillways or flow release structures; consequently, the physical design of a structure is important. Water spilling onto a concrete apron or a rocky scarp and water forming a hydraulic jump at the base of a dam have reaeration potentials different from those of water falling into a deep, quiet pool. Preul and Holler (1969) showed that the size of the hydraulic jump created in Tainter gate stilling basins was the most important factor regulating reaeration at the two Ohio River dams studied. Their conclusion was that submerged hydraulic jumps are inefficient aerators. For optimum oxygen absorption, the supercritical flow under a gate must break the surface for gates that discharge into stilling basins.

Velz (1947) and many others have shown experimentally that aeration is a direct function of water temperature, i.e., warm water reaerates at a faster rate than cold water. This fact should be accounted for in the development of a dam aeration model.

Another criterion which should be directly accounted for in an aeration formulation is water quality. After conducting a literature review on the effects of contaminants on reaeration rates, Kothandaraman (1971) reported that most contaminants retard oxygen uptake although a few appear to enhance it. Aeration rates have been reduced up to 60 percent by adding large portions of sewage to tap water, whereas suspended sediments, depending on the type, either increase or decrease the aeration rate to a slight degree.

Preul and Holler (1969) recognized the existence of this phenomenon in their work, but they made no attempt to ascertain its effect on their DO observations which were made year-round. In the laboratory scale model study of a Tainter gate, they assume that alpha, the oxygen transfer ratio of polluted to unpolluted water, is unity. While this assumption may be correct, it is open to question because the chemical contaminants sodium sulfite and cobalt chloride had to be added to deoxygenate the experimental water. Susag et al. (1967) used alpha values ranging from 0.9 to 1.0.

Gameson (1957), in some original dam aeration work, proposed the use of an equation involving both theoretical and rational concepts which relate water fall height, water temperature, structure geometry, and water quality to a factor defined as the deficit ratio, r. The definition of r is:

$$r - (C_S-C_A)/(C_S-C_B) \qquad (1)$$

where Cg is the DO saturation concentration at a given temperature and C_A and C_B are, respectively, the DO concentrations above and below the dam or flow release structure.

Although equation 1 is simple, it serves to illustrate two principles important to dam aeration concepts. First, it demonstrates that the upstream DO concentration dictates the rate of oxygen exchange at any dam. Second, for a given set of water and temperature conditions, higher ratios reflect higher aeration efficiencies. Relative to the first concept, Gameson (1957) and Gameson et al. (1958) found in laboratory experiments that the ratio is independent of above-dam DO concentrations of Cg + 10 mg/l. However, data collected by Barrett et al. (1960) indicate that this independence may be reduced to Cg + 4 mg/l for full-sized field structures.

The original dam aeration formula (Gameson, 1957; Gameson et al., 1958) relating temperature, water quality, dam cross-sectional design, and differential water levels to the deficit ratio has been modified and refined and appears in the following form (Water Research Centre, 1973):

$$r = 1 + 0.38\,abh\,(1 - 0.11h)(l + 0.046T) \qquad (2)$$

where a is the water quality factor; b is the weir, spillway, or gate aeration coefficient; h is the static head loss at the dam (i.e., upstream and downstream water surface elevation difference) in meters; and T is the water temperature in °C.

This equation can be used to model the relative and absolute efficiencies of a spillway or flow release structure by determining specific values of "b". Every spillway or gate has a specific coefficient, but generalized categories can be developed in reference to a standard. The standard weir ($b = 1.0$) by definition is a sharp-crested weir with the flow free-falling into a receiving pool having a depth equal to or greater than 0.16 h. An idealized step weir (a series of sharp-crested weirs) has a b-value of 1.9 (Water Research Centre, 1973); however, actual field-measured values are usually lower.

Equation 2 was developed by British researchers from data collected at many relatively low head channel dams and weirs transecting small streams.. Good reproducibility can be achieved when h does not exceed 3 to 4 meters, the maximum height of the dams at which data collections were made during development of the equation. In addition, close examination of the equation reveals that the factor $(h)(1 - 0.11\,h)$ mathematically restrains the use of the equation to heights of 4.55 meters or less.

The water quality factor (a) has to be evaluated experimentally in the field or estimated from published criteria. Refinements of Gameson's (1957) early categorization of a-values are: grossly polluted water, $a = 0.65$; moderately polluted, $a = 1.0$; slightly polluted, $a = 1.6$; and clean water, $a = 1.8$. These values are based on a minimal amount of field and laboratory data and are refinements of those originally published by Gameson (1957). The direct applications of these values are subjective, and since considerable latitude exists numerically between values, significant errors can result.

This study and the management strategies which will be developed as a result of it are based upon the dam aeration theory as expressed by equations 1 and 2. Equation 2 has some minor deficiencies, but the SWS has collected extensive information relative to its use for a wide variety of weir and dam structures throughout Illinois, including all the dams along the Illinois Waterway (Butts and Evans, 1978, 1980; Butts and Adkins, 1987). The last reference is very important to this study because it involved an in-depth study of the aeration characteristics of the Starved Rock dam Tainter gate flow release structures during the summer of 1985. The methods developed made possible an accurate assessment of the effects hydropower development at Starved Rock would have on downstream DO resources (Butts et al., in press). The Starved Rock hydropower study, in turn, has been used as a "model" for evaluating the aeration characteristics of the Dresden Island dam.

METHODS AND PROCEDURES

This study consisted of two distinct phases. First, extensive field work had to be done to generate data for use in evaluating the aeration characteristics of the Dresden Island dam flow relase gates. The methods and procedures used were similar to those developed and applied by Butts and Adkins (1987) for gathering data for use in evaluating the aeration characteristics of the Starved Rock dam Tainter gate flow release controls. The second part of the study involved applying a BOD-DO model to the Illinois Waterway to assess the variability in DO levels under a wide range of flow and temperature conditions between river mile 291.04 (Lockport dam) and river mile 219.80 in the Peoria pool. After this information was derived, it was used to evaluate the potential effects the establishment of a hydropower plant at the Dresden Island dam at river mile 271.52 would have on downstream DO resources, particularly those in the Marseilles and Starved Rock pools (figures 1 and 2), under critical low-flow, high-temperature conditions. Above-dam DO concentrations (C_A in equation 1) were generated for each model run. These values dictated the development of various probability functions relative to the frequency of plant shutdowns needed to prevent unacceptable negative impacts on downstream DO levels.

Field Studies

The purpose of conducting field studies was to obtain data for deriving b-values for the Dresden Island dam for use in equation 2. The procedure for doing this entailed two steps. First a weir-box system, with a known b-value, was set up to determine the a-value in equation 2. River water was pumped from a point upstream of the dam into an elevated box equipped with a 30° V-notch weir having a weir aeration coefficient (b) of 1.038 (Butts and Adkins, 1987). The water quality factor (a) can be calculated by measuring water temperature, DO changes, and water fall height. The calculated a-value, in turn, can be used in equation 2 to accurately determine Tainter gate b-values. After the weir box data were generated for a particular run, instream DO and temperature data were collected above and below the dam.

Upon arrival at the dam, immediate contact was made with the lockmaster or one of his assistants to arrange for setting all the gates at a specific uniform opening height, to record pool elevations, and to obtain a bucket of well water for use in calibrating the DO meters. The weir box and appurtenances were then set up on a mooring pier above the upstream lock gates (figure 4).

A 4-liter sample of river water was obtained and poured back and forth between two 5-gallon buckets four or five times and then placed in an 8-liter plastic jug for further aeration (or deaeration in the case of supersaturated conditions). Jug aeration was accomplished by attaching a fine bubble aeration stone to a portable air compressor equipped with a cigarette lighter electrical attachment. At the end of the weir box run (1-1/2 to 2 hours) two samples were drawn off for DO and temperature measurements. If the DO differences exceeded 0.1 mg/l, a third sample was drawn and measured.

Four DO probes were calibrated in the field using the tap water from the well located at the lock control house. River water does not suffice for calibrating because algal activity can cause river water DOs to fluctuate widely over the 20 minutes needed for calibration. Well water is naturally low in DO, but once it becomes highly aerated, the DO concentration remains stable. Aeration was accomplished by pouring the water between two 5-gallon buckets at least 10 times.

The weir and receiving boxes were set up to attain a maximum water-fall height of 1.3 m, a maximum receiving depth of 0.5 m, and a maximum pumping rate of 1.77 1/sec. DO and temperature measurements were taken 30 minutes after the boxes filled. Water was pumped using a 1.5-inch portable gasoline-powered Honda WB15 centrifugal pump. A tarp was hung around the weir box setup when necessary to prevent wind from affecting the results.

The general layout of the dam is shown on figure 3; figures 4 and 5 show upstream and downstream photographic views of the dam. Flow is normally controlled and released through one or more of nine Tainter gates located along the north end of the locks. The head gates are used only during special situations such as during excessive flooding or during Tainter gate repairs. Gate manipulation at Dresden Island is flexible and similar to that at Starved Rock. The Dresden Island gates can be opened from 0.5 to 16.0 feet (Mades, 1981). The gates are 60 feet wide and 16 feet high and are set on a low ogee spillway having a crest elevation of 490.5 (Mades, 1981). A normal upstream pool elevation of 504.50 feet (figure 3) is maintained via gate manipulation. During this study, four runs at gate settings of 2, 3, and 4 feet and five runs at 1-foot were completed resulting in a total of 17 runs. If a total of 8 feet of opening were needed by the Corps of Engineers at the time of sampling, gate settings of either 8 gates open 1 foot, 4 gates open at 2 feet, or 2 gates open at 4 feet were used.

DO and temperature measurements were taken from a boat about 400 feet upstream of the dam at 2-foot intervals, beginning at the surface, on verticals on line with the center of each open gate. Downstream sampling was performed at middepth at one location because of difficulty in maneuvering the boat around in the shallow, turbulent, rocky area below the dam. Also, the well-mixed, shallow conditions precluded the need for sampling at more than one location. Sampling was usually performed at a location just upstream of the lower tip of Big Dresden Island.

Downstream DO and temperature readings were taken in concert with the upstream readings, with an additional downstream reading taken five to ten minutes after termination of the upstream measurements to allow for the matchup with the last upstream reading. The above-dam and below-dam boat crews coordinated their sampling efforts through the use of hand-held, marine-frequency radios.

The sampling depths were accurately and easily controlled by attaching the stirrer-probe to a heavily weighted fishing downrigger. Algae samples were collected both upstream and downstream. A 2-liter water quality sample was obtained downstream for analysis in the laboratory for suspended solids, chemical oxygen demand, and methylene blue active substances (MBAS) in terms of linear alkylate sulfonate (LAS). The latter chemical parameter is a measure of the surface active agent (detergent) content of the water. These parameters, along with algal enumeration, are easily measured variables considered (on an intuitive and subjective basis) to have a significant influence on reaeration.

Runs were made once or twice a week during July and August and were alternated between day and night periods during the warm summer months. Night runs are essential because significant diurnal fluctuations in the DO above the dam can occur due to algal activity. Algal blooms occasionally appear immediately above the Dresden Island dam thereby producing supersaturated DO concentrations. Theoretically, deaeration of supersaturated water is supposed to occur at the same rate as aeration of equally under-saturated water. However, some information has been published which indicates that this may not always be valid. On the basis of studies of several head loss structures in Ontario, Gowda (1984) concludes that, counter to theory, separate aeration coefficients should be developed for aeration and deaeration conditions. Although algal activity may not always raise the DO levels to supersaturated levels, the increase may be great enough that saturation is closely approached, which, as Butts and Evans (1984) point out, makes data interpretation difficult and often impossible. By performing night sampling, the chances of avoiding this predicament are enhanced.

All DO and temperature measurements were made using YSI model 58 digital dissolved oxygen meters equipped with YSI model 5795A submersible stirrers and YSI model 5739 dissolved oxygen field probes.

SWS BOD-DO Model

The basic model used by the SWS to evaluate BOD-DO relationships in a flowing stream is a simple one-dimensional model in which the basic components are computed separately and are then combined algebraically to obtain a net DO concentration. The basic formulation is:

$$DO_n = DO_a - DO_U + DO_r + DO_X \qquad (3)$$

where DO_n is the net DO at the end of a reach; DO_a is the initial DO at the beginning of a reach; DO_U is the DO used biologically; DO_r is the DO addition due to aeration and photosynthetic oxygen production (P); and DO_X is the DO addition due to dam aeration and/or tributary inputs.

Details of the methodologies that can be used to compute the various components of equation 3 have been outlined in detail in previous SWS publications and reports (Butts et al., 1970, 1974, 1975, 1981).

Biochemical Oxygen Demand (BOD)

DO_U may include dissolved oxygen usage resulting from carbonaceous BOD (CBOD), nitrogenous BOD (NBOD), sediment oxygen demand (SOD), and algal respiration (R). Algal activity can supplement stream DO through photosynthetic oxygen production (P), it can suppress stream DOs when R exceeds P, or it may have no effect when P equals R. For this study, P is assumed to equal R. Both CBOD and NBOD are programmed to follow first-order biochemical oxidation reactions as expressed by the general equation:

$$BOD_t = L_a \quad (1-e-K_1(t-t_0)) \qquad (4)$$

where BOD_t is the BOD exerted over a time period t in days; L_a is the ultimate BOD; K_1 is the rate coefficient to the base of the natural logarithm, e; and t_o is the lag time in days to the onset of usage. For this study, t_o was set equal to zero for carbonaceous demand. However, tests have shown that oxidation of the large ammonia-N load discharged from the Chicago area does not commence until about three days travel time below the Lockport dam (Butts et al., 1975; Butts et al., 1987).

Sediment Oxygen Demand (SOD)

The SOD portion of DO usage is computed by using the expression:

$$G' = \frac{3.28Gt}{H} \qquad (5)$$

where G' is the oxygen usage per reach in mg/l; G is the SOD rate in $g/m^2/day$; t is the detention time per reach in days; and H is the average reach water depth in feet. No allowance is made for reducing the SOD rates when the overlying water DO falls below 2 mg/l, as is done in some models. On the basis of several hundred in situ SOD measurements made by the Water Survey over the last few years, the conclusion has been reached that when the SOD is due primarily to bacterial respiration, the DO uptake rate remains relatively constant even at DO concentrations below 2 (Butts et al., 1974, 1981, 1982; Lee et al., 1975; Butts and Evans, 1978, 1979; Roseboom et al., 1979; Mathis and Butts, 1981). The benthic biomass in the whole length of the waterway, except in a few short reaches, is sparse, and most SOD is bacteria-related.

Natural Stream Aeration and Tributary Inputs

The aeration factor DO_r is computed by using the theoretical concepts advocated by Velz (1947, 1970). Reference should be made to the Velz publications or to the report by Butts et al. (1973) for a detailed discussion of this somewhat complicated and lengthy computational procedure.

Dissolved oxygen, ammonia, and BOD inputs from tributaries are adjusted on a mass balance basis.

Dissolved Oxygen Saturation

Dissolved oxygen saturation concentrations used in equation 1 and in the BOD-DO model, as schematically represented by equation 3, were computed by means of the ASCE formula (American Society of Civil Engineers, 1960):

$$DO_S - 14.652 - 0.41022T + 0.007991T^2 - 0.00007777T^3 \qquad (6)$$

where DOg = DO saturation at T°C. Equation 6 is referenced to mean sea level (MSL). Consequently, DO saturation computations for locations other than at MSL need to be corrected for changes in elevation. A correction factor of 0.982 needs to be applied when equation 6 is used to calculate DOg at Dresden Island. Also, equation 6 was developed experimentally using distilled water. Natural waters may be capable of sustaining saturation levels higher or lower than those predicted by using equation 6 since natural waters contain various kinds and amounts of impurities. The ratio of the ambient saturation concentration to equation 6 values corrected for elevation is referred to as beta (β).

Dam Aeration

Aeration at the dams was accounted for by incorporating equation 2 in the computer model. As part of this overall study, field data and information were gathered for use in determining the aeration characteristics of the Brandon Road and Dresden Island flow control gates. The dam aeration coefficients for the Marseilles dam were obtained from Butts and Evans (1980) and those for the Starved Rock dam from Butts and Adkins (1987).

Hydraulic and Hydrologic Model

Stream water quality modeling requires hydraulic and hydrologic information as part of its input. Hydraulic and hydrologic parameters for the waterway between Lockport and Grafton were computed with the use of a flow and time-of-travel simulation program based on volume displacement, i.e., time equals the volume of water divided by the flow rate. This concept, although basically very simple, can be used to generate reliable information for steady-state flows, the conditions under which most DO investigations are made. Critical to the accuracy and reliability of information generated are the quality and quantity of stream cross-sectional data available and used.

The Corps of Engineers is required to maintain minimal channel depths in navigable streams such as the Illinois Waterway. As a part of the process of maintaining a navigation channel in the Illinois Waterway, the Corps has established permanent bench marks along the river which define cross sections. Soundings of the river bed are routinely made, and these data are plotted on maps at scales of 1" = 200'. Using the most current maps, the SWS has generated a computer data base of more than 1650 cross sections spaced at an average interval of 930 feet between the Lockport dam and the Mississippi River at Grafton.

The output from the hydraulic-hydrologic program includes cross section number, mile point, flow at the end of a reach, average flow within a reach, average cross-sectional area and average depth within a reach, time of travel within a reach, accumulated time of travel, and reach lengths and volumes. Inputs required are staff gage elevations and main stem and tributary discharges. Tributary and main stem discharges were developed and used in this study in terms of flow duration, i.e., the percent of time a given flow is equaled or exceeded in value. The daily average flows over all the years of record for all existing main stem and tributary gaging stations were entered into a computer file and sorted according to increasing rank. Percentage values were then computed, and the flows for given percentages were plotted on extreme log probability paper according to the procedure outlined by Mitchell (1957). Thirty flow conditions were used, ranging from an extremely low flow value of 99.8 percent duration (only 0.2 percent of the historically observed daily average flows were less) to a moderately high flow value of 8 percent (92 percent of the daily average flows have been less) .

Duration curves were established for three main stem gaging stations and five tributaries. The main stem stations are Lockport (Corps MP 291.04), Marseilles (246.98), and Henry (196.12); the tributaries and their confluence MPs are the Des Plaines River (290.00), DuPage River (276.82), Kankakee River (272.86), Fox River (239.77), and Vermilion River (226.34).

The Corps of Engineers maintains staff gages at frequent intervals along the whole course of the waterway, which are read daily. The flows derived from the duration curves were matched with similar recorded flows for which staff gage readings (pool elevations or stage) were available. The matchup stages were used in the hydraulic-hydrologic model runs.

The Illinois Waterway mile points (MP) used by the SWS are slightly different from those appearing on official navigation charts and maps published by the Corps of Engineers. The SWS, in compiling their computer file of cross sections, also electronically traced the longitudinal distances along the navigation channel and found the distances to be somewhat different from the Corps' in some locations. Besides differences attributable to accuracy errors, which obviously can be a factor, the Corps distances deviate from those measured by the Water Survey for two major reasons: 1) the Corps retains original mileage designations even when channel shortening and straightening have occurred, and 2) the Corps measures mileage along direct navigation approaches to the locks, whereas the actual water flow is usually over a more circuitous route via spillway and riffle areas. The effect of the former practice is to exaggerate the length, whereas the effect of the latter is to reduce it. The two, however, appear to balance each other in the end as the net difference at Lockport (Corps MP 291.0) is only 0:04 of a mile.

Water Temperature Considerations

Water temperature is probably the single most important factor governing dissolved oxygen concentrations in surface waters. Two reasons account for this. One is that as water temperatures become lower, the capacity of the water to retain DO becomes greater. For instance, the DO saturation of pure water at 30°C is 7.44 mg/l, whereas at 0°C it is 14.65 mg/l. The second reason is that as water temperatures become lower, bacterial and biological activity is reduced, resulting in less oxygen usage in the biochemical processes, which stabilizes dissolved organic matter and organic-laden bottom sediments. For example, the bacterial oxidation rate of dissolved ammonia is three times as great at 22°C as at 10°C.

Availability of daily water temperatures covering a recent 3- or 4-year period, and access to them, were needed to make this study meaningful and to achieve its goals and objectives. Surprisingly and unfortunately, such information has not been routinely generated along the Illinois Waterway. For the study performed at Starved Rock for the City of Peru (Butts et al., in press), a sophisticated computer model was used to generate theoretical Illinois River water temperatures on the basis of recorded average daily air temperatures as supplied by the U.S. Weather

Service. This approach was not practical for the waterway in the vicinity of the Brandon Road and Dresden Island dams, since a poor correlation exists between air and river water temperatures in this area. This poor correlation is attributable to the unnatural temperature variability introduced upstream by discharges from very large wastewater treatment plants, to cooling water discharges from large coal-fired electric generating plants, and to the periodic diversion of Lake Michigan water for flushing purposes.

An extensive search was conducted to find a source of recorded information. A "last minute" source was found, but in the end, it proved to be inadequate for use in the modeling effort. However, it was informative. The Commonwealth Edison steam generating plant at Joliet provided data from June 11, 1984 - October 17, 1984; May 10, 1985 - November 3, 1985; and May 16, 1986 - August 31, 1986. The critical temperature for the middle reaches of the Illinois River, as determined by the Starved Rock study (Butts et al., in press), fell somewhere between 18°C and 20°C. Past data indicates that river water temperatures between 18°C and 20°C usually occur between June 1 and September 30 in the middle and lower reaches of the waterway during a typical year. As a consequence, the duration curves referred to in the previous subsection, "Hydraulic and Hydrologic Model," were developed for this period. The Commonwealth Edison data indicated, however, that water temperatures in the 18°C to 20°C range commonly occur between early May and early November. This discovery was made after the majority of the BOD-DO model simulations had been completed on the basis of duration curves developed for the 122-day period between June 1 and September 30.

The study had progressed to a point that did not permit redoing the duration curves, but a final effort did turn up a new source of continuously recorded daily water temperatures. During the 1970's, the U.S. Geological Survey (USGS) maintained a temperature recording station at the Dresden Island dam. Examination of these data (United States Geological Survey, 1976, 1977, 1978, 1979) revealed that the most realistic period for 18-20°C temperatures falls between April 1 and November 30 for a typical year. Consequently, temperature frequencies were developed for this 244-day period. Included in the frequency distribution were the years 1975, 1976, and 1977. The authors of this report feel that the flow duration curves adequately represent the expanded period of analysis. Future revisions can be made if the preliminary results warrant them.

Parameters and Parametric Coefficient Modeling

Computer modeling results are no better than the quality of the input data. In this case, high-quality water quality data were available from a study of the upper waterway conducted by the WQS of the SWS during June through September of 1982. This information was needed and helped make this study possible.

Basic regression curve fitting techniques were used to equate certain required parameters to flow so that estimates could be made as to what these values would be for the 30 specified flow-duration flows. In other words, reliable boundary conditions had to be established for a wide range of flow conditions. The parameters equated to flow are the initial carbonaceous and nitrogenous BOD input loads at Lockport on the main stem, the tributary carbonaceous and nitrogenous BOD load inputs, the initial starting DO at Lockport (assumed to be 0.5 mg/l on the basis of extensive historical data), the tributary DO concentrations at their mouths, the instream carbonaceous BOD usage factor (K_c), and the instream nitrogenous BOD usage factor (K_n).

The last two parameters vary from reach to reach along the main stem. Consequently, separate regression equations were developed to fit the needs of certain reaches. Flow and water quality data were not available for three small tributaries: the Mazon River, Bureau Creek, and the Illinois and Mississippi Canal. Inputs were estimated for these sources by using some water quality information gathered prior to 1982 and estimating flows on the basis of the Vermilion River duration curve.

Fair to good positive correlations were found to exist between BOD loads and flows by using the simple linear model:

$$Y = AQ + B \tag{7}$$

where Y is either L_{ac} (ultimate carbonaceous BOD) or L_{an} (ultimate nitrogenous BOD) in lbs/day or DO in mg/l

Q = Lockport (Q_L) or tributary flows: Des Plaines, Q_{DS}; DuPage, Q_D; Kankakee, Q_K; Fox, Q_F; or Vermilion, Q_V, in cfs

A and B = regression coefficients

The logarithms of the BOD-usage rates, K_c and K_n, were more highly correlated to the logs of the three main stem gaging station flows (table 5) than their untransformed values. Consequently, the usage rates fit the nonlinear multiple regression model:

$$\log K = A \log Q_L + B \log Q_M + C \log Q_H + D \tag{8}$$

where K = either K_c or K_n in l/days

Q_L, Q_M, Q_H = flows at Lockport, Marseilles, and Henry, respectively, In cfs

A,B,C,D = regression coefficients

Waste loads originating from point sources between the Lockport and Peoria dams were lifted from table 18 of SWS Contract Report 324 (Butts et al., 1983). The summer month values listed in the table were used in this analysis.

Modeling Procedure

DO usage was initiated at Lockport, i.e., the model runs had to start there because the bulk of the carbonaceous and nitrogenous wastes originate from the Chicago area. " Consequently, Chicago area wastes, particularly ammonia-N, dictate to a great degree what the downstream DO concentrations will be in the absence of photosynthetic oxygen production. The residual Chicago area wastes were routed downstream and reinforced with point and tributary sources. When flows were less than 8600 cfs at Marseilles, all the flow arriving at the Marseilles dam was routed through the hydroelectric power plant. Only flows in excess of 8600 cfs were routed through the dam flow release gates and allowed to reaerate. This, in effect, produced a continuous DO sag curve across the dam boundary at low flows and resulted in significantly lower DO levels immediately above the Starved Rock dam. This phenomenon is supported by historical data generated along this reach of the river as shown by figure 6 (Butts et al., 1975).

Dissolved oxygen sag curves were generated at 2°C intervals starting at 12°C and ending at 28°C. Curves were extrapolated for 10, 11, 29, and 30°C and for the odd degrees between 12°C and 28°C. Each combination of flow and temperature produced a minimum DO value downstream. These values were used as a basis for determining what minimum DO concentrations were needed immediately below the Dresden Island dam to maintain a minimum 5.0 mg/l at the low point on the sag curve.

Stepwise Repression Analyses

A mathematical statistical computational procedure, known as stepwise regression analysis, was used to evaluate interrelationships between certain variables or parameters measured or examined during this study. A certain parameter is designated as a dependent variable while others are specified as independent variables. A computer program correlates the dependent variable to each of the independent variables and ranks each independent variable in the order of importance relative to its predictive reliability. Also, regression coefficients are computed for use in developing or formulating prediction equations.

RESULTS

The results of this study are presented in three parts. First the information and data collected from the field calibration work are presented along with ensuing results. Next, all the information collected for preparing and formulating input to the BOD-DO model is presented in a reduced manner. This is followed by presentation of the results of 270 model runs resulting from a combination of 30 flow durations and 9 temperatures. These results form the basis for an extended, more detailed discussion.

Dam Calibration

Seventeen field calibration runs were made from July 8, 1986 through August 27, 1986. Eight runs were made during daylight, and 9 runs were made during the night. Table 1 summarizes the hydraulic conditions which occurred over the course of the field study period. A good range of conditions existed: flows ranged from a low of 3863 cfs, with only 3 feet of total gate open, to a high of 15,323 cfs, with 12 feet of total gate open. This makes the results meaningful over a wide range of expected warm weather flows. The data collected on the night of August 13 were incomplete. The weir box pumping equipment was stolen, and only instream information could be collected above and below the dam. Consequently, a water quality factor could not be calculated for use in determining the dam aeration coefficient.

Weir Box Data and Results

The results of the weir box field experiments conducted to determine the water quality factor "a" in equation 2 are presented in table 2. A somewhat poor range of conditions occurred during the sampling period. Above-the-weir (inlet) DOs, the most important criterion governing the results, were relatively high and ranged from 6.05 mg/l or 75.5 percent of book-value (clean-water) saturation to 8.50 mg/l or 111.4 percent of book-value saturation. Note that actual saturation values deviated somewhat from clean water published values. Most of the time the saturation values were within + 4 or 5 percent. The actual experiment saturation concentrations were used in the evaluation of the weir box data and in the evaluation of the river-run data collected for evaluating the dam aeration coefficient "b". The water quality factor varied significantly from run to run, ranging from a low of 1.08 to an anomalously high 2.69, with the average being 1.56. An a-value equal to 1.56 is indicative of slightly polluted water.

The wide variability in water quality is not surprising since Illinois River water immediately above the Dresden Island dam is a mix of very clean Kankakee River water and moderately polluted Des Plaines River water. The Des Plaines River at Brandon Road displayed an average a-value of 1.10 during the same period in which this study was conducted. The average Brandon Road and Dresden Island a-values were used for all BOD-DO model runs.

River-Run Data and Results

The data collected instream to "calibrate" the aeration efficiency of the Tainter gates are presented in table 3a. The above-dam DOs were often near saturation levels, which made data reduction and analyses difficult. Slight adjustments had to be made in the observed data in some cases to prevent producing exaggerated r-values as defined by equation 1. Butts and Adkins (1987) provide a detailed discussion of the appropriateness of making these adjustments.

Table 3b lists the b-values by gate height opening. The 1.0, 2.0, 3.0, and 4.0 values for Dresden Island are values directly calculated from the data presented in table 3a. The other (intermediate) values are extrapolated values. The Starved Rock values are shown for comparative purposes. The Dresden Island values show much less variability in aeration capability over a wide range of gate height openings.

Presented in table 4 is a gate management scheme which was developed to achieve maximum reaeration efficiencies for the 30 various flows used in the BOD-DO model. The weighted b-values listed in the last column were used in the modeling effort. Actually, any gate opening 2.0 feet or greater will provide essentially maximum aeration.

Model Support Data

Hydraulic and Hydrologic Information

The flow duration curves developed for the three main stem flow gaging stations and the five tributaries are presented in Appendix A. The 30 duration percentages and the corresponding flows for the three main stem gaging stations located within the study area are presented in Appendix B. The listing for the Kingston Mines gage is an empirical downstream extension of the Henry gage results and was incorporated into the system to carry the hydraulic and hydrologic computer model computations through to the Peoria lock and dam. Note that the mile listings are SWS designations. The tributary flows are presented in Appendix C. The Mazon, I & M Canal, and Bureau Creek flows were derived by taking percentages of Vermilion River duration curve values. In reality, these four relatively small streams exhibited little effect on main stem conditions over the entire range of flows. The pool elevations selected to match up with the flows presented in Appendix B are given in Appendix D. The times of travel to the various point source waste load inputs are given in Appendix E.

Note in Appendix E the extreme length of time required for water to travel between the Lockport dam (290.99) and the Peoria dam (158.06) during very low flow periods compared to that required during the higher flows. This has a significant influence on the waste assimilative capacity of the waterway. It essentially dictates the reach or reaches in the waterway where critical low DO values will occur. High flows often produce lower DOs in the lower pools than do very low flows. Several factors account for this. Most significant is the fact that high flows usually have a higher BOD concentration, and most of this unproportionally higher BOD load is flushed farther downstream where it is oxidized. At high flows, the detention times in the short upper pools are insufficient to allow bio-oxidation to commence to a great degree, and what little oxygen depletion is incurred is instantly made up via reaeration at the dam flow release control structures. Another factor which is not considered in the modeling results presented in this report is photosynthetic oxygen production. The DO resources along the waterway are supplemented very little by primary productivity during high flows. The higher the flow, the more turbid the water; also, the high velocities tend to "wash out" algal cells. During low to very low flows, photosynthetic oxygen production is a valuable supplement to Illinois Waterway DO resources, from the lake-area above the Starved Rock dam down to the Peoria lock and dam.

Water Quality Information

The regression coefficients associated with the simple regression (equation 7) and multiple regression (equation 8) formulations developed for generating realistic water quality parameters and waste load inputs for the 30 flow conditions (Appendices B and C) are presented in table 5a. Five sets of long-term 1982 BOD data were available for the main stem and tributaries for generating carbonaceous and nitrogenous waste loads in terms of pounds per day, and their attendant instream usage rate factors (K-values) in terms of l/days. Seventeen DO measurements were available for use in estimating daily average DO concentrations at each tributary mouth. Inputs from the Mazon River, I & M Canal, and Bureau Creek were arrived at by using the Vermilion River equations.

Overall, good predictive relationships were produced for the waste load inputs. Correlation coefficients between waste loads in lbs/day and flow in cfs ranged from a low of 0.60 for the Kankakee River to a high of 0.99 for the Vermilion and DuPage Rivers for carbonaceous BOD (CBOD), and from a low of 0.39 for the Kankakee to a high of 0.99 for the Des Plaines for nitrogenous BOD (NBOD). The respective CBOD-flow and NBOD-flow correlation coefficients at Lockport were 0.88 and 0.67. An inverse relationship occurred between DO and flow for all the tributaries as evidenced by the negative A-values listed under DO in table 5a. Correlation coefficients, relating DO in mg/l to flow in cfs, ranged from a low of -0.27 for the Kankakee to a high of -0.77 for the Des Plaines. The negative relationship results from the influence of photosynthetic oxygen production on low-flow DOs as briefly discussed in the preceding subsection. Flows in small tributaries usually decrease significantly during warm summer months, thereby creating slow moving water and pools. This promotes primary productivity and attendant increases in peak daily DO levels. Larger streams, such as the relatively nutrient-free Kankakee, are not nearly so vulnerable to photosynthetic oxygen production influences and fluctuations.

The ultimate L_{ac} and L_{an} values for the Sanitary and Ship Canal at Lockport and for the tributaries, computed by using the coefficients in table 5a in conjunction with equation 7 for conditions involving the 30 duration flows, are presented in Appendix F. The tributary input-DOs for the 30 flow conditions are presented in Appendix G.

The carbonaceous BOD usage rate (K_c) and the nitrogenous usage rate (K_n) are variable throughout the study reach. Table 5b lists the regression coefficients associated with equation 8 for various reaches down to the Peoria Lock and Dam (river mile 157.0). Multiple correlation coefficients ranged from 0.780 to 0.995 for CBOD rates and from 0.675 to 0.998 for NBOD rates.

The K_c and K_n values computed by using equation 8 in conjunction with the coefficient and intercept values listed in table 5b are presented in Appendix H for the 30 flow durations. For the extremely low flow conditions of 99.8 and 99 percent durations, equation 8 produced K_c rates slightly too high to be realistically used in the BOD-DO model. To rectify this, values computed for the 98 percent duration were extended for use at the two lower flows. Also, note from table 5b and Appendix H that equation 8 produced nonsensical K_c results for the data available for the reach between Corps miles 179.0 and 222.6. To rectify this, the averages of the values for the reaches upstream and downstream of this reach were substituted here.

Note that, at Lockport, as the flows increase the waste loads increase in terms of total pounds per day (Appendix F), but the rate of usage, as measured by the K-values contained in Appendix H, decreases with increasing flow rates. This situation has been documented by other waterway studies conducted by Butts et al. (1970), Butts et al. (1975), and Butts et al. (1981). This fact, along with the occurrence of decreasing time of travel with increasing flows, helps transfer a tremendous amount of Chicago area wastes into critical reaches of the Starved Rock and Peoria pools. Recognition of this phenomenon helps in understanding why low DOs have been routinely documented in the Peoria pool even during relatively high flows during warm summer months. Any water quality management scheme that is developed in conjunction with hydropower development along the waterway, especially at Starved Rock and to a lesser degree at Dresden Island, has to consider this fact.

A water temperature duration curve, developed by using the USGS data at Dresden Island for April 1 through November 30 for the years 1975, 1976, and 1977, is presented as figure 7. The frequency distribution is plotted on arithmetical normal probability paper.

BOD-DO Model Products

Examples of results of BOD-DO model runs for two flow conditions, 99.8 and 8 percent flow durations, at two temperatures, 12 and 28°C, are presented in Appendix I. The computer program used to derive these results, written in BASIC, is presented in Appendix J. The DO concentrations predicted to occur immediately downstream of the Dresden Island dam and the minimum DO concentrations predicted to occur downstream in either the Marseilles or Starved Rock pools for the 270 simulations run at various flows and temperatures are given in tables 6 and 7, respectively.

These results represent predicted ambient conditions, i.e., river-run situations without hydropower at the Dresden Island dam. Clearly evident is the fact that even without hydropower the minimum DO standard of 5.0 mg/l is violated in the downstream pools. The frequency of violations would not be nearly as great as that indicated in table 7 if the existing hydropower plant at Marseilles did not exist, or if it were required to provide reaeration in the water it draws from the river for power generation. Figure 6 clearly shows the effects the power plant has on DO resources in the Starved Rock pool under low flow conditions.

Stepwise Regression Analyses

Stepwise regression techniques were used to equate 13 independent variables, (1) number of open gates; (2) gate opening height; (3) total head loss; (4) head at the sill; (5) discharge; (6) water quality factor (a); (7) COD; (8) MBAS; (9) suspended solids (SS); (10) above-dam algae counts; (11) below-dam algae counts; (12) water temperature; and (13) above-dam DO, to either of three dependent variables, (1) the deficit ratio (r); (2) the dam aeration coefficient (b); or (3) the below-dam DO (P_0). The results of the analyses, arranged in the order of the significance of the inclusion of each independent variable into the regression equation, are presented in table 8. The parametric data used to generate these results are given in Appendix K. The 3 dependent variables represent optional ways of presenting dam aeration efficiencies.

Most of the observed variability in "r" can be explained by two parameters, the water quality factor (a) and water temperature. These two factors account for approximately 78.5 percent of the explained variation while the other 11 parameters account for only about 14.6 percent. Note that the regression equation coefficient for "a" in table 8 is positive. This indicates that dam aeration at Dresden Island should increase somewhat with enhancement of Illinois River water quality. Increases in water temperatures will also improve aeration since the regression coefficient associated with this variable is positive. These two positive coefficients represent stochastic verification of the theoretical relationships incorporated in equation 2, i.e., both temperature and the water quality factor are shown to be directly related to "r" in equation 2.

The dam or weir aeration coefficient (b) represents structural influences on aeration at a head loss structure in a stream or river. Consequently, low correlations should exist between "b" and general water quality parameters and the physical aspects of dam site which are not directly associated with structure geometry. The results of this study essentially support these theoretical inferences. Examination of the b-value data in table 8 shows that none of the 13 independent variables are highly correlated with "b". Each step addition contributes only a small fraction to the total explained variation. The one factor which potentially should show the highest positive correlation, but does not, is the gate opening height. It ranked fourth and is negative. This, however, is somewhat in agreement with the Dresden Island "b" calibration values listed in table 3b, in that, for gate openings greater than one foot, "b" remains relatively unchanged. This is in contrast to the results derived from a similar analysis of data collected at the Starved Rock dam. Butts and Adkins (1987) found that gate opening heights at Starved Rock affected the variability in "b" to a much greater extent than any other factor. This was due to the fact that "b" changed commensurately with changes in gate opening height (table 3b).

No highly correlated relationships were evident between P_0 and the various independent variables (table 8). Good predictions of downstream DOs could only be achieved by including at least 11 independent variables in the regression equation. This would not be a practical approach for estimating reaeration at a dam site.

Stepwise regression techniques were also used to equate 9 independent variables, (1) discharge; (2) water quality factor (a); (3) COD; (4) MBAS; (5) suspended solids (SS); (6) above-dam algae counts; (7) below-dam algae counts; (8) water temperature; and (9) above-dam DO, to the β-values given in Appendix K. The results of the analyses, arranged in the order of the significance of the independent variable inclusion, are presented in table 9. Note that only 4 of the 9 independent variables contribute significantly toward providing a good estimate of β since the standard error of estimate begins to increase after the COD-variable is included. This means that prediction equations which successively include the independent variables represented by steps 5 through 9 will produce successively poorer estimates of β. The regression coefficient associated with the water quality factor (a) is negative, which indicates that enhanced Illinois River water quality could possibly lower DO saturation levels, and this, in turn, could have a negative effect on reaeration efficiencies at the dam.

DISCUSSION

Information is presented and discussed in this section which will allow decisions to be made by proper authorities concerning the feasibility of developing hydropower facilities at Dresden Island without directly causing additional downstream DO standard violations. The minimum simulated DOs presented in table 7 are used as the nucleus for making this evaluation. Probability factors are developed.

The problem can be attacked simply by assigning a minimum acceptable 5.0 mg/l DO limit in the Marseilles-Starved Rock pool reach and initiating simulations below the Dresden Island dam to determine what minimum below-darn DOs (Cg) are needed for all cases (flow and temperature combinations) to sustain a minimum 5.0 mg/l DO level throughout the affected pools. The precise Cg required in each specific instance can be ascertained only by a trial-and-error process. Various values need to be assigned to Cg and used in the BOD-DO model to make simulations between the Dresden Island and Starved Rock dams. Adjustments need to be made in Cg for each successive trial until the critical 5.0 mg/l value is achieved.

To perform such an evaluation for the nine temperatures and 30 flow conditions presented in table 6 would be costly and would greatly delay the dissemination of the results. Consequently, a simple, alternative, indirect method was used to achieve the same results without significantly sacrificing the accuracy and integrity of the final product.

An assumption was made that the Cg-values needed to maintain a minimum downstream DO (C_m) of 5.0 mg/l would be equal to the differences between the appropriate Cg and C_m values listed in tables 6 and 7 (with some adjustment for natural stream aeration) added to 5.0 mg/l. The adjustments for natural stream aeration can be either negative or positive depending upon whether the adjusted Cg-values are greater or less than the corresponding values in table 6. If greater, the natural stream aeration addition is positive; if less, the addition is negative. For example, the simulation run for a flow duration of 45 percent at 12°C yielded a Cg = 10.01 mg/l and a C_m = 9.05 mg/l (tables 6 and 7), resulting in a new Cg, unadjusted for stream aeration, of 5.0 + 10.01 - 9.05 or 5.96 mg/l. This value is considerably less than the simulated Cg; consequently, the 5.96 has to be reduced somewhat to account for the potential increase in the natural stream reaeration rate at this lower concentration. Table 10 lists these adjusted values. For the above example, the final Cg rate is equal to 5.63 mg/l with an allowance of 0.33 mg/l for natural stream reaeration. Conversely, for 28°C at a flow duration of 75 percent, the Cg was readjusted upward from 9.12 mg/l to 9.20 mg/l because of potentially reduced reaeration since 9.12 mg/l (5.0 + 7.15 - 3.03) is greater than the original simulated Cg-value of 7.15 mg/l.

The adjusted Cg-values listed in table 10 have to be related to the frequency of occurrence of existing or observed above-dam DOs (C_A) to be meaningful. Table 11 shows a tabulation of above-dam DOs which are relatively current and reliable for the months of June through October. Included are the 17 values which were collected during this study. The last two columns of table 11 present the low-to-high rankings of all 49 values in the table and of the current 17 (1986) values, for use in developing frequency distribution plots on normal probability paper as shown in figure 8.

The feasibility or the practicality of building a hydropower plant essentially hinges on simple probability analysis. In general, if E_1, E_2, E_3, . . ., E_n are "n" independent events having respective probabilities of P1, P_2, P_3 . . ., P_n, then the probability of occurrence of E_1 and E_2 and E3 and . . . E_n is $(P_1)(P_2)(P_3)$ . . . (P_n). For this study, by letting P_1 equal the probability of occurrence of a given flow rate, P_2 equal the probability of occurrence of a given temperature, and P3 equal the probability of occurrence of a given DO concentration, the number of seasonal days during which power generation would be restricted would be $(P_1)(P_2)(P_3)(244)$.

The flows at Dresden Island for the 30 specified duration percents were computed by using the ISWS Illinois Waterway hydraulic-hydrologic model in conjunction with the flow duration information presented in Appendix A. The Dresden Island flows and corresponding duration percents are given in table 12. The temperature probabilities were obtained from the temperature duration curve (figure 7). The DO probabilities were obtained from the DO duration curve (figure 8).

The probability factors and the corresponding number of days during which the downstream DOs are expected to fall below 5.0 mg/l are summarized in table 12 for P3 referenced to the 49-value frequency distribution curve (figure 8) and in table 13 for P3 referenced to the 1986 17-value curve (figure 8) for the condition whereby all the upstream flow is used for power generation. This obviously exemplifies the worst possible scenario, but it provides considerable insight into the practical feasibility of the project. The end results indicate that slightly more than 100 24-hour periods of shutdown will be required irrespective of which frequency distribution curve is used. The frequency distribution curve developed with the 1986 data, however, indicates that DOs above the dam may be slowly increasing, since the 1986 curve produces only 106 days of shutdown compared to 114 when using the 49-value curve.

This total could possibly be reduced somewhat by artificially introducing dissolved oxygen into the water and/or by using only a fraction of the stream flow for power generation and routing the remainder over the dam spillway.

One alternative for artificial reaeration is turbine venting, which includes diffusing oxygen in the turbine flow, aspirating air into the downstream draft tube, and injecting air directly by using a compressor. Possibly a 2 to 4 mg/l DO increase could be achieved by using these procedures. The actual amount would depend on prevailing conditions such as saturation deficit, water temperature, and water quality. If a 2.0 mg/l addition could routinely be achieved by one of these methods, present downstream conditions probably could be maintained. The field study results given in table 3 show that the average DO pickup over the dam was 1.20 mg/l including a low of 0.03 mg/l and a high of 2.38 mg/l. Because of reduced turbine efficiency and direct operating power costs, turbine venting methods should be considered only if a minimum DO increase of 2.0 mg/l can be achieved routinely. Anything less would probably not be acceptable to regulatory agencies since downstream standard violations do occur even with the flow passing over the dam spillway.

Another alternative often considered for use in increasing the DO at low-head power installations on small streams is the upstream supplementation of DO by either instream aeration or direct injection of pure oxygen. Neither of these appears feasible immediately above the Dresden Island dam, largely because of the relatively wide channel and large flows associated with this reach of the river. The Metropolitan Sanitary District of Greater Chicago (MSD) has operated two instream aeration stations upstream and has experienced operation and maintenance problems with them. MSD is now preparing to construct "sidestream elevated pool aeration stations" (SEPA) as an alternative (Macaitis et al., 1984). However, again because of the relatively large flows which occur at Dresden Island, this concept does not appear feasible for use here. The SEPA concept involves diverting a portion of the instream flow to an off-channel location where it is lifted by energy-efficient, low-head screw pumps to a reservoir. From here, it is allowed to spill back into the main stream channel after being aerated over weirs. Experimental data derived from a prototype weir system experiment indicate that DO saturation levels of over 90 percent can be achieved by using a three-step weir system with a total water drop of 15 feet (Butts, 1988). In terms of absolutes, DO concentrations appear to be capable of being raised by as much as 5.4 mg/l during high-deficit conditions.

A possible alternative for supplementing DO below the Dresden Island dam is the use of mechanical instream surface aerators. Kim et al. (1987) report the efficient, effective use of such devices on a large scale on the Suyong River in Korea. A detailed engineering investigation would be needed to evaluate the feasibility of using these devices below Dresden Island during critical periods of the year.

The Dresden Island dam presently is a good aerator. This high efficiency results from the fact that the structural design of the flow control spillway incorporates a high dam reaeration coefficient with a high water fall (table 1). Modification of the existing structure to increase aeration appears impractical, and an attempt to do so would probably go unrewarded. However, manipulation of the gate openings can significantly improve the reaeration rate over the spillway. Gate openings in the range of 2.0 to 4.0 feet produce more aeration than do gates open only 0.5 to 1.5 feet.

The key element in developing, designing, and implementating a management scheme for minimizing downstream deterioration of DO resources in the event of power development at Dresden Island is continuous knowledge of the upstream DO concentrations. The upstream DO concentrations need to be monitored at frequent intervals and the results instantly provided to the plant manager for operational decisions. A "one-shot" data base needs to be developed relative to daily fluctuations in the downstream DO profiles within the Marseilles and Starved Rock pools. These data should be collected for at least one season from April 1 through November 30. A statistical relationship could then be developed relating the minimum DO in the Marseilles pool to that observed upstream of the dam. Other factors such as flow, water quality, and weather conditions would be incorporated into this relationship if they were found to have significant influence on

DO levels in this reach of the waterway. Once the relationship or model was developed, periodic DO monitoring in the Marseilles pool should be done to verify the model and to routinely update and make adjustments in it to insure that water quality degradation does not occur.

Although the purpose and scope of this study did not include an evaluation of the feasibility of operating a power plant at Dresden island by manipulating flows and supplementing or adding DO to the power flow, some limited computations were done with this in mind. Tables 14 and 15 list predicted minimum downstream DOs based on using 90 and 70 percent of Illinois River flows at 3585 cfs (95 percent duration) and 6140 cfs (50 percent duration) for power generation. Included in the analyses were 2.0 mg/l and 4.0 mg/l DO additions to the power flow. These examples are included in this report only to put the overall feasibility of operating a power plant at Dresden Island into better perspective. In reality, an infinite number of combinations exists. A limited extension of these computations could possibly be used to develop probability values analogous to those presented in tables 12 and 13, which were derived for total flow diversion for power generation.

Note from tables 14 and 15 that neither a 2.0 mg/l nor a 4.0 mg/l DO addition at very low flows (such as the 95 percent duration value used in this example) will prevent DO standard violations from occurring frequently even if as much as 30 percent of the flow is routed over the spillway, irrespective of upstream conditions. However, just a 2.0 mg/l addition at medium to high flows having DO levels of 4 to 5 mg/l will almost always prevent the occurrence of downstream DO violations even when 90 percent of the flow is used for power generation. In all cases, the flow routed over the spillway was done using a gate opening combination which produced the maximum reaeration rate as presented in table 4. Also, keep in mind that the probability of the above-dam DO being 4.0 mg/l or greater is very high (over 99.3 percent) as shown by figure 8.

The above computations could be done on the basis of maintaining a fixed flow over the spillway, such as 1000 cfs, and routing the rest through the proposed power plant instead of prescribing a percentage of flow for power use.

CONCLUSIONS

Conclusions reached relative to the questions addressed during this study are:

1. The Dresden Island dam flow release structure can be operated as an efficient aerator. Gate openings of 0.5 feet produce a weir reaeration coefficient of 1.05, essentially equal to the standard of 1.0 assigned to a simple, sharp-crested, free-falling weir or spillway. The reaeration coefficient can be increased to over 1.5 by using gate openings in the range of 2.0 to 4.0 feet. For this study, the average above-dam DO saturation percentage was 86.9, whereas the below-dam percentage was 102.5. These percentages are figured on the basis of published saturation values. Experiments conducted during this study indicate that Illinois River water at Dresden Island can be

aerated to hold dissolved oxygen concentrations which exceed the book values. The minimum above-dam DO observed during this study was 5.90 mg/l and the maximum value was 7.76 mg/l. The minimum and maximum downstream values were 7.40 mg/1 and 8.41 mg/1, respectively.

2. The minimum DO standard of 5.0 mg/1 is presently being violated in the Marseilles and Starved Rock pools immediately below the Dresden Island dam only during very warm. low-flow periods. The frequency of violations increases significantly during low flows because a hydropower plant is presently being operated at the Marseilles dam without supplementing dissolved oxygen in the power flow. BOD-DO computer model simulations run during this study indicate that a stream flow of approximately 4200 cfs at 20°C is required to maintain water quality standards in either the Marseilles or Starved Rock pools; however, at 28°C a flow of about 6500 cfs is required.

3. Establishment of hydropower facilities at Dresden Island will create additional stress on downstream DO resources without artificial supplementation of DO at the plant site. Computer model simulations indicate that substandard DOs may occur on at least 106 days a year if a hydropower plant is operated without supplementing DO. This figure is a conservative estimate, since the exact operating procedure of the hydropower plant at Marseilles was unknown, and the amount of flow assumed to be diverted for power generation at Marseilles was maximized at all times.

4. Establishment of a hydropower plant at Dresden Island would probably be feasible if means were provided for artificially supplementing DO in the river. This could possibly be done by turbine-venting the flow used for power generation; however, a more feasible alternative would be to use instream mechanical aerators below the spillway. Cursory computer model simulations indicate that at very low flows during warm weather the plant could not be operated even with supplemental DO input. However, at low to medium flows DO supplementation as low as 2.0 mg/1 would insure compliance with downstream DO standards under almost all but extremely warm weather conditions.

5. Improvements in Illinois River water quality above the Dresden Island dam probably would not have a significant impact on dam aeration efficiency. A statistically significant positive correlation was found to exist between dam aeration efficiency and general water quality. This indicates that the cleaner the water the greater the dam aeration rate. However, this positive factor is partially cancelled by the fact that a negative correlation was found to exist between the DO saturation limit and general water quality. This suggests that cleaner water lowers the DO saturation limit at Dresden Island. Lower DO saturation levels reduce the potential for dam aeration. Also, the ambient water quality at Dresden Island is good, leaving little room for improvement. Inflow from the Kankakee River immediately above the dam contributes greatly to this good water quality.

TABLES

Table 1. Hydraulic Conditions Existing during Dresden Island Dam Calibration Sampling Runs

1986	Gate operation		Pool elevations			
Date	No. open	Ft. open/gate	Above (MSL)	Below (MSL)	Difference (ft.)	Flow (cfs)
7/08 a.m.	4	2	504.77	487.28	17.49	11,419
7/15 a.m.	6	2	504.77	489.08	15.69	15,323
7/15 p.m.	5	2	504.66	488.09	16.57	12,720
7/22 a.m.	2	3	504.86	485.66	19.33	7,534
7/22 p.m.	2	3	504.82	485.76	19.06	7,523
7/28 a.m.	2	3	504.72	485.44	19.28	7,440
7/28 p.m.	2	3	504.64	485.26	19.30	7,477
8/12 a.m.	4	1	504.77	484.68	20.09	5,169
8/12 p.m.	4	1	504.81	484.50	20.31	5,179
8/13 a.m.	5	1	504.79	484.76	20.03	6,465
8/13 p.m.	3	1	504.67	484.13	20.54	3,863
8/18 a.m.	1	4	504.77	484.36	20.41	4,873
8/18 p.m.	1	4	504.65	484.19	20.46	4,856
8/19 a.m.	1	4	504.78	484.47	20.31	4,878
8/19 p.m.	1	4	504.70	484.44	21.26	4,864
8/20 p.m.	2	2	504.78	483.49	20.29	5,106
8/27 p.m.	4	1	504.76	484.65	20.11	5,166

Table 2. Water Quality Factor Results Obtained by Using the Calibrated Weir Box (b = 1.038) at Dresden Island

	Experimental DO saturation results			Dissolved oxygen				Temp (°C)			
				Above-weir overflow		Below-weir overflow					
1986 date	Temp (°C)	DO (mg/l)	% of book value	Conc, (mg/l)	Sat. (%)	Conc, (mg/l)	Sat. (%)	Above weir	Below weir	Deficit ratio r	Water quality factor a
7/08 a.m.	29.8	7.58	103.4	8.04	105.2	7.83	102.5	27.6	27.6	3.00	1.50
7/15 a.m.	31.6	7.41	104.6	8.18	102.2	7.53	93.6	25.2	24.9	3.18	1.81
7/15 p.m.	27.2	7.63	99.1	6.95	91.5	7.36	96.7	27.9	27.8	3.15	1.71
7/22 a.m.	31.4	7.43	104.5	6.44	87.7	7.16	97.7	29.7	29.8	2.47	1.08
7/22 p.m.	27.9	7.69	101.2	7.24	98.9	7.39	100.4	29.9	29.6	2.88	1.40
7/28 a.m.	30.2	7.70	105.8	6.98	94.7	7.43	100.2	29.5	29.2	2.69	1.23
7/28 p.m.	26.0	8.47	107.5	7.06	95.2	7.73	103.7	29.2	28.9	3.17	1.59
8/12 a.m.	26.5	7.71	98.8	6.19	79.8	7.24	93.5	26.8	26.9	3.59	2.05
8/12 p.m.	24.5	8.63	106.5	7.84	102.2	8.11	104.9	27.4	27.0	2.75	1.39
8/13 a.m.	24.7	8.12	100.6	6.28	80.6	7.36	94.2	26.6	26.4	3.10	1.68
8/13 p.m.	23.1	8.46	101.6	*	*	*	*	*	*	*	*
8/18 a.m.	26.2	7.75	98.8	7.10	93.6	7.40	97.4	28.0	27.9	3.73	2.16
8/18 p.m.	23.4	8.08	97.6	7.07	92.2	7.47	95.7	27.4	26.5	2.89	1.53
8/19 a.m.	26.8	7.63	98.3	7.06	92.7	7.46	97.1	27.8	27.3	4.35	2.69
8/19 p.m.	23.4	8.41	100.6	8.45	109.7	8.12	104.5	27.2	26.7	2.80	1.46
8/20 p.m.	23.4	8.00	96.6	8.50	111.4	7.90	102.8	27.7	27.3	2.38	1.11
8/27 p.m.	19.9	8.70	98.0	6.05	75.5	7.24	89.8	25.1	24.8	2.74	1.44
										Average -	1.56

Note: Runs were made at water drop heights of approximately 1.3 meters, receiving water depths of approximately 0.5 meters, and flow rates of approximately 1.77 liters per second; * indicates no weir box data was generated because the pumping equipment was stolen. The %-of-book values are computed by using equation 6 DO saturation values which have been corrected for altitude by multiplying by 0.982.

Table 3. Dresden Island Dam Calibration Results

a. Field Run Results

1986 Date	Depth averaged dissolved oxygen: Concentrations (mg/l), Above dam	Concentrations (mg/l), Below dam	% book saturation, Above dam	% book saturation, Below dam	Depth averaged temperatures (°C), Above dam	Depth averaged temperatures (°C), Below dam	Deficit ratio r	Dam aeration factor b
7/08 a.m.	6.14	7.77	81.4	102.6	28.3	28.1	6.64	1.89
7/15 a.m.	6.18	8.56	78.0	108.1	25.6	25.7	5.94	1.44
7/15 p.m.	6.08	7.72	80.3	101.6	28.1	27.9	5.52	1.34
7/22 a.m.	7.15	8.03	97.2	109.3	29.6	29.7	4.60	1.63
7/22 p.m.	7.59	8.15	102.9	110.7	29.5	29.6	5.31	1.51
7/28 a.m.	6.72	8.01	90.3	107.4	29.0	28.9	4.94	1.59
7/28 p.m.	7.74	8.29	104.6	112.0	29.3	29.3	6.00	1.55
8/12 a.m.	5.90	7.85	75.4	100.4	26.4	26.4	7.17	1.57
8/12 p.m.	7.34	8.41	95.1	110.5	27.1	27.8	4.80	1.40
8/13 a.m.	6.26	7.99	79.9	102.2	26.3	26.4	4.78	1.18
8/13 p.m.	6.29	7.99	81.2	103.4	26.9	27.0	5.22	*
8/18 a.m.	6.53	7.70	85.1	101.0	27.4	27.7	8.53	1.78
8/18 p.m.	7.02	7.40	91.0	97.0	27.1	27.7	4.90	1.30
8/19 a.m.	6.67	7.82	86.0	101.2	26.8	27.0	7.87	1.32
8/19 p.m.	7.76	8.08	101.4	105.3	27.5	27.4	5.67	1.64
8/20 p.m.	7.74	7.77	100.7	101.5	27.8	27.5	4.00	1.38
8/27 p.m.	5.94	7.92	74.4	98.8	25.3	25.1	4.14	1.18

b. b-values Grouped By Height of Gate Opening

Gate opening (ft.)	Average dam aeration coefficient, b: Dresden Island	Starved Rock
0.5	1.05	0.23
1.0	1.33	0.46
1.5	1.43	0.68
2.0	1.52	0.91
2.5	1.55	1.14
3.0	1.57	1.37
3.5	1.56	1.60
4.0	1.51	1.82

Note: * indicates no weir box data was generated because the pumping equipment was stolen. The %-of-book values are computed by using equation 6 DO saturation values which have been corrected for altitude by multiplying by 0.982. The b-values for 1.0', 2.0', 3.0', and 4.0' gate openings are measured; others are extrapolations.

Table 4. Gate Management Scheme Developed to Produce Maximum Aeration for Hydraulic Conditions Used at the Dresden Island Dam for 30 BOD-DO Model Runs

Flow duration		Number of pates open at							Gate-flow
(%)	(cfs)	0.5'	1.0'	1.5'	2.0'	2.5'	3.0'	3.5'	Weighted "b"
99.8	2546				1				1.52
99	2921	1			1				1.42
98	3156					1			1.55
97	3319					1			1.55
96	3459					1			1.55
95	3585					1			1.55
90	3986	1				1			1.46
85	4291		1			1			1.49
80	4585		1			1			1.49
75	4809		1			1			1.49
70	5067				2				1.52
65	5300				2				1.52
60	5581				1	1			1.54
55	5850				1	1			1.54
50	6140					2			1.55
45	6502					2			1.55
40	6925					1	1		1.56
35	7433						2		1.57
30	8072						1	1	1.56
25	9739							2	1.56
20	9677	1						2	1.52
17	10571			1				2	1.54
15	11306				1			2	1.55
14	11604	1			1			2	1.52
13	12032	1			1			2	1.52
12	12503		1		1			2	1.53
11	13058			1	1			2	1.53
10	13696				2			2	1.55
9	14496				1	1		2	1.55
8	15271					2		2	1.56
Aeration Coef b=		1.05	1.33	1.43	1.52	1.55	1.57	1.56	

Table 5. Regression Coefficients Associated with Equations 7 and 8

a. DO and L_a Values for Equation 7

	DO (mg/l)		Ultimate CBOD L_{ac} (lbs/day)		Ultimate NBOD L_{an} (lbs/day)	
Location	A (10-4}	B	A	B	A	B
Lockport	-	-	25.57	5818	86.97	74617
Des Plaines	-6.8	11.72	16.01	6272	34.82	1249
DuPage	-45.5	8.64	30.17	605	37.03	148
Kankakee	-1.5	8.80	10.22	25384	6.75	26198
Fox	-7.5	11.39	25.92	22228	43.03	2431
Vermilion	-6.7	9.31	18.65	567	12.59	1450

b. Main Stem Values for Equation 8

Inclusive	K_c (l/day)				K_n (l/day)			
MP	A	B	C	D	A	B	C	D
291.0								
	-2.899	0.665	0.128	6.331	-3.433	1.436	0	5.422
288.7								
	-6.503	1.988	0.158	13.754	-2.352	1.425	-0.156	2.357
278.0								
	-5.823	1.978	0.124	11.507	-3.538	1.360	0.013	6.163
270.6								
	-4.291	1.145	0.150	9.158	-6.054	2.527	0	10.657
231.0								
	-4.351	1.179	0.108	9.403	-6.054	2.527	0	10.657
222.6								
	*	*	*	*	-4.287	2.548	-0.155	4.934
179.0								
	-5.744	1.545	0.117	12.914	-1.631	1.289	-0.115	0.218
167.0								
	-5.744	1.545	0.117	12.914	-1.352	-0.631	0.060	0.983
157.0								

* The regression coefficients were nonsensical for this reach

Table 6. Summary of DO Concentrations for a Point Immediately below the Dresden Island Dam for BOD-DO Model Simulations Run at Various Temperatures and Flow Durations

Flow duration (%)	Below dam DO concentrations (mg/l), C_B, at Corps of Engineers river mile 271.46 for water temperatures (°C) of								
	12	14	16	18	20	22	24	26	28
99.8	9.27	8.79	8.34	7.91	7.71	7.47	7.12	7.12	6.37
99	9.31	8.85	8.42	7.99	7.59	7.40	7.17	6.84	6.85
98	9.58	9.14	8.72	8.33	7.96	7.60	7.26	6.92	6.88
97	9.62	9.18	8.76	8.37	8.00	7.65	7.31	6.98	6.90
96	9.62	9.18	8.77	8.38	8.01	7.66	7.32	7.00	6.91
95	9.67	9.23	8.82	8.43	8.06	7.71	7.37	7.04	6.73
90	9.78	9.35	8.96	8.58	8.23	7.89	7.58	7.27	6.98
85	9.85	9.43	9.03	8.66	8.31	7.98	7.66	7.36	7.07
80	9.88	9.46	9.07	8.70	8.35	8.02	7.70	7.40	7.11
75	9.90	9.49	9.10	8.73	8.38	8.05	7.74	7.44	7.15
70	9.94	9.53	9.14	8.77	8.42	8.09	7.78	7.49	7.20
65	9.95	9.54	9.15	8.78	8.44	8.11	7.80	7.51	7.22
60	9.98	9.57	9.18	8.82	8.47	8.15	7.84	7.54	7.26
55	9.99	9.58	9.20	8.84	8.49	8.17	7.86	7.57	7.28
50	10.01	9.60	9.21	8.85	8.51	8.19	7.88	7.59	7.31
45	10.01	9.61	9.23	8.87	8.53	8.21	7.90	7.61	7.33
40	10.03	9.62	9.24	8.89	8.55	8.23	7.92	7.63	7.35
35	10.04	9.64	9.26	8.90	8.57	8.25	7.95	7.66	7.38
30	10.05	9.65	9.27	8.92	8.59	8.27	7.97	7.68	7.40
25	10.05	9.66	9.28	8.93	8.60	8.28	7.98	7.70	7.42
20	10.05	9.65	9.28	8.93	8.60	8.29	7.99	7.71	7.43
17	10.05	9.66	9.29	8.94	8.62	8.31	8.01	7.73	7.46
15	10.05	9.66	9.30	8.95	8.62	8.32	8.02	7.74	7.47
14	10.04	9.65	9.29	8.94	8.62	8.31	8.02	7.74	7.47
13	10.04	9.65	9.29	8.94	8.62	8.31	8.02	7.74	7.47
12	10.04	9.65	9.29	8.95	8.62	8.32	8.03	7.75	7.48
11	10.04	9.65	9.29	8.95	8.63	8.32	8.03	7.75	7.49
10	10.04	9.65	9.29	8.95	8.63	8.33	8.04	7.76	7.49
9	10.03	9.65	9.29	8.95	8.63	8.32	8.04	7.76	7.50
8	10.02	9.64	9.28	8.95	8.63	8.33	8.04	7.76	7.50

Table 7. Summary of Minimum DO Concentrations in the Marseilles-Starved Rock Pools for BOD-DO Model Simulations Run at Various Temperatures and Flow Durations

Flow duration (%)	Minimum DO concentrations (mg/l), cm. ln the Marseilles-Starved Rock pools for water temperatures (°C) of								
	12	14	16	18	20	22	24	26	28
99.8	6.05	5.17	4.28	3.40	2.63	1.82	1.45	1.02	0.00
99	5.94	5.08	4.17	3.24	2.29	1.47	1.24	0.20	0.00
98	6.04	5.14	4.24	3.33	2.37	1.38	1.16	0.01	0.00
97	6.27	5.39	4.50	3.60	2.69	1.84	1.79	0.57	0.00
96	6.40	5.54	4.66	3.77	2.87	1.96	1.08	1.06	0.03
95	6.63	5.78	4.93	4.06	3.17	2.44	1.49	1.45	0.58
90	7.23	6.47	5.69	4.89	4.08	3.24	2.38	1.84	1.21
85	7.66	6.95	6.23	5.50	4.75	3.99	3.19	2.37	1.48
80	8.01	7.34	6.67	5.99	5.30	4.59	3.86	3.11	2.32
75	8.28	7.66	7.03	6.40	5.76	5.11	4.44	3.75	3.03
70	8.52	7.92	7.33	6.74	6.14	5.53	4.92	4.28	3.61
65	8.61	8.03	7.45	6.88	6.30	5.71	5.10	4.48	3.83
60	8.88	8.34	7.81	7.28	6.76	6.23	5.69	5.14	4.58
55	8.97	8.44	7.92	7.41	6.90	6.39	5.87	5.34	4.79
50	9.00	8.48	7.97	7.46	6.96	6.45	5.93	5.40	4.86
45	9.05	8.55	8.04	7.55	7.05	6.55	6.05	5.53	4.99
40	9.12	8.63	8.14	7.66	7.17	6.69	6.20	5.69	5.17
35	9.20	8.72	8.25	7.78	7.32	6.85	6.37	5.89	5.38
30	9.27	8.81	8.35	7.91	7.46	7.01	6.56	6.09	5.61
25	9.50	9.07	8.64	8.23	7.82	7.41	7.01	6.59	6.17
20	9.63	9.19	8.77	8.37	7.98	7.61	7.25	6.87	6.47
17	9.66	9.23	8.82	8.43	8.05	7.69	7.34	6.99	6.65
15	9.68	9.26	8.85	8.47	8.10	7.74	7.39	7.06	6.72
14	9.68	9.26	8.86	8.47	8.11	7.75	7.41	7.07	6.74
13	9.70	9.28	8.88	8.50	8.14	7.79	7.45	7.11	6.79
12	9.71	9.30	8.90	8.53	8.17	7.82	7.48	7.15	6.83
11	9.73	9.32	8.93	8.55	8.19	7.85	7.52	7.19	6.87
10	9.74	9.33	8.95	8.58	8.22	7.88	7.56	7.24	6.92
9	9.75	9.35	8.97	8.60	8.25	7.92	7.60	7.28	6.97
8	9.76	9.37	8.99	8.63	8.28	7.95	7.63	7.32	7.01

Table 8. Summary of Results of Stewpise Regression Analyses Relating the Deficit Ratio (r), the British Dam Aeration Coefficient (b), and the Below-darn DO Percent Saturation (P_0) to Appendix K Data

Dependent variable	Step No.	Independent variable added	Regression equation coefficient	Standard error of estimate	Multiple correlation coefficient, R	Explained variation R^2
r	1	Water quality factor, a	3.4758	0.721	0.834	0.696
	2	Water temperature (°C)	0.3017	0.628	0.886	0.785
	3	Suspended solids (mg/l)	0.0208	0.599	0.905	0.819
	4	Below-dam algae (No./ml)	0.0009	0.568	0.921	0.848
	5	Gate opening height (ft.)	-1.7022	0.553	0.932	0.869
	6	Above-dam DO (% sat.)	-0.0460	0.520	0.946	0.895
	7	Number of open gates	-1.8493	0.542	0.947	0.897
	8	Discharge (cfs)	0.0018	0.555	0.951	0.904
	9	Above-dam algae (No./ml)	-0.0003	0.577	0.953	0.908
	10	COD (mg/l)	-0.1954	0.612	0.955	0.912
	11	Head at sill (ft.)	1.6209	0.644	0.959	0.920
	12	Total head (ft.)	1.2839	0.682	0.963	0.927
	13	MBAS (mg/l)	-8.0118	0.770	0.965	0.931
b	1	Water temperature (°C)	0.0877	0.178	0.495	0.245
	2	Suspended solids (mg/l)	0.0068	0.164	0.630	0.397
	3	Below-dam algae (No./ml)	0.0002	0.151	0.727	0.529
	4	Gate opening height (ft.)	-0.5084	0.137	0.801	0.641
	5	Above-dam DO (% sat.)	-0.0137	0.131	0.838	0.702
	6	Water quality factor, a	0.2177	0.128	0.861	0.741
	7	Total head (ft.)	0.4580	0.134	0.863	0.744
	8	Number of open gates	-0.5476	0.137	0.873	0.762
	9	Discharge (cfs)	0.0006	0.140	0.885	0.783
	10	COD (mg/l)	-0.0559	0.145	0.894	0.799
	11	Head at sill (ft.)	0.4379	0.147	0.911	0.829
	12	MBAS (mg/l)	-3.0948	0.150	0.926	0.858
	13	Above-dam algae (No./ml)	-0.0001	0.172	0.926	0.858
P_o	1	Above-dam DO (% sat.)	0.4755	3.810	0.585	0.342
	2	Number of open gates	7.4487	3.092	0.772	0.596
	3	Suspended solids (mg/l)	0.0677	2.860	0.824	0.679
	4	Water temperature (°C)	0.8260	2.561	0.873	0.762
	5	MBAS	119.7060	2.460	0.894	0.799
	6	Total head (ft.)	-3.7410	2.442	0.905	0.820
	7	Head at sill (ft.)	-14.2986	2.285	0.926	0.857
	8	Discharge (cfs)	-0.0098	2.168	0.942	0.886
	9	COD (mg/l)	1.1131	2.126	0.951	0.904
	10	Gate opening height (ft.)	6.5487	2.030	0.962	0.925
	11	Above-dam algae (No./ml)	-0.0024	1.993	0.970	0.940
	12	Water quality factor, a	-2.4618	2.127	0.972	0.945
	13	Below-dam algae (No./ml)	0.0005	2.443	0.973	0.946

Note: The "Regression equation coefficient" value presented in the table for each parameter is the coefficient value for that parameter at the point when the parameter first enters into the stepwise regression equation. Each new successive parameter entry will result in slight modifications of the absolute values presented here, but the sign will not change.

Table 9. Summary of Stepwise Regression Analyses Relating the ß-factor to Selected Independent Variable Data Listed in Appendix K

Step No.	Independent variable added	Regression equation coefficient	Standard error of estimate	Multiple correlation coefficient. R	Explained variation R^2
1	Water temperature (°C)	0.01868	0.031	0.450	0.203
2	Suspended solids (mg/l)	0.00194	0.024	0.762	0.581
3	Above-dam algae (No./ml)	0.00003	0.024	0.776	0.603
4	Water quality factor, a	-0.01536	0.024	0.789	0.623
5	COD (mg/l)	-0.00136	0.025	0.796	0.634
6	Discharge (cfs)	-0.00001	0.025	0.801	0.641
7	Below-dam algae	-0.00001	0.027	0.803	0.644
8	MBAS (mg/l)	-0.05867	0.029	0.803	0.645
9	Above-dam DO (% sat.)	0.00003	0.031	0.803	0.645

Note: The "Regression equation coefficient" value presented in the table for each parameter is the coefficient value for that parameter at the point when the parameter first enters into the stepwise regression equation. Each new successive parameter entry will result in slight modifications of the absolute values presented here, but the sign will not change.

Table 10. Minimum DOs Required below Dresden Island Dam to Maintain a Minimum 5.0 mg/l Concentration in the Marseilles-Starved Rock Pools

(Concluded on next page)

Flow duration (%)	Minimum DO concentrations (mg/l) required immediately below the Dresden Island dam to maintain a 5.0 mg/l minimum standard downstream for water temperatures (°C) of										
	10	11	12	13	14	15	16	17	18	19	20
99.8	7.80	8.00	8.20	8.41	8.62	8.85	9.07	9.32	9.56	9.88	10.19
99	7.93	8.14	8.35	8.56	8.77	9.02	9.26	9.54	9.81	10.13	10.45
98	8.04	8.28	8.52	8.76	9.00	9.25	9.49	9.78	10.06	10.40	10.73
97	7.85	8.09	8.32	8.56	8.79	9.03	9.27	9.57	9.87	10.15	10.42
96	7.73	7.96	8.18	8.41	8.63	8.87	9.11	9.38	9.64	9.94	10.23
95	7.54	7.77	7.99	8.22	8.44	8.67	8.87	9.14	9.39	9.68	9.96
90	7.06	7.26	7.45	7.65	7.84	8.05	8.26	8.48	8.69	8.93	9.17
85	6.70	6.88	7.05	7.23	7.40	7.59	7.77	8.07	8.16	8.36	8.56
80	6.37	6.53	6.69	6.85	7.01	7.18	7.34	7.52	7.69	7.87	8.05
75	6.11	6.26	6.40	6.55	6.69	6.84	6.99	7.14	7.29	7.45	7.61
70	5.90	6.04	6.17	6.31	6.44	6.57	6.70	6.84	6.97	7.11	7.25
65	5.83	5.96	6.08	6.21	6.33	6.46	6.58	6.71	6.83	6.97	7.11
60	5.59	5.70	5.80	5.91	6.01	6.11	6.21	6.33	6.44	6.55	6.65
55	5.50	5.60	5.70	5.80	5.90	6.01	6.11	6.21	6.31	6.42	6.52
50	5.50	5.60	5.69	5.79	5.88	5.97	6.06	6.17	6.27	6.37	6.47
45	5.45	5.54	5.63	5.72	5.81	5.91	6.01	6.10	6.19	6.30	6.40
40	5.41	5.49	5.57	5.65	5.73	5.82	5.90	6.00	6.09	6.19	6.29
35	5.34	5.42	5.49	5.57	5.64	5.72	5.80	5.89	5.97	6.06	6.14
30	5.27	5.34	5.41	5.48	5.55	5.63	5.70	5.77	5.84	5.93	6.01
25	5.04	5.10	5.15	5.21	5.26	5.32	5.38	5.44	5.49	5.56	5.62
20	4.87	4.93	4.99	5.05	5.11	5.17	5.23	5.28	5.33	5.39	5.44
17	4.85	4.91	4.96	5.02	5.07	5.13	5.18	5.23	5.27	5.33	5.38
15	4.82	4.88	4.93	4.99	5.04	5.10	5.15	5.20	5.24	5.29	5.33
14	4.81	4.87	4.92	4.98	5.03	5.08	5.13	5.18	5.23	5.28	5.32
13	4.80	4.85	4.90	4.95	5.00	5.06	5.11	5.16	5.20	5.24	5.28
12	4.80	4.85	4.89	4.94	4.98	5.04	5.09	5.13	5.17	5.21	5.25
11	4.76	4.81	4.86	4.91	4.96	5.01	5.05	5.10	5.15	5.20	5.24
10	4.75	4.80	4.85	4.90	4.95	4.99	5.03	5.07	5.11	5.16	5.20
9	4.74	4.79	4.83	4.88	4.92	4.96	5.00	5.05	5.09	5.13	5.17
8	4.73	4.77	4.81	4.85	4.89	4.93	4.97	5.02	5.06	5.10	5.13

Table 10. (Concluded)

Flow duration (%)	Minimum DO concentrations (mg/l) required immediately below the Dresden Island dam to maintain a 5.0 mg/l minimum standard downstream for water temperatures (°C) of									
	21	22	23	24	25	26	27	28	29	30
99.8	10.52	10.85	10.89	10.92	11.17	11.42	11.65	11.87	12.10	12.32
99	10.82	11.18	11.20	11.21	11.66	12.10	12.23	12.35	12.48	12.60
98	11.11	11.48	11.44	11.39	11.90	12.41	12.40	12.38	12.37	12.35
97	10.72	11.01	10.87	10.73	11.27	11.80	12.10	12.40	12.70	13.00
96	10.56	10.88	11.22	11.55	11.40	11.25	11.81	12.37	12.43	13.49
95	10.18	10.40	10.77	11.13	10.99	10.84	11.19	11.54	11.89	12.24
90	9.44	9.71	10.03	10.34	10.49	10.63	10.85	11.06	11.28	11.49
85	8.79	9.01	9.28	9.54	9.84	10.13	10.49	10.84	11.20	11.55
80	8.24	8.43	8.65	8.87	9.12	9.36	9.65	9.93	10.22	10.50
75	7.78	7.94	8.13	8.31	8.52	8.72	8.96	9.20	9.44	9.68
70	7.40	7.55	7.71	7.86	8.04	8.22	8.43	8.63	8.84	9.04
65	7.25	7.39	7.55	7.70	7.87	8.04	8.23	8.42	8.61	8.80
60	6.77	6.89	7.02	7.14	7.27	7.40	7.54	7.68	7.82	7.96
55	6.63	6.74	6.86	6.97	7.10	7.23	7.36	7.49	7.62	7.75
50	6.59	6.70	6.82	6.93	7.06	7.19	7.32	7.45	7.58	7.71
45	6.51	6.61	6.72	6.83	6.95	7.07	7.21	7.34	7.48	7.61
40	6.39	6.48	6.59	6.69	6.81	6.93	7.06	7.18	7.31	7.43
35	6.24	6.33	6.44	6.54	6.65	6.75	6.88	7.00	7.13	7.25
30	6.10	6.18	6.27	6.36	6.47	6.57	6.68	6.78	6.89	6.99
25	5.69	5.75	5.82	5.89	5.98	6.06	6.14	6.22	6.30	6.38
20	5.49	5.54	5.59	5.64	5.71	5.77	5.85	5.92	6.00	6.07
17	5.43	5.48	5.52	5.56	5.61	5.66	5.71	5.76	5.81	5.86
15	5.38	5.43	5.48	5.52	5.56	5.60	5.65	5.69	5.74	5.78
14	5.37	5.41	5.45	5.49	5.54	5.58	5.63	5.67	5.72	5.76
13	5.32	5.36	5.41	5.45	5.50	5.54	5.58	5.62	5.66	5.70
12	5.30	5.34	5.39	5.43	5.47	5.51	5.55	5.58	5.62	5.65
11	5.28	5.31	5.35	5.39	5.43	5.46	5.51	5.55	5.60	5.64
10	5.24	5.28	5.32	5.35	5.39	5.42	5.46	5.50	5.54	5.58
9	5.20	5.23	5.27	5.30	5.34	5.38	5.42	5.45	5.49	5.52
8	5.17	5.21	5.24	5.27	5.30	5.33	5.37	5.41	5.45	5.49

Table 11. Dissolved Oxygen Data Recorded Immediately above the Dresden Island Dam Which Were Used to Generate the Probability Function, P2

				Sorted DO-values (mg/l) from high to low		
Date	Reference	Temp (°C)	DO mg/l	Rank	All values	1986 values
8/25/78	Butts and Evans (1980)	26.4	5.65	1	4.53	5.90
9/24/78	"	26.3	4.53	2	5.60	5.94
8/08/78	"	30.8	5.67	3	5.65	6.08
8/14/78	"	25.1	6.00	4	5.67	6.14
9/05/78	"	28.2	6.13	5	5.90	6.18
7/28/81	Crawford, Murphy, & Tilly (1982)	22.0	6.00	6	5.90	6.26
7/11/81	"	25.0	6.50	7	5.94	6.29
7/25/81	"	27.8	6.35	8	6.00	6.53
8/08/81	"	24.0	7.10	9	6.00	6.67
8/22/81	"	20.0	7.85	10	6.00	6.72
10/06/81	"	17.5	8.20	11	6.05	7.02
10/19/81	"	16.5	6.60	12	6.08	7.15
6/01/82	"	21.0	6.75	13	6.10	7.34
6/15/82	"	26.8	7.20	14	6.10	7.59
6/30/82	"	25.3	6.95	15	6.13	7.74
7/13/82	"	27.0	6.05	16	6.14	7.74
6/03/82	Butts et al. (1987)	19.5	7.20	17	6.18	7.76
6/08/82	"	21.3	7.30	18	6.26	
6/15/82	"	26.2	6.50	19	6.29	
6/22/82	"	23.6	10.30	20	6.30	
6/30/82	"	23.0	6.00	21	6.35	
7/08/82	"	27.5	6.10	22	6.35	
7/14/82	"	27.5	6.40	23	6.40	
7/20/82	"	29.5	5.90	24	6.50	
7/27/82	"	29.0	5.60	25	6.50	
8/03/82	"	29.5	6.30	26	6.50	
8/10/82	"	25.5	6.50	27	6.53	
8/17/82	"	27.9	6.35	28	6.60	
8/30/82	"	22.5	6.70	29	6.67	
9/10/82	"	26.5	6.10	30	6.70	
9/24/82	"	21.5	6.70	31	6.70	
10/01/82	"	22.0	7.60	32	6.72	
7/08/86	This study	28.3	6.14	33	6.75	
7/15/86	"	25.6	6.18	34	6.95	
7/16/86	"	28.1	6.08	35	7.02	
7/22/86	"	29.6	7.15	36	7.10	
7/23/86	"	29.5	7.59	37	7.15	
7/28/86	"	29.0	6.72	38	7.20	
7/29/86	"	29.3	7.74	39	7.20	
8/12/86	"	26.4	5.90	40	7.30	
8/13/86	"	27.1	7.34	41	7.34	
8/13/86	"	26.3	6.26	42	7.59	
8/14/86	"	26.9	6.29	43	7.60	
8/18/86	"	27.4	6.53	44	7.74	
8/19/86	"	27.1	7.02	45	7.74	
8/19/86	"	26.8	6.67	46	7.76	
8/20/86	"	27.5	7.76	47	7.85	
8/20/86	"	27.8	7.74	48	8.20	
8/27/86	"	25.3	5.94	49	10.30	

Table 12. Probability of the Occurrence of Specified Flows, Temperatures, and 1978-1986 Above-Dam DOs (C_A) and their Combined Effects on Days of Operation

(Concluded on next page)

Dresden Island flow			Probability of occurrence of above-dam DOs (P3) which are equal to or less than those required to maintain a 5.0 mg/l minimum standard (table 10) for temperatures (°C) of												
Rate (cfs)	Duration (%)	Probability P1	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22
		P2 =	.0116	.0280	.0225	.0171	.0239	.0239	.0437	.0506	.0478	.0772	.0328	.0273	.0396
2546	99.8	.002	.930	.955	.967	.977	.985	.992	.996	.999	1.000	1.000	1.000	1.000	1.000
2921	99	.01	.954	.963	.982	.983	.990	.995	.998	1.000	1.000	1.000	1.000	1.000	1.000
3156	98	.01	.949	.970	.973	.989	.995	.998	.999	1.000	1.000	1.000	1.000	1.000	1.000
3319	97	.01	.940	.960	.966	.983	.991	.995	.998	1.000	1.000	1.000	1.000	1.000	1.000
3459	96	.01	.915	.953	.955	.977	.985	.992	.996	.999	1.000	1.000	1.000	1.000	1.000
3585	95	.05	.865	.924	.845	.968	.968	.986	.993	.997	.999	1.000	1.000	1.000	1.000
3986	90	.05	.720	.788	.720	.890	.938	.960	.970	.980	.987	.994	.997	.999	1.000
4291	85	.05	.620	.675	.612	.780	.830	.875	.922	.960	.965	.975	.982	.990	.995
4585	80	.05	.420	.510	.440	.672	.708	.758	.814	.858	.900	.940	.960	.969	.978
4809	75	.05	.280	.352	.372	.520	.614	.670	.692	.742	.800	.845	.880	.935	.950
5067	70	.05	.100	.220	.252	.400	.460	.530	.622	.670	.695	.740	.788	.860	.865
5300	65	.05	.075	.145	.070	.348	.410	.465	.554	.640	.688	.690	.740	.784	.825
5581	60	.05	.049	.058	.053	.120	.200	.265	.342	.404	.468	.520	.580	.660	.675
5850	55	.05	.042	.050	.051	.070	.100	.200	.270	.344	.400	.454	.500	.564	.648
6140	50	.05	.042	.050	.050	.066	.085	.160	.222	.322	.360	.420	.475	.538	.620
6502	45	.05	.040	.045	.048	.060	.070	.100	.195	.260	.340	.390	.440	.500	.550
6925	40	.05	.039	.043	.043	.055	.062	.070	.100	.190	.250	.340	.370	.434	.480
7433	35	.05	.035	.039	.038	.047	.054	.060	.070	.088	.160	.230	.300	.348	.400
8072	30	.05	.032	.034	.026	.040	.045	.053	.058	.064	.075	.130	.200	.265	.330
8739	25	.05	.024	.025	.023	.028	.032	.034	.036	.039	.042	.047	.052	.057	.063
9677	20	.05	.019	.022	.022	.024	.026	.028	.030	.032	.033	.036	.040	.042	.045
10571	17	.03	.018	.021	.021	.023	.025	.026	.028	.029	.031	.034	.037	.039	.040
11306	15	.02	.017	.019	.021	.023	.024	.025	.027	.028	.029	.032	.035	.036	.038
11604	14	.01	.017	.019	.020	.023	.024	.025	.026	.027	.029	.032	.034	.036	.038
12032	13	.01	.017	.019	.020	.022	.023	.024	.025	.026	.028	.030	.033	.034	.035
12503	12	.01	.017	.019	.020	.022	.023	.024	.025	.026	.027	.029	.031	.032	.034
13058	11	.01	.017	.018	.020	.021	.022	.023	.024	.025	.027	.028	.030	.031	.032
13696	10	.01	.016	.018	.019	.020	.021	.023	.023	.024	.026	.027	.030	.029	.031
14496	9	.01	.016	.017	.018	.019	.020	.021	.022	.023	.025	.026	.028	.029	.030
15271	8	.01	.016	.017	.018	.019	.020	.021	.022	.023	.024	.025	.026	.027	.029

Table 12. (Concluded)

Dresden Island flow			Probability of occurrence of above-dam DOs (P3) which are equal to or less than those required to maintain a 5,0 mg/l minimum standard (table 10) for temperatures (°C) of								Combined	No. of
Rate	Duration	Probability	22-23	23-24	24-25	25-26	26-27	27-28	28-29	>29	probability	shutdown
(cfs)	(%)	P1	P2=.0458	.0553	.0455	.0485	.0669	.0485	.0711	.0908	(P1)(P2)(P3)	days*
2546	99.8	.002	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.001828	0.446
2921	99	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009153	2.233
3156	98	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009156	2.234
3319	97	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009147	2.232
3459	96	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009135	2.229
3585	95	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009087	2.217
3986	90	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.044712	10.910
4291	85	.05	.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.043738	10.672
4585	80	.05	.986	.992	.996	.999	1.000	1.000	1.000	1.000	.041876	10.218
4809	75	.05	.963	.972	.982	.998	.994	.996	.999	1.000	.039551	9.650
5067	70	.05	.918	.940	.958	.968	.979	.985	.992	.996	.036846	8.990
5300	65	.05	.864	.900	.945	.958	.968	.978	.985	.994	.035268	8.605
5581	60	.05	.710	.745	.795	.830	.868	.895	.933	.953	.029113	7.103
5850	55	.05	.672	.690	.735	.780	.825	.851	.885	.920	.026753	6.528
6140	50	.05	.662	.685	.715	.740	.805	.840	.775	.905	.025507	6.224
6502	45	.05	.642	.670	.685	.725	.772	.813	.850	.880	.024485	5.974
6925	40	.05	.540	.610	.660	.684	.720	.758	.805	.835	.022064	5.384
7433	35	.05	.460	.510	.580	.658	.675	.700	.740	.785	.019214	4.688
8072	30	.05	.360	.414	.475	.525	.600	.660	.675	.700	.016057	3.918
8739	25	.05	.072	.084	.165	.222	.300	.348	.380	.430	.008268	2.017
9677	20	.05	.049	.054	.060	.064	.075	.120	.190	.240	.003586	0.875
10571	17	.03	.044	.046	.050	.054	.058	.062	.070	.078	.001258	0.307
11306	15	.02	.040	.044	.046	.050	.053	.057	.063	.065	.000766	0.187
11604	14	.01	.039	.041	.044	.048	.051	.053	.060	.062	.000369	0.092
12032	13	.01	.037	.039	.042	.045	.048	.051	.053	.058	.000299	0.091
12503	12	.01	.036	.038	.040	.043	.044	.048	.050	.053	.000342	0.084
13058	11	.01	.035	.036	.039	.040	.043	.045	.049	.051	.000319	0.078
13696	10	.01	.033	.034	.036	.038	.040	.042	.044	.048	.000301	0.073
14496	9	.01	.031	.032	.034	.036	.038	.040	.041	.043	.000284	0.069
15271	8	.01	.030	.031	.032	.035	.036	.038	.039	.041	.000273	0.066
											Total days	114.394

* Number of days of shutdown required in the 244 day period between April 1 and November 30 of any given year to maintain a downstream DO of 5 mg/l

Table 13. Probability of Occurrence of Specified Flows, Temperatures, and 1986 Above-Dam DOs (C_A) and Their Combined Effects on Days of Operation

(Concluded on next page)

Dresden Island flow			Probability of occurrence of above-dam DOs (P3) which are equal to or less than those required to maintain a 5.0 mg/l minimum standard (table 10) for temperatures (°C) of												
Rate	Duration	Probability	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22
(cfs)	(%)	P1	P2=.0116	.0280	.0225	.0171	.0239	.0239	.0437	.0506	.0478	.0772	.0328	.0273	.0396
2546	99.8	.002	.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2921	99	.01	.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3156	98	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3319	97	.01	.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3459	96	.01	.845	.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3585	95	.05	.780	.900	.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3986	90	.05	.615	.720	.765	.820	.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4291	85	.05	.510	.570	.615	.710	.760	.795	.880	1.000	1.000	1.000	1.000	1.000	1.000
4585	80	.05	.405	.445	.505	.565	.605	.700	.750	.785	.820	.982	1.000	1.000	1.000
4809	75	.05	.165	.175	.415	.445	.510	.565	.600	.660	.755	.770	.805	.900	.998
5067	70	.05	.037	.140	.220	.390	.425	.455	.515	.560	.595	.645	.720	.760	.790
5300	65	.05	.028	.054	.150	.260	.380	.420	.460	.515	.585	.590	.695	.720	.755
5581	60	.05	.016	.020	.027	.044	.235	.175	.270	.380	.425	.445	.495	.540	.575
5850	55	.05	.014	.017	.020	.027	.040	.115	.175	.270	.380	.425	.445	.485	.530
6140	50	.05	.014	.017	.020	.026	.038	.090	.145	.210	.350	.400	.435	.465	.510
6502	45	.05	.012	.015	.018	.022	.028	.050	.115	.170	.250	.365	.410	.435	.475
6925	40	.05	.011	.014	.015	.019	.022	.030	.040	.110	.116	.250	.360	.405	.430
7433	35	.05	.010	.012	.014	.015	.017	.020	.027	.040	.100	.145	.195	.320	.385
8072	30	.05	.009	.010	.012	.013	.015	.018	.021	.025	.034	.050	.123	.160	.220
8739	25	.05	.006	.007	.007	.008	.009	.010	.012	.012	.014	.015	.018	.020	.023
9677	20	.05	.005	.005	.005	.006	.007	.007	.008	.009	.010	.011	.012	.014	.015
10571	17	.03	.005	.005	.005	.006	.006	.007	.007	.008	.009	.010	.011	.012	.013
11306	15	.02	.004	.004	.005	.005	.006	.007	.007	.008	.009	.009	.011	.011	.012
11604	14	.01	.004	.004	.005	.005	.005	.006	.006	.008	.008	.009	.010	.011	.011
12032	13	.01	.004	.004	.005	.005	.005	.006	.006	.007	.008	.008	.009	.010	.011
12503	12	.01	.004	.004	.005	.005	.005	.006	.006	.007	.007	.008	.009	.010	.010
13058	11	.01	.003	.004	.004	.005	.005	.006	.006	.006	.007	.008	.009	.009	.009
13696	10	.01	.003	.004	.004	.004	.005	.005	.006	.006	.006	.007	.008	.009	.009
14496	9	.01	.003	.004	.004	.004	.005	.005	.005	.006	.006	.007	.008	.008	.008
15271	8	.01	.003	.004	.004	.004	.004	.005	.005	.006	.006	.006	.007	.008	.008

Table 13. (Concluded)

Dresden Island flow			Probability of occurrence of above-dam DOs (P3) which are equal to or less than those required to maintain a 5.0 mg/l minimum standard (table 10) for temperatures (°C) of									
Rate (cfs)	Duration (%)	Probability P1	22-23	23-24	24-25	25-26	26-27	27-28	28-29	>29	Combined Probability (P1)(P2)(P3)	No. of shutdown days*
			P2= .0458	.0553	.0455	.0485	.0669	.0485	.0711	.0908		
2546	99.8	.002	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.001836	0.448
2921	99	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009184	2.241
3156	98	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009184	2.241
3319	97	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009183	2.241
3459	96	.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009165	2.236
3585	95	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.009130	2.228
3986	90	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.044847	10.943
4291	85	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.043559	10.628
4585	80	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.041449	10.114
4809	75	.05	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.039154	9.310
5067	70	.05	.835	.990	1.000	1.000	1.000	1.000	1.000	1.000	.035301	8.613
5300	65	.05	.785	.825	.992	1.000	1.000	1.000	1.000	1.000	.033325	8.131
5581	60	.05	.605	.670	.730	.830	.760	.815	.980	.998	.026810	6.542
5850	55	.05	.565	.595	.640	.780	.720	.770	.805	.850	.023556	5.748
6140	50	.05	.555	.580	.615	.740	.695	.765	.790	.825	.022677	5.533
6502	45	.05	.530	.570	.590	.725	.625	.745	.772	.802	.021233	5.184
6925	40	.05	.460	.510	.550	.684	.585	.700	.745	.785	.0218796	4.589
7433	35	.05	.420	.445	.500	.658	.535	.600	.650	.740	.016248	3.964
8072	30	.05	.345	.395	.440	.525	.460	.545	.575	.600	.013077	3.191
8739	25	.05	.032	.039	.100	.222	.150	.300	.370	.400	.005568	1.359
9677	20	.05	.018	.018	.022	.064	.025	.050	.115	.150	.001743	0.425
10571	17	.03	.014	.017	.018	.054	.019	.023	.027	.034	.000442	0.108
11306	15	.02	.013	.014	.015	.050	.017	.020	.023	.026	.000255	0.063
11604	14	.01	.012	.014	.015	.048	.016	.019	.022	.024	.000121	0.030
12032	13	.01	.012	.013	.014	.045	.015	.018	.019	.021	.000111	0.027
12503	12	.01	.011	.011	.013	.043	.014	.017	.018	.019	.000104	0.025
13058	11	.01	.010	.011	.012	.040	.013	.015	.017	.018	.000092	0.022
13696	10	.01	.010	.010	.011	.038	.012	.014	.015	.016	.000090	0.022
14496	9	.01	.009	.010	.010	.036	.011	.013	.014	.014	.000083	0.020
15271	8	.01	.009	.009	.009	.035	.010	.012	.013	.013	.000078	0.019
											Total Days	106.245

* number of days of shutdown required in the 244 day period between April 1 and November 30 of any given year to maintain a downstream DO of 5 mg/l.

Table 14. Predicted DOs Based on Using 90 Percent of Illinois River Flows at 95 and 50 Percent Flow Durations for Power Generation with 2 mg/l and 4 mg/l DO Additions to Power Flow

Temperature	Predicted DOs (mg/l) for 95% flow duration with above-dam DO(C_A) in me/l =						Predicted DOs (mg/l) for 50% flow duration with above-dam DO(C_A) in me/1 =					
(°C)	1	2	3	4	5	6	1	2	3	4	5	6
					a. 2.0 mg/l Addition							
12	1.61	2.36	3.11	3.86	4.61	5.37	3.77	4.51	5.26	6.08	6.75	7.50
14	1.10	1.85	2.60	3.35	4.10	4.85	3.56	4.30	5.05	5.79	6.54	7.28
16	0.56	1.31	2.06	2.81	3.56	4.31	3.35	4.09	4.83	5.58	6.31	7.06
18	0.00	0.74	1.49	2.24	2.99	3.73	3.11	3.84	4.59	5.33	6.08	6.82
20	0.00	0.13	0.88	1.63	2.38	3.12	2.86	3.60	4.34	5.09	5.82	6.57
22	0.00	0.00	0.42	1.16	1.91	2.66	2.59	3.33	4.07	4.82	5.55	6.30
24	0.00	0.00	0.00	0.47	1.22	1.89	2.31	3.04	3.78	4.53	5.27	5.93
26	0.00	0.00	0.00	0.68	1.43	1.88	1.99	2.74	3.47	4.22	4.95	5.40
28	0.00	0.00	0.00	0.44	0.79	1.03	1.66	2.40	3.14	3.88	4.62	4.85
					b. 4.0 me/1 Addition							
12	3.05	3.80	4.55	5.30	6.05	6.81	5.21	5.95	6.70	7.45	8.19	8.94
14	2.54	3.29	4.04	4.79	5.54	6.08	5.19	5.94	6.68	7.42	8.17	8.70
16	2.00	2.75	3.50	4.25	5.00	5.24	4.79	5.53	6.27	7.01	7.75	7.99
18	1.44	2.18	2.93	3.68	4.36	4.38	4.55	5.28	6.03	6.77	7.44	7.47
20	0.83	1.57	2.32	3.07	3.53	3.55	4.53	5.27	6.01	6.76	7.20	7.23
22	0.36	1.11	1.86	2.60	2.78	2.80	4.52	5.25	6.00	6.74	6.90	6.92
24	0.00	0.50	1.16	1.83	1.87	1.89	3.75	4.48	5.23	5.89	5.91	5.93
26	0.00	0.63	1.37	1.83	1.86	1.88	3.43	4.18	4.91	5.36	5.38	5.40
28	0.00	0.00	0.74	0.98	1.00	1.03	3.10	3.84	4.58	4.81	4.84	4.85

Note: From table 4, 95% flow duration = 3585 cfs and 50% flow duration = 6140 cfs; underlined values denote values that fall within the 5.0 mg/l minimum standard.

Table 15. Predicted DOs Based on Using 70 Percent of the Illinois River Flows at 95 and 50 Percent Flow Durations for Power Generation with 2 mg/l and 4 mg/l DO Additions to Power Flow

Temperature	Predicted DOs (mg/1) for 95% flow duration with above-dam DO(C_A) in mg/1 =						Predicted DOs (mg/1) for 50% flow duration with above-dam DO(C_A) in mg/1 =					
(°C)	1	2	3	4	5	6	1	2	3	4	5	6
a. 2.0 mg/1 Addition												
12	2.50	3.13	3.75	4.38	5.01	5.64	4.66	5.29	5.90	6.53	7.14	7.77
14	1.94	2.56	3.19	3.81	4.44	5.07	4.41	5.02	5.65	6.26	6.88	7.50
16	1.36	1.99	2.61	3.23	3.85	4.47	4.15	4.77	5.39	5.99	6.61	7.23
18	0.75	1.37	1.99	2.61	3.23	3.85	3.87	4.48	5.09	5.71	6.32	6.94
20	0.70	1.32	1.93	2.56	3.17	3.79	3.58	4.20	4.81	5.42	6.03	6.64
22	0.00	0.22	0.84	1.46	2.07	2.69	3.28	3.89	4.50	5.11	5.71	6.33
24	0.00	0.00	0.11	0.72	1.34	1.89	2.95	3.56	4.17	4.78	5.39	5.94
26	0.00	0.00	0.23	0.90	1.51	1.89	2.61	3.22	3.82	4.43	5.03	5.42
28	0.00	0.00	0.00	0.22	0.84	1.05	2.24	2.85	3.46	4.06	4.67	4.88
b. 4.0 mg/1 Addition												
12	3.62	4.25	4.87	5.50	6.13	6.76	5.78	6.41	7.02	7.65	8.26	8.89
14	3.06	3.68	4.31	4.93	5.56	6.02	5.53	6.14	6.77	7.38	8.00	8.45
16	2.48	3.11	3.73	4.35	4.97	5.20	5.27	5.89	6.51	7.11	7.73	7.95
18	1.87	2.49	3.11	3.73	4.29	4.36	4.99	5.60	6.21	6.83	7.39	7.44
20	1.23	1.84	2.46	3.08	3.47	3.53	4.70	5.32	5.93	6.54	6.93	6.98
22	0.73	1.34	1.96	2.58	2.74	2.80	4.40	5.01	5.62	6.23	6.39	6.44
24	0.01	0.62	1.23	1.79	1.84	1.89	4.07	4.68	5.29	5.84	5.89	5.94
26	0.18	0.79	1.36	1.79	1.84	1.89	3.73	4.34	4.94	5.33	5.37	5.42
28	0.00	0.24	0.85	1.06	1.12	1.17	3.36	3.97	4.58	4.79	4.84	4.88

Note: From table 4, 95% flow duration = 3585 cfs and 50% flow duration = 6140 cfs; underlined values denote values that fall within the 5.0 mg/1 minimum standard.

FIGURES

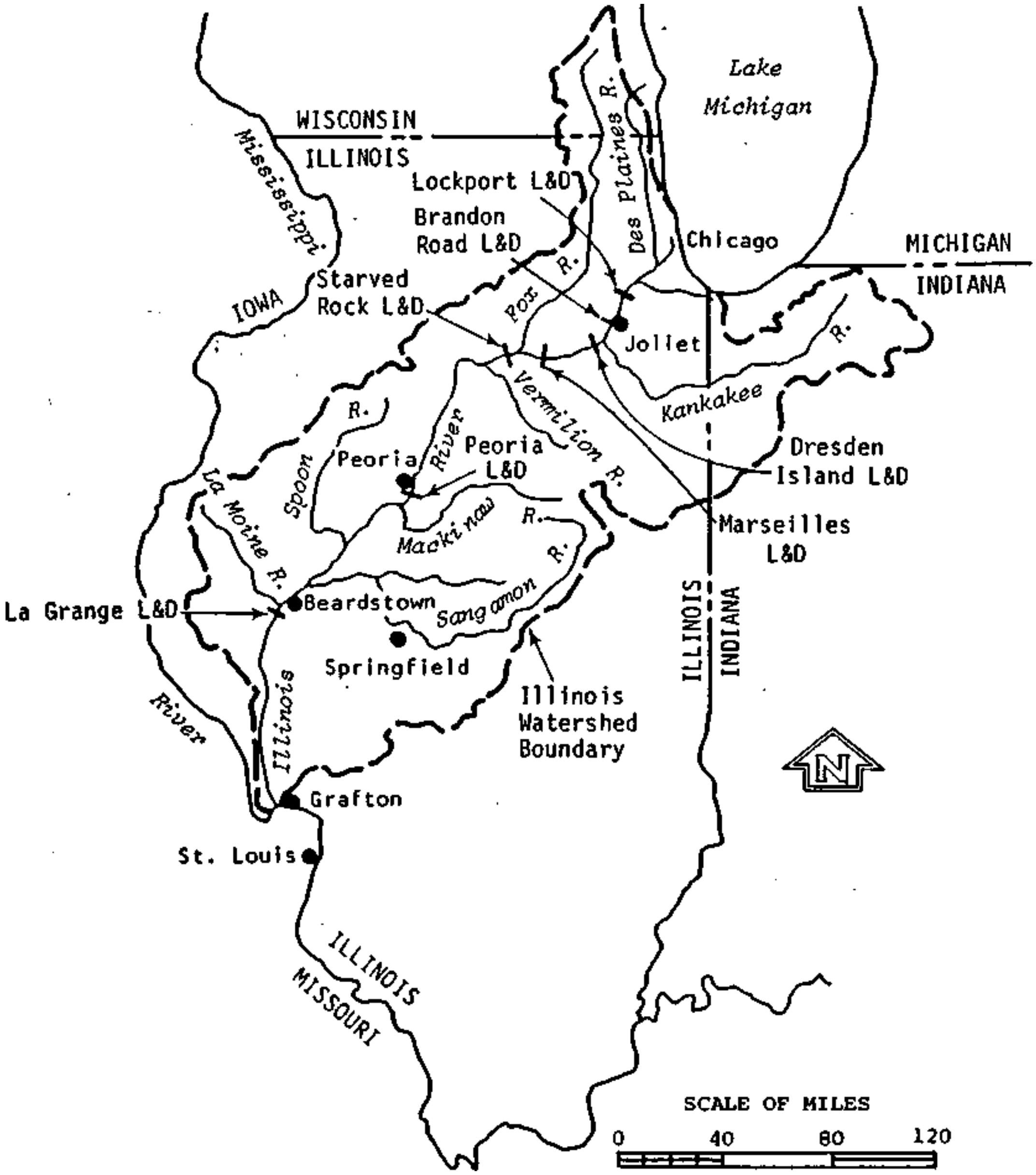


Figure 1. Illinois Waterway

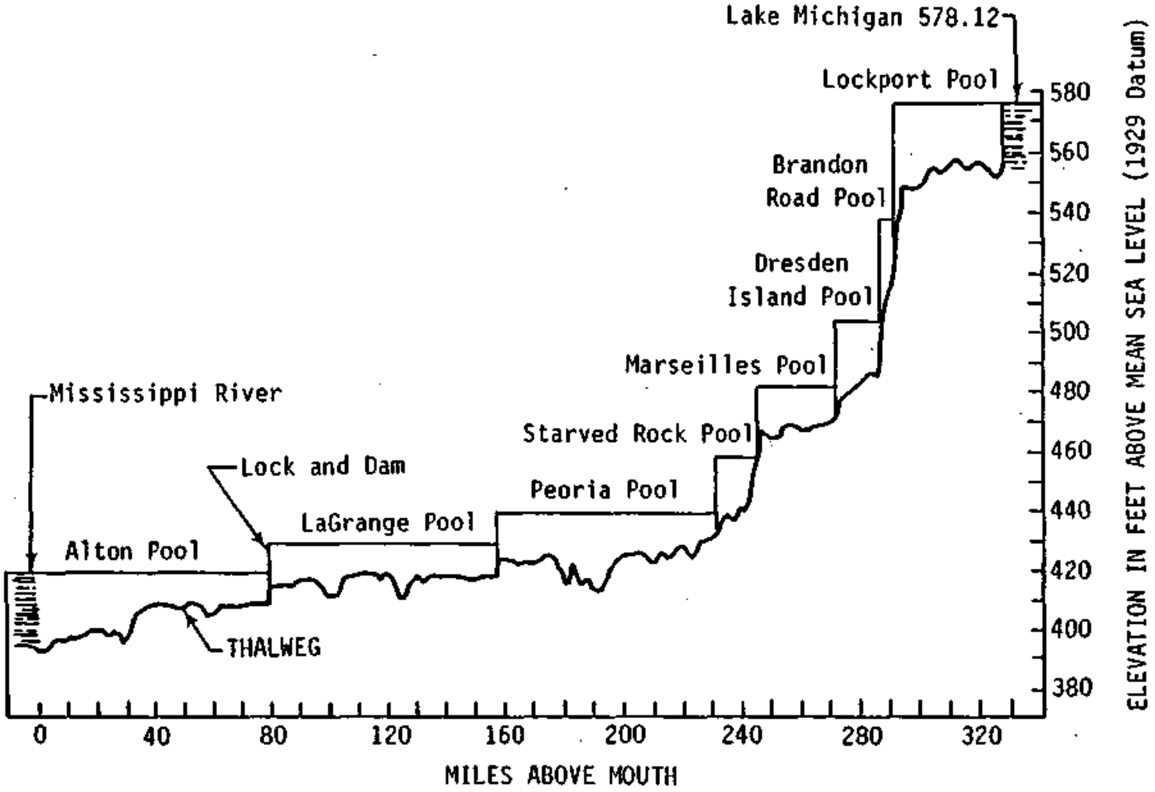


Figure 2. Illinois Waterway profile

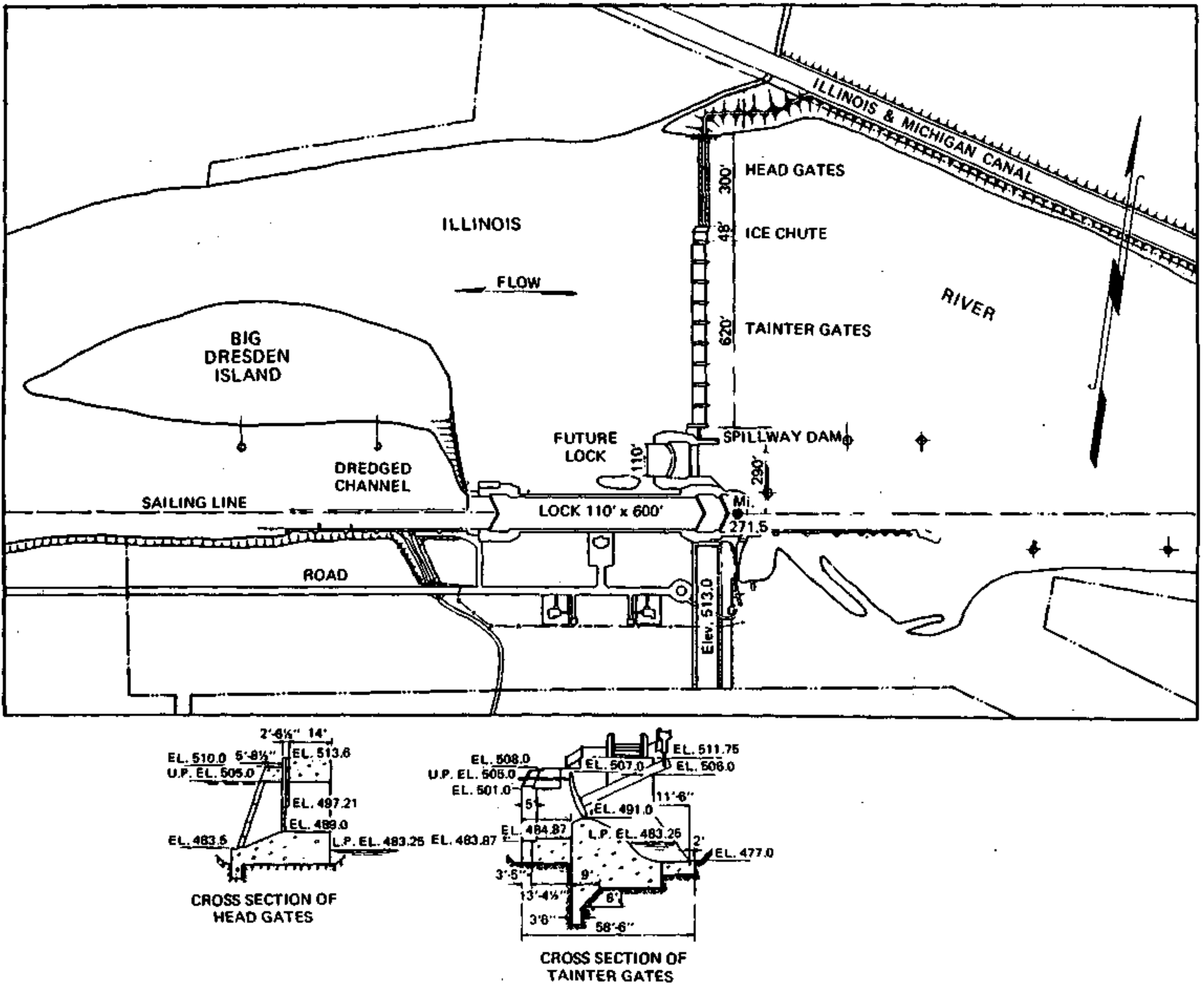


Figure 3. Plan and section view of Dresden Island dam

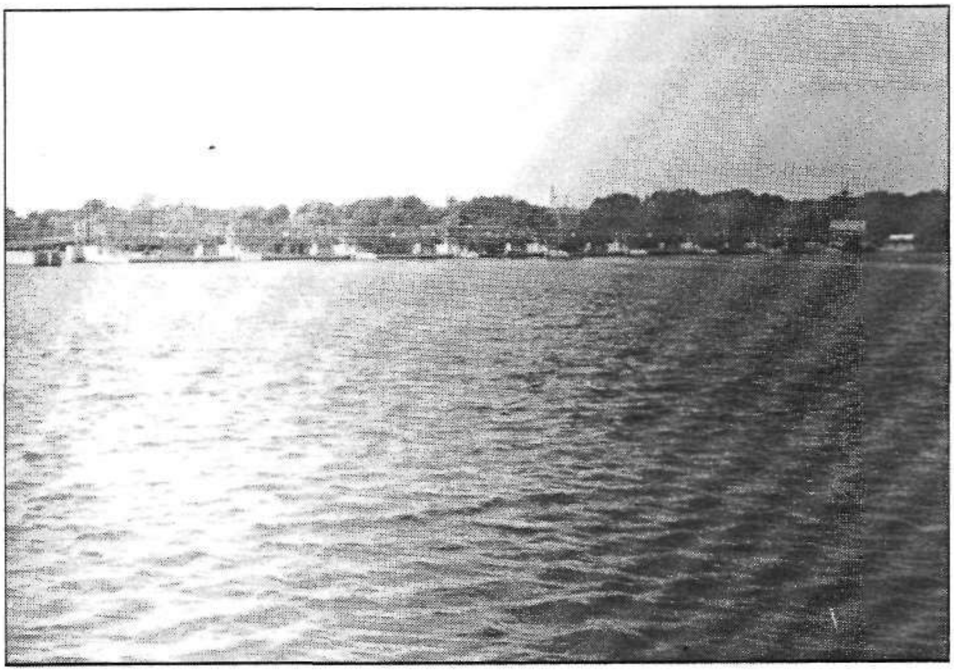


Figure 4. Above Dresden Island dam

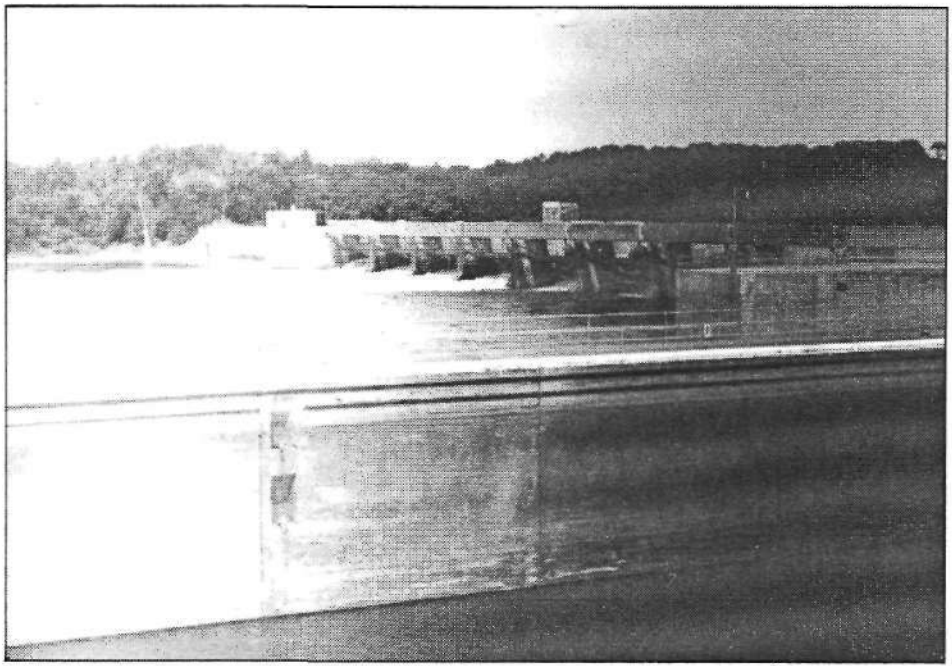
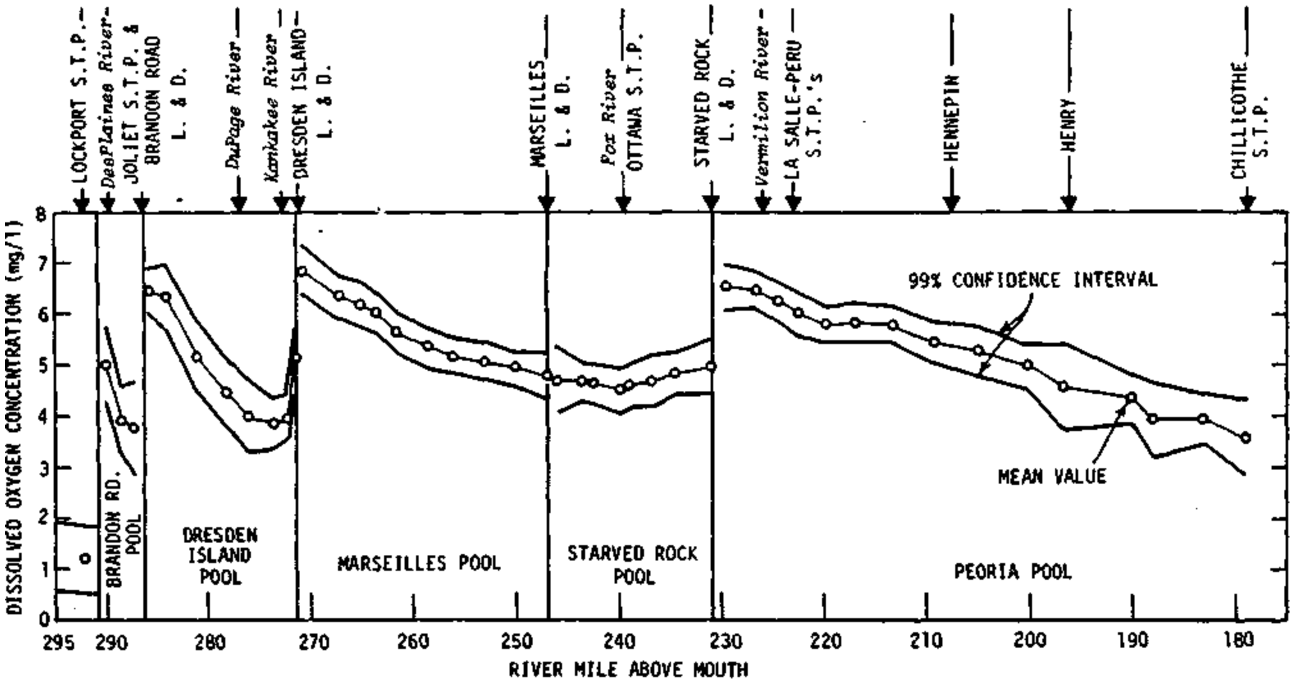
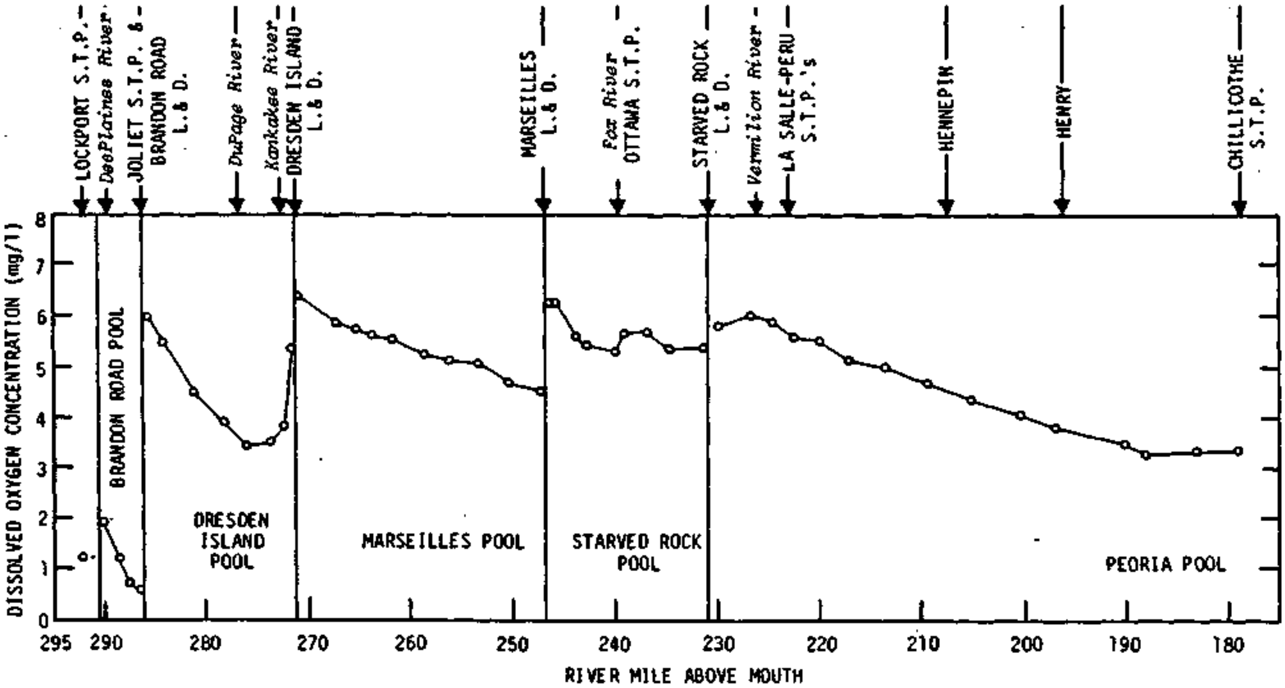


Figure 5. Below Dresden Island dam



Mean dissolved oxygen profile, 1971 dates



Mean dissolved oxygen profile, July 11,18, 24, 26,1972

Figure 6. Upper Illinois Waterway DO profile

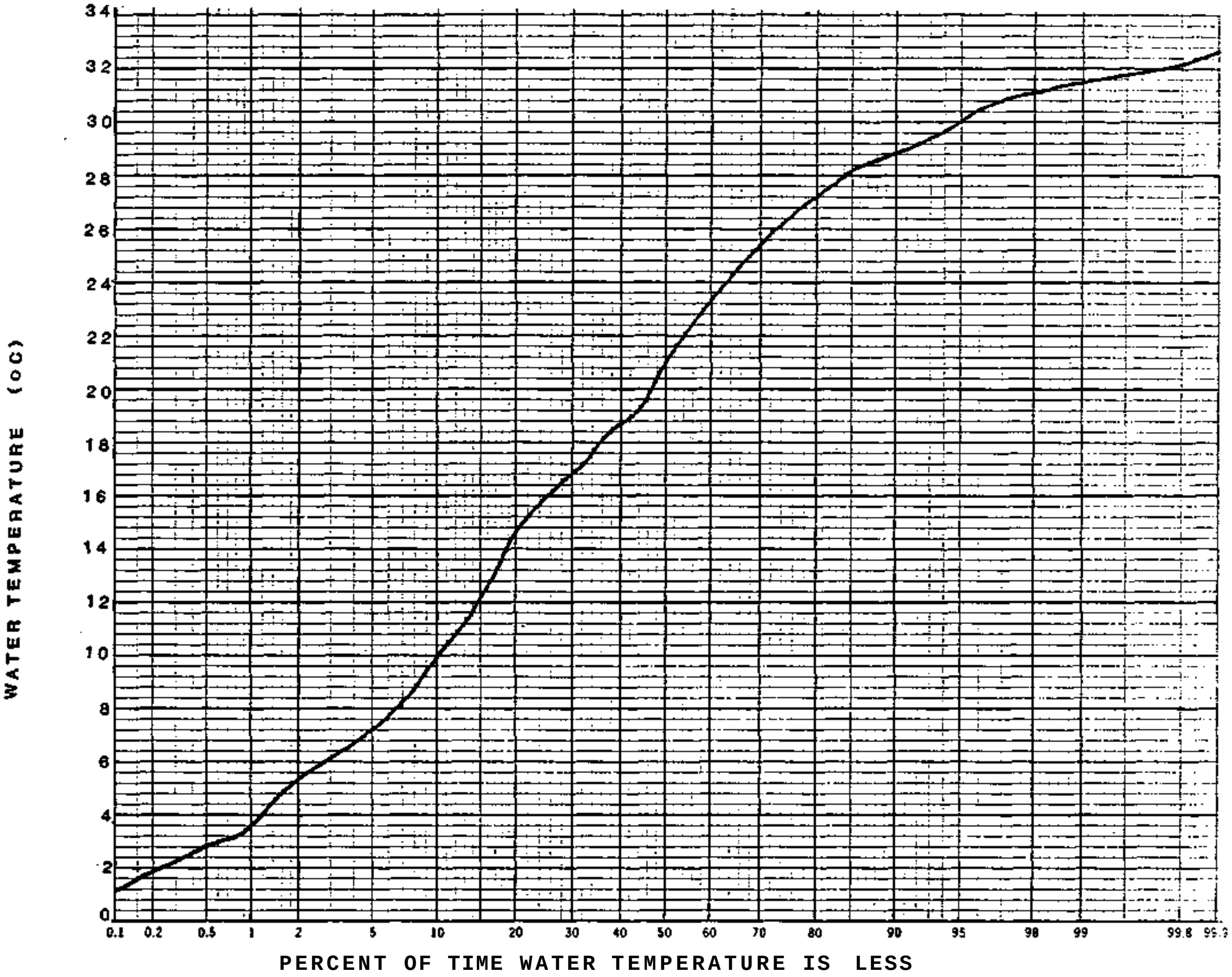


Figure 7. April 1 - November 30 frequency distribution of water temperatures at Dresden Island

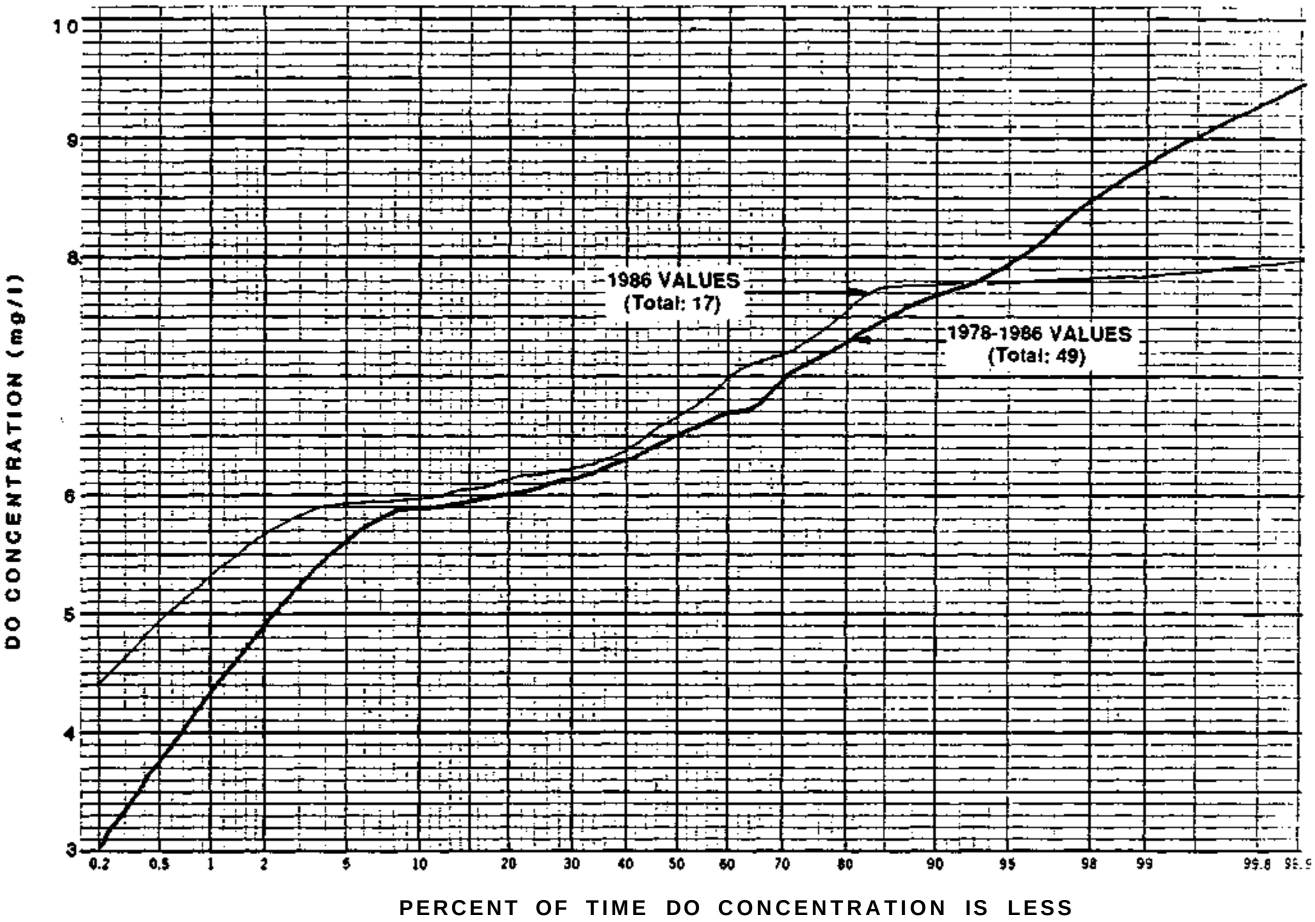


Figure 8. Frequency distribution of DO above the Dresden Island dam

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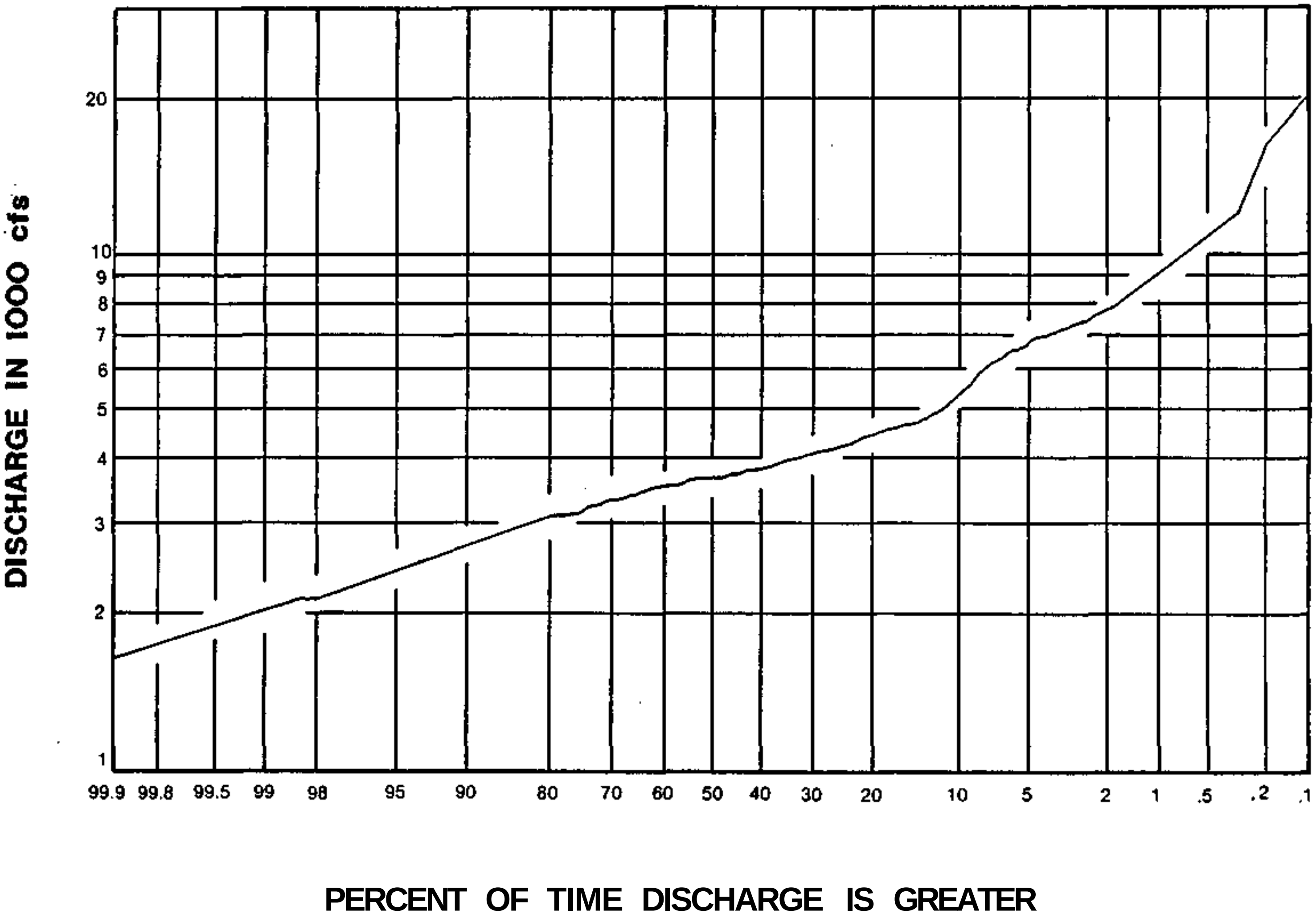
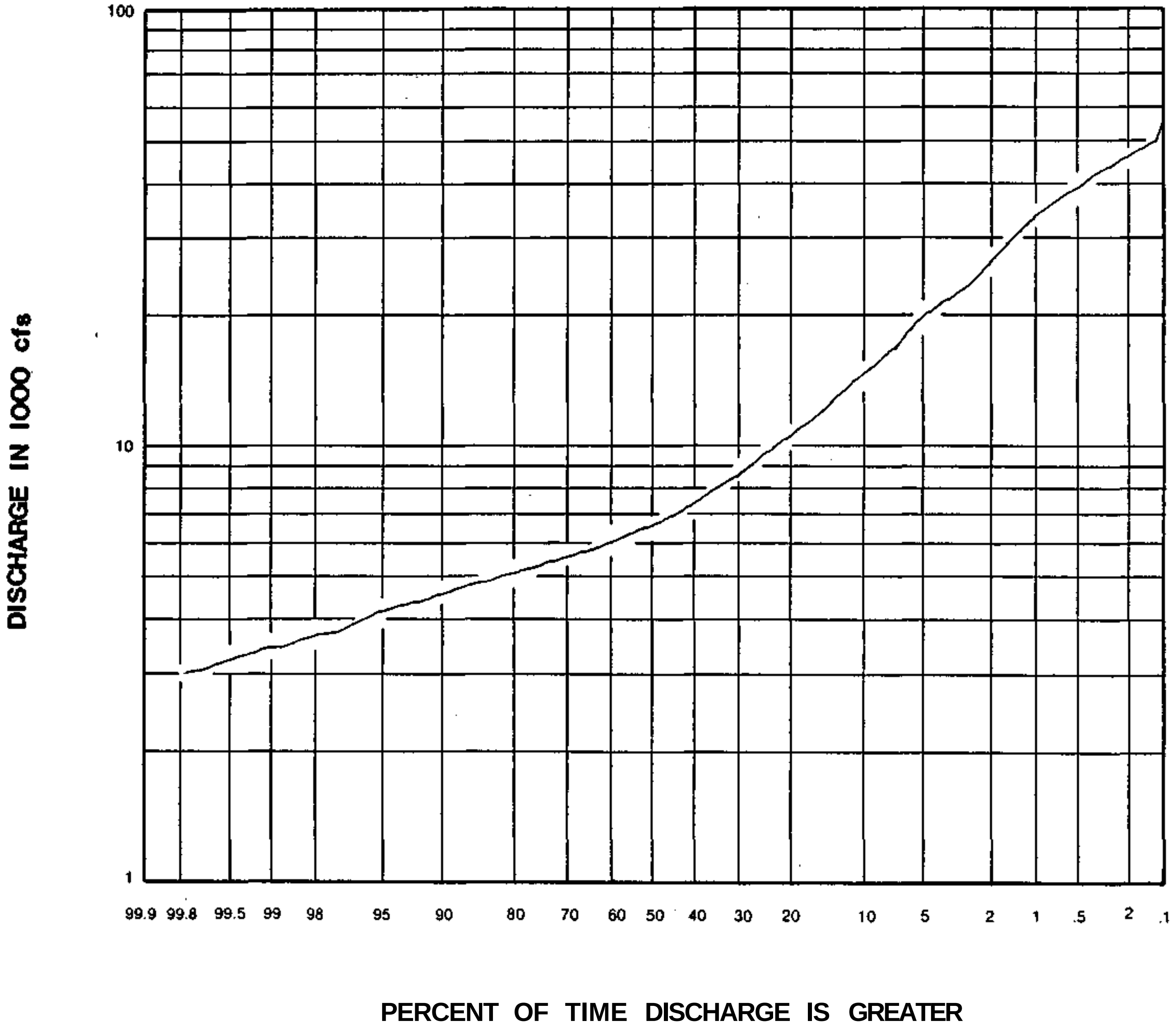
Appendix A

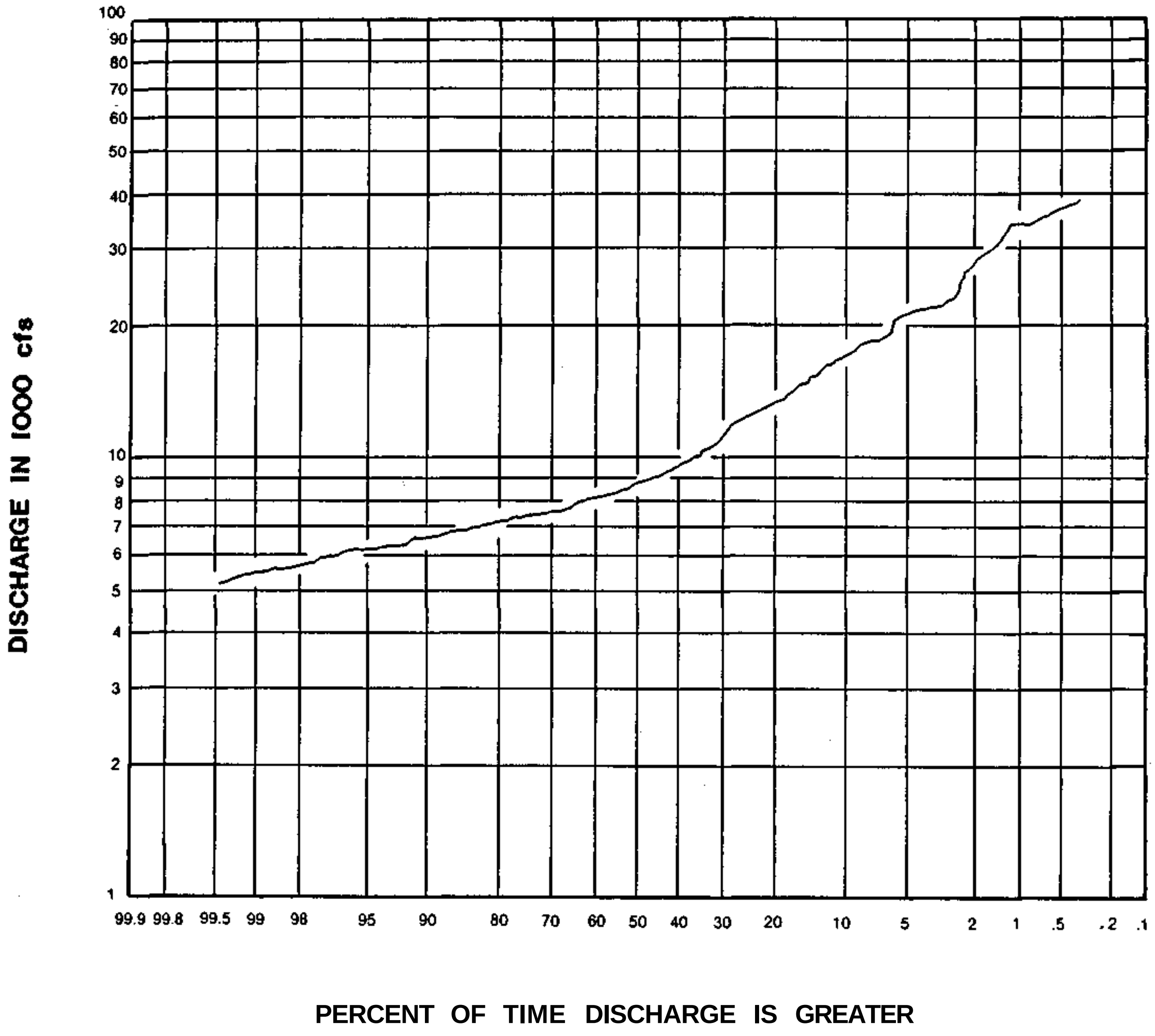
Flow Duration Curves for Main Stem Gaging Stations at Lockport, Marseilles, and Henry, and for the Tributaries: Des Plaines, DuPage, Kankakee, Fox, and Vermilion Rivers



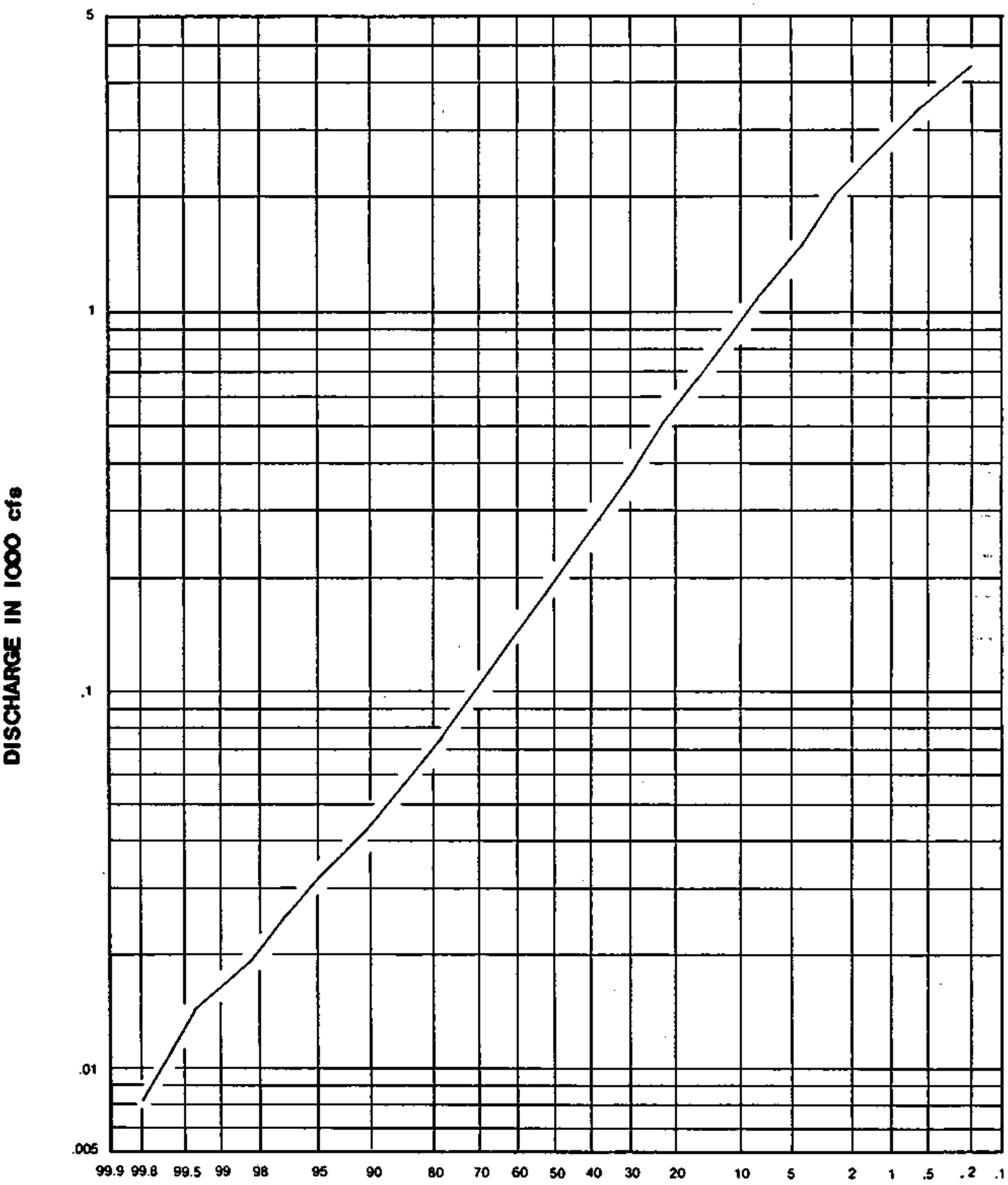
SANITARY AND SHIP CANAL AT LOCKPORT



ILLINOIS RIVER AT MARSEILLES

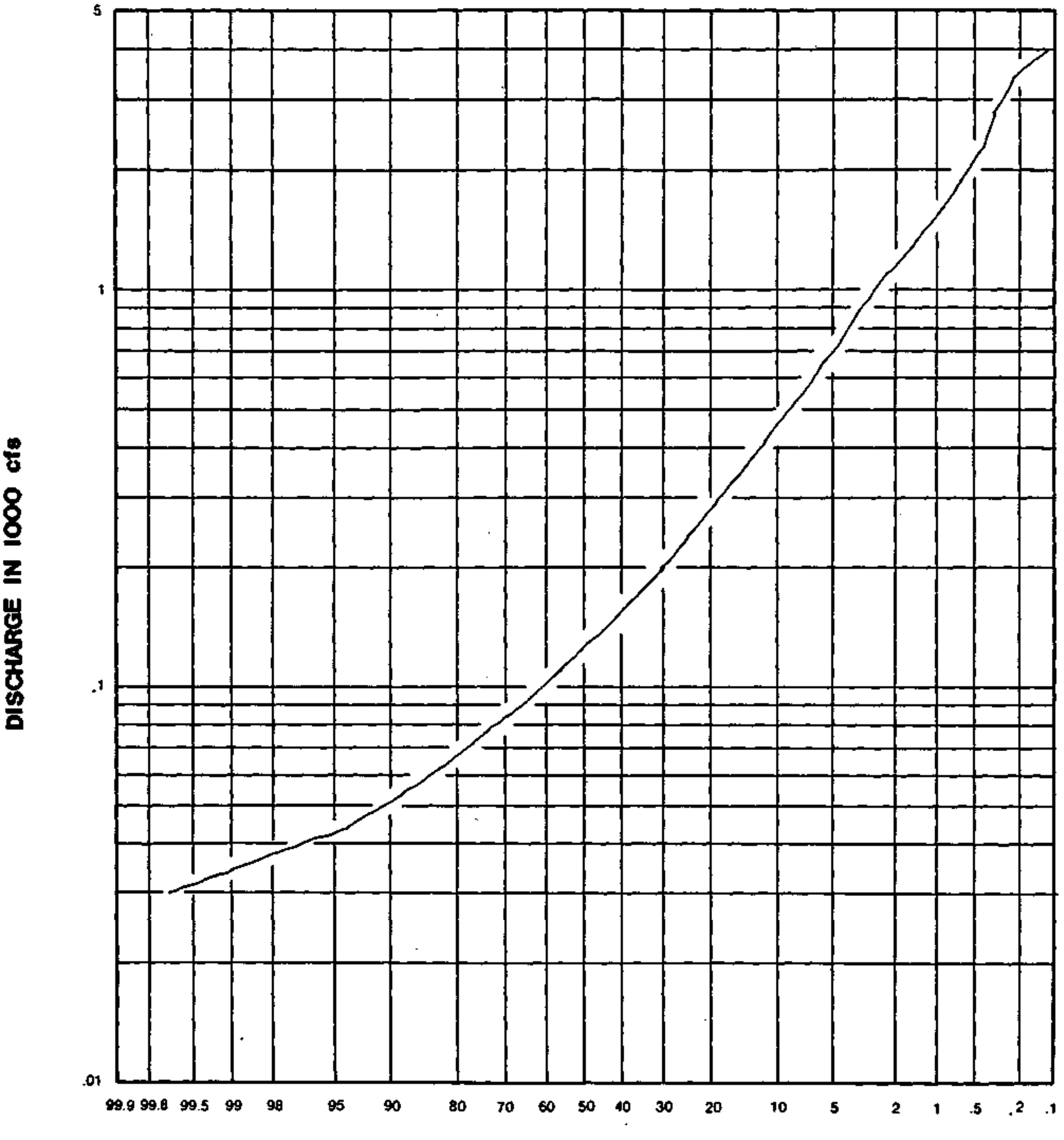


ILLINOIS RIVER AT HENRY



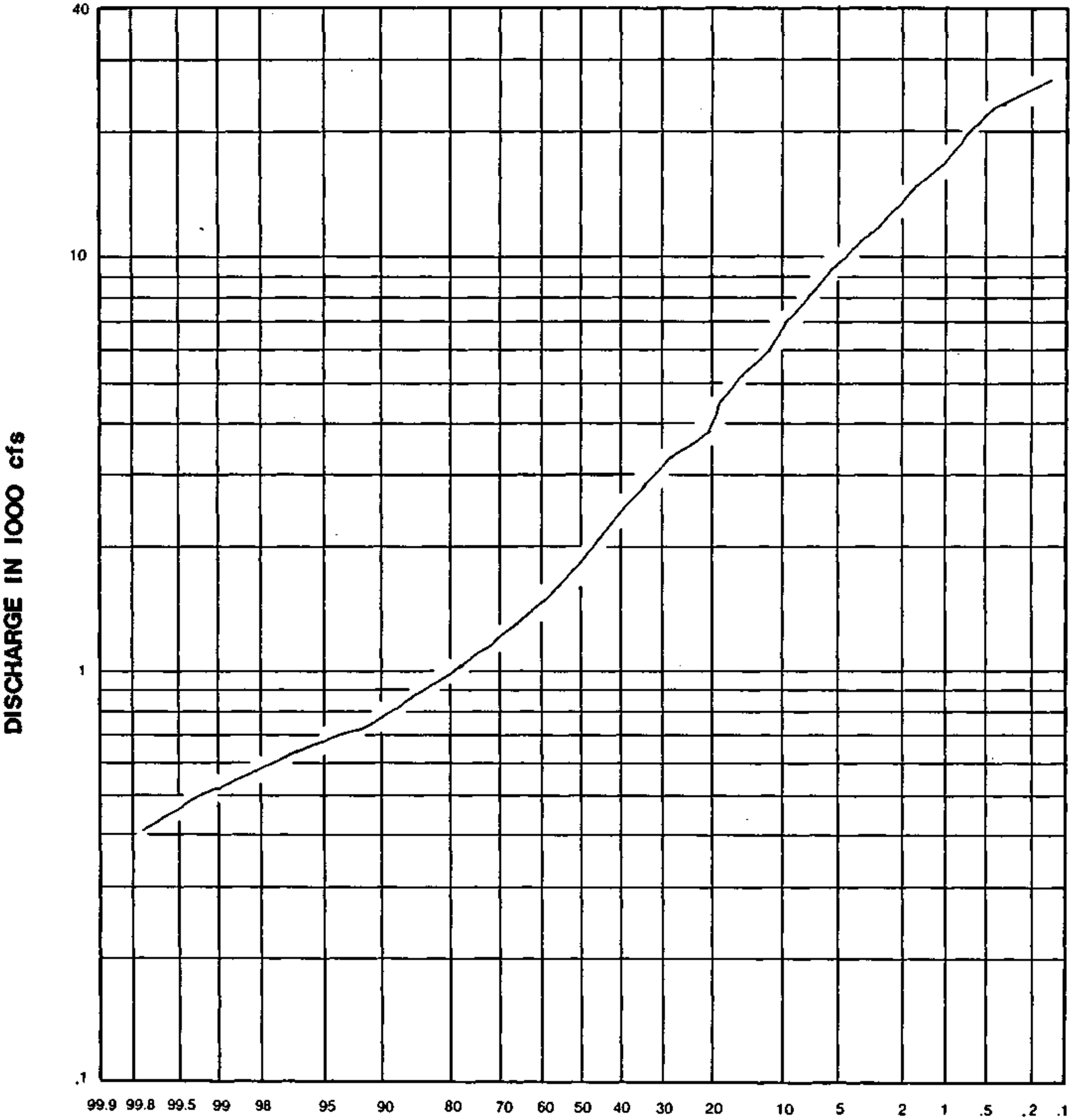
PERCENT OF TIME DISCHARGE IS GREATER

DES PLAINES RIVER AT RIVERSIDE



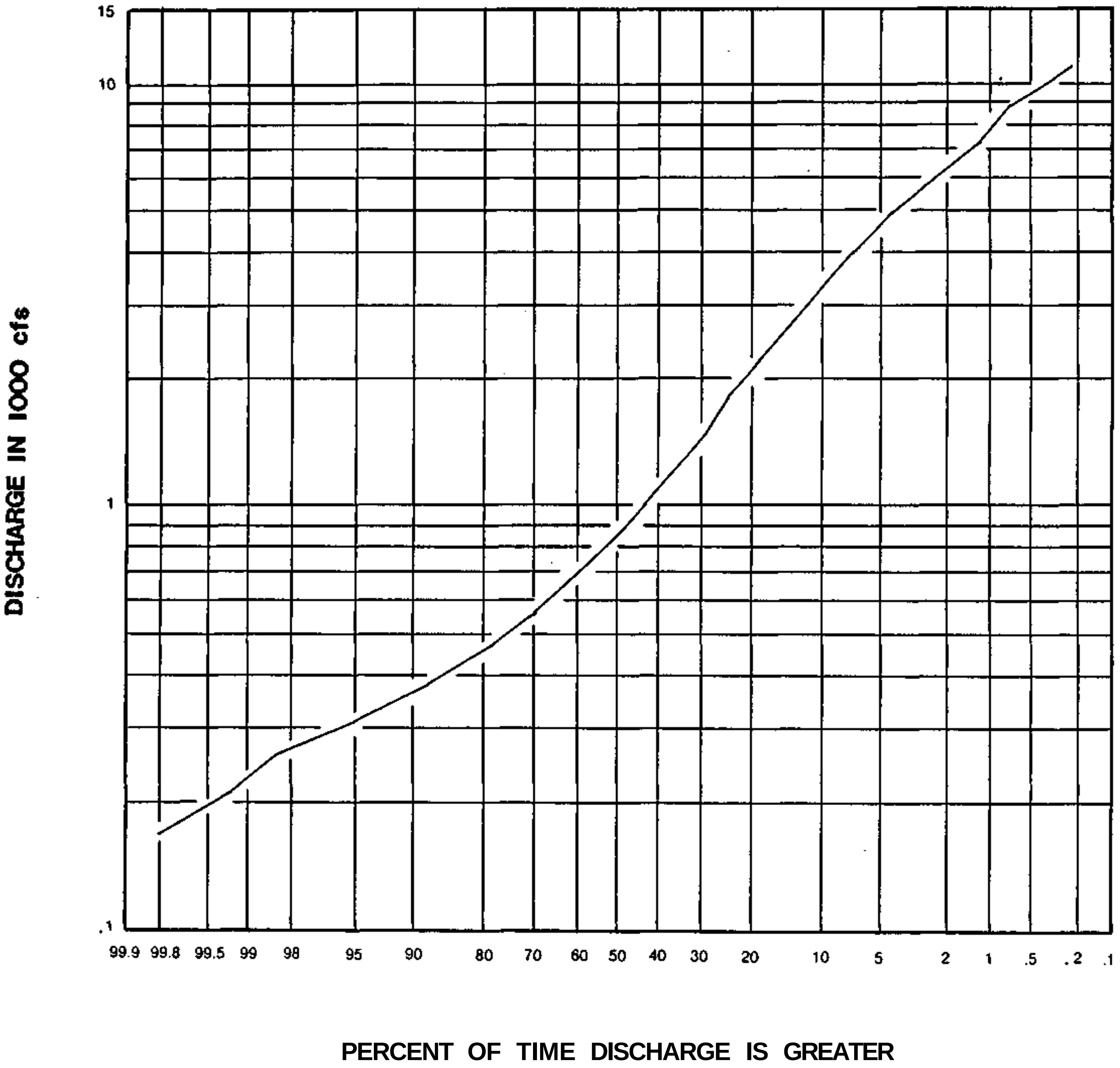
PERCENT OF TIME DISCHARGE IS GREATER

DU PAGE RIVER AT SHOREWOOD

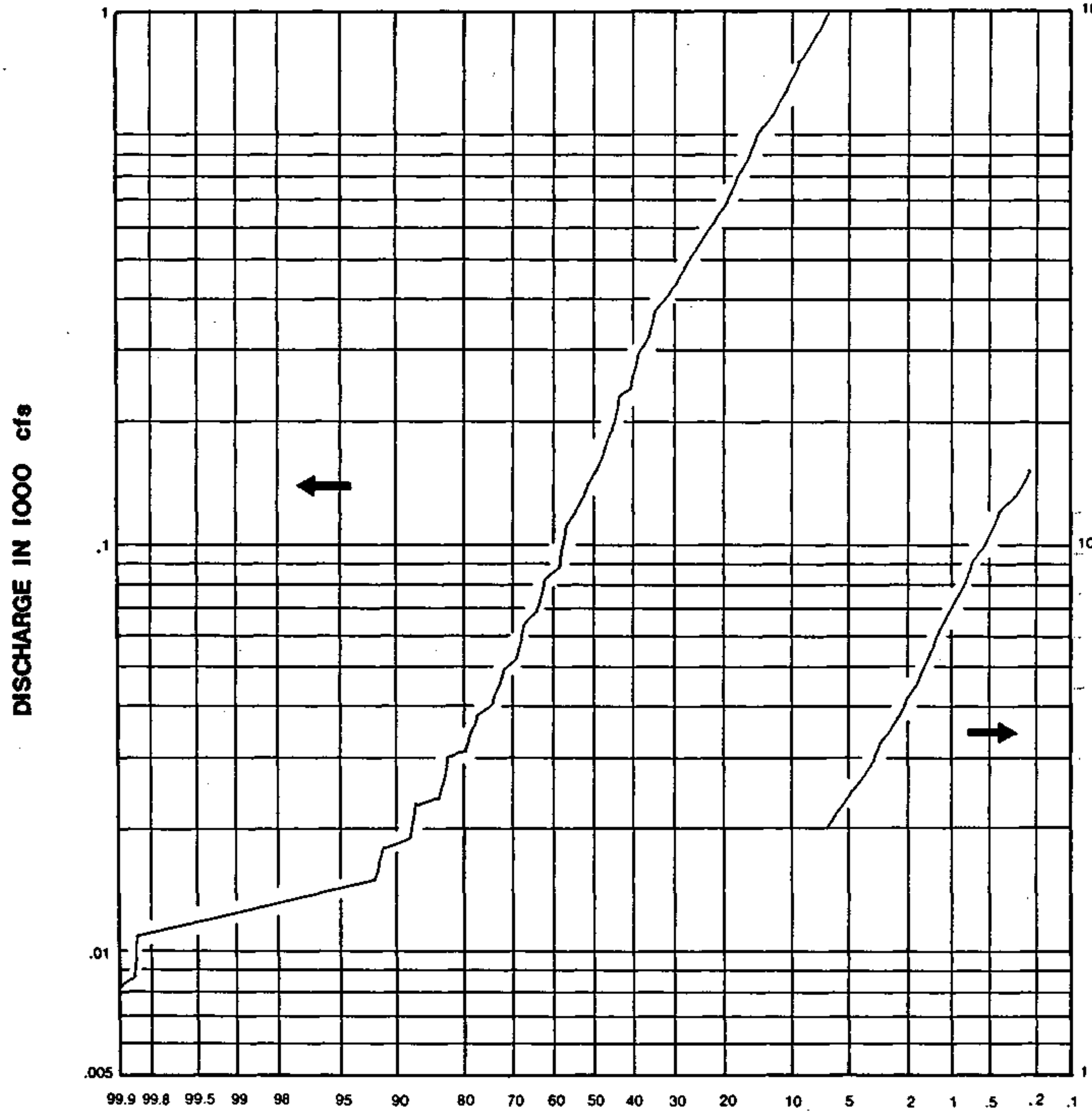


PERCENT OF TIME DISCHARGE IS GREATER

KANKAKEE RIVER AT WILMINGTON



FOX RIVER AT DAYTON



PERCENT OF TIME DISCHARGE IS GREATER

VERMILION RIVER AT LOWELL - LEONORE

Appendix B

Main Stem Flows for Various Flow Duration Percents

Main Stem Flows for Various Flow Duration Percents

Gage Name	Lockport	Marseilles	Henry	Kingston Mines
SWS Mile	291.00	246.39	196.66	145.76
Flow Duration %				
99.8	1761	3000	4891	6641
99	1988	3400	5367	7135
98	2140	3650	5664	7437
97	2250	3820	5867	7656
96	2320	4000	6081	7890
95	2410	4140	6247	8067
90	2690	4550	6735	8576
85	2900	4800	7033	8867
80	3080	5100	7390	9228
75	3189	5300	7628	9442
70	3340	5500	7866	9646
65	3420	5750	8163	9910
60	3550	6000	8461	10164
55	3650	6250	8758	10386
50	3690	6550	9115	10672
45	3750	6950	9591	11063
40	3830	7350	10067	11401
35	3950	7900	10722	11859
30	4100	8550	11495	12469
25	4210	9400	12507	13201
20	4430	10600	13935	14366
17	4580	11400	14887	15012
15	4680	12100	15720	15580
14	4720	12500	161%	15886
13	4850	13000	16791	16365
12	5000	13500	17386	16816
11	5200	14000	17981	17225
10	5400	14500	18576	17540
9	5700	15200	19409	18120
8	6000	15900	20242	18677

Appendix C

Tributary Flows for Various Flow Duration Percents

Tributary Flows for Various Flow Duration Percents

Gage Name	Des Plaines	DuPage	Kankakee	Mazon	Fox	Vermilion	I & M Canal	Bureau Creek
SWS Mile	289.94	276.96	272.90	263.52	239.17	226.50	211.19	209.36
Flow Duration %								
99.8	8	29	400	4	170	11	1	2
99	16	34	515	5	228	12	1	2
98	20	37	580	5	269	13	1	2
97	25	40	620	5	2 86	13	1	2
96	28	41	655	6	300	14	1	2
95	31	43	675	6	312	15	2	3
90	43	51	770	7	366	18	2	3
85	56	59	890	10	414	24	2	4
80	69	67	980	13	458	31	3	5
75	85	76	1100	16	508	40	4	7
70	103	84	1220	21	565	51	5	9
65	120	92	1340	27	625	66	7	11
60	141	103	1490	35	690	86	9	15
55	165	113	1650	48	770	188	12	20
50	192	126	1860	60	860	147	15	25
45	224	140	2100	77	965	190	19	32
40	260	155	2430	102	1100	250	25	42
35	305	177	2750	143	1270	350	35	59
30	365	203	3170	175	1450	430	43	73
25	450	235	3500	217	1760	530	53	89
20	560	280	3900	269	2080	660	66	111
17	635	320	4650	331	2340	810	81	137
15	700	355	5250	380	2580	930	93	157
14	740	370	5400	413	2720	1010	101	171
13	785	388	5600	441	2840	1080	108	182
12	830	410	5850	465	3000	1140	114	192
11	885	435	6200	507	3150	1240	124	209
10	950	460	6700	564	3340	1380	138	233
9	1000	485	7250	625	3530	1530	153	258
8	1080	525	7700	674	3780	1650	165	279

Appendix D

Estimated Pool Elevations for Various Flow Duration Percents

Pool Elevations (feet above MSL) for Various Flow Duration Percents

Gage Name	Lockport Lo	Brandon Road Up	Brandon Road Lo	Dresden Is. Up	Dresden Is. Lo	Marseilles Up	Marseilles Lo	Starved Rock Up
SWS Mile	291.00	286.25	286.24	271.52	271.51	246.78	246.77	231.02
Flow Duration %								
99.8	538.6	538.6	504.8	504.8	483.3	483.3	459.0	459.0
99	538.6	538.6	504.8	504.8	483.3	483.3	459.0	459.0
98	538.9	538.9	505.0	505.0	484.3	484.4	459.0	459.1
97	538.9	538.9	505.1	505.2	484.3	483.5	459.1	459.2
96	539.0	539.0	505.3	505.3	484.4	483.6	459.1	459.3
95	539.0	539.0	505.5	505.5	484.4	483.7	459.1	459.3
90	539.1	539.0	505.5	505.3	484.4	483.7	459.3	459.3
85	539.2	539.0	505.4	505.1	484.4	483.7	459.5	459.4
80	539.2	539.0	505.5	505.1	484.5	483.7	459.4	459.3
75	539.3	539.2	505.6	505.1	484.6	483.7	459.4	459.3
70	539.3	539.2	505.6	505.1	484.6	483.7	459.4	459.3
65	539.3	539.1	505.6	505.1	484.7	483.7	459.5	459.3
60	539.3	539.0	505.6	505.1	484.8	483.7	459.5	459.4
55	539.3	538.9	505.6	505.1	484.9	483.7	459.5	459.4
50	539.3	538.9	505.6	505.2	485.6	483.7	459.6	459.4
45	539.3	539.0	505.6	505.2	485.6	483.7	459.6	459.4
40	539.4	539.1	505.6	505.2	485.6	483.7	459.7	459.4
35	539.2	539.0	505.6	505.2	485.8	483.7	459.8	459.4
30	539.0	538.9	505.6	505.2	486.0	483.7	459.9	459.4
25	539.0	538.9	505.6	505.2	486.2	483.7	460.0	459.4
20	539.0	538.9	505.6	505.2	486.4	483.7	460.2	459.4
17	539.0	538.9	505.6	505.2	486.4	483.7	460.2	459.4
15	539.0	538.8	505.5	504.8	486.6	483.5	460.2	459.3
14	539.0	538.8	505.5	504.8	486.9	483.4	460.2	459.2
13	539.0	538.7	505.5	504.8	487.2	483.3	460.2	459.1
12	539.1	538.7	505.5	504.8	487.5	483.3	460.3	459.0
11	539.2	538.6	505.5	504.8	487.9	483.3	460.4	458.9
10	539.3	538.6	505.7	504.8	488.0	483.2	460.5	458.7
9	539.4	538.6	505.9	504.8	488.2	483.2	460.6	458.9
8	539.6	538.6	506.1	504.8	488.5	483.1	460.7	458.9

Pool Elevations (feet above MSL) for Various Flow Duration Percents (cont)

Gage Name	Starved Rock Lo	LaSalle	Spring Valley	Henry	Peoria Boat Yd	Peoria Upper	Peoria Lower
SWS Mile	231.01	223.05	218.69	196.66	164.61	158.06	158.05
Flow Duration %							
99.8	440.6	440.6	440.6	440.6	440.0	440.0	430.9
99	440.6	440.6	440.6	440.6	440.0	440.0	430.9
98	440.7	440.7	440.6	440.6	440.0	440.0	431.3
97	440.7	440.7	440.6	440.6	440.1	440.0	431.6
%	440.8	440.8	440.6	440.6	440.1	440.0	431.9
95	440.8	440.8	440.6	440.5	440.1	440.0	431.9
90	440.8	440.8	440.7	440.5	440.1	440.0	432.3
85	440.8	440.8	440.7	440.5	440.0	440.0	432.3
80	441.2	441.0	440.8	440.4	439.9	439.8	433.8
75	441.3	441.1	440.9	440.4	439.8	439.7	434.0
70	441.6	441.3	441.0	440.4	439.8	439.6	434.0
65	441.9	441.5	441.1	440.4	439.7	439.5	434.0
60	442.0	441.6	441.3	440.6	440.0	439.8	434.4
55	442.1	441.8	441.5	440.9	440.3	440.1	434.8
50	442.2	442.0	441.7	441.1	440.6	440.4	435.2
45	442.3	442.2	441.9	441.3	440.9	440.7	435.6
40	442.3	442.2	442.0	441.3	440.7	440.4	436.0
35	442.4	442.3	442.1	441.4	440.5	440.1	436.5
30	442.4	442.3	442.2	441.4	440.3	439.8	437.0
25	442.6	442.5	442.4	441.5	440.5	440.1	437.3
20	444.0	443.8	443.4	442.6	440.7	440.3	438.0
17	446.0	445.5	445.1	443.3	440.9	440.4	439.0
15	448.0	447.2	446.6	443.8	441.1	440.5	440.5
14	448.1	447.4	446.8	444.0	441.5	440.8	440.8
13	448.2	447.6	447.0	444.2	441.8	441.2	441.2
12	448.4	447.7	447.1	444.5	442.5	441.6	441.6
11	448.9	448.2	447.4	444.7	442.7	441.9	441.9
10	449.3	448.7	447.7	445.0	443.0	442.2	442.2
9	449.9	449.3	448.3	445.6	443.6	442.8	442.8
8	450.5	449.9	448.9	446.2	444.2	443.4	443.4

Appendix E

Time of Travel from Lockport Dam to Point Source Waste Load Inputs for Various Flow Duration Percents

Time of Travel (days) from Lockport Dam to Point Source Waste Load Location

Flow Duration %	Point Source River Mile 290.99	289.94	286.25	283.72	276.96	272.90
99.8	.00075	.14188	.34683	1.30374	2.82286	3.79622
99	.00066	.12572	.83789	1.15423	2.50425	3.37115
98	.00063	.11923	.79591	1.09879	2.38296	3.20807
97	.00060	.11342	.75660	1.04933	2.29047	3.09100
96	.00058	.11072	.73775	1.02869	2.24674	3.02774
95	.00056	.10659	.709%	.99826	2.19561	2.96278
90	.00050	.09610	.63774	.89586	1.96540	2.64800
85	.00047	.08974	.59396	.83084	1.81907	2.45107
80	.00044	.08451	.55841	.78423	1.72114	2.31833
75	.00043	.08249	.54609	.76753	1.68187	2.26285
70	.00041	.07858	.51969	.73099	1.60699	2.16558
65	.00040	.07668	.50368	.70911	1.56119	2.10379
60	.00039	.07384	.48208	.67992	1.50228	2.02652
55	.00038	.07178	.46538	.65734	1.45678	1.96670
50	.00037	.07101	.45794	.64691	1.43635	1.94044
45	.00037	.06992	.44970	.63416	1.40433	1.89463
40	.00036	.06893	.44140	.62126	1.37402	1.85332
35	.00035	.06602	.42078	.59378	1.31818	1.77811
30	.00033	.06282	.39805	.56324	1.25594	1.69488
25	.00032	.06114	.38126	.53849	1.19480	1.60688
20	.00030	.05804	.35569	.50126	1.10539	1.48064
17	.00029	.05619	.34236	.48284	1.06925	1.43392
15	.00029	.05497	.33165	.46595	1.02592	1.37047
14	.00029	.05449	.32673	.45870	1.00789	1.34466
13	.00028	.05298	.31525	.44296	.97398	1.29904
12	.00027	.05170	.30588	.42939	.94311	1.25730
11	.00026	.04999	.29347	.41237	.90855	1.21266
10	.00025	.04846	.28338	.40132	.88956	1.18794
9	.00024	.04621	.27013	.38563	.85931	1.14790
8	.00023	.04443	.25784	.37054	.82788	1.10485

Time of Travel (days) from Lockport Dam to Point Source Waste Load Location (cont.)

Flow Duration	Point Source River Mile					
%	271.52	263.52	252.42	246.78	239.17	231.02
99.8	4.26001	5.22895	6.75886	7.75489	8.38545	9.62905
99	3.77541	4.62218	5.96533	6.84304	7.40240	8.50616
98	3.58738	4.45501	5.76690	6.59890	7.12329	8.15657
97	3.45652	4.28370	5.54147	6.34239	6.85193	7.85092
96	3.38107	4.18328	5.39861	6.17072	6.65963	7.62274
95	3.30834	4.08393	5.26384	6.01563	6.48851	7.42097
90	2.95469	3.65377	4.72207	5.40524	5.84695	6.70130
85	2.73197	3.38281	4.38750	5.03359	5.46444	6.28303
80	2.58128	3.19792	4.14421	4.75249	5.15267	5.91697
75	2.51357	3.10817	4.01888	4.60413	4.98981	5.72404
70	2.40347	2.96947	3.84104	4.40399	4.77623	5.48212
65	2.33122	2.87761	3.71432	4.25323	4.61406	5.28993
60	2.24243	2.76716	3.56884	4.08518	4.43273	5.08384
55	2.17265	2.67870	3.44885	3.94456	4.27866	4.90235
50	2.13799	2.65269	3.40872	3.88482	4.20816	4.80296
45	2.08119	2.56722	3.27971	3.72841	4.03381	4.59355
40	2.02845	2.48555	3.15631	3.58009	3.87299	4.40169
35	1.94128	2.37515	3.00363	3.39853	3.67508	4.16699
30	1.84512	2.25227	2.83631	3.20165	3.46080	3.91555
25	1.74572	2.12772	2.66633	2.99977	3.23904	3.65065
20	1.60607	1.95623	2.44110	2.73791	2.95563	3.32183
17	1.54871	1.87033	2.31740	2.59276	2.79572	3.13555
15	1.47495	1.78053	2.19908	2.45471	2.64568	2.96294
14	1.44646	1.75130	2.16026	2.40664	2.59111	2.89580
13	1.39723	1.69831	2.09476	2.33057	2.50749	2.79870
12	1.35179	1.64902	2.03530	2.26301	2.43494	2.71373
11	1.30312	1.59777	1.97488	2.19510	2.36244	2.63004
10	1.27421	1.55775	1.91908	2.12988	2.29253	2.54767
9	1.22944	1.50227	1.84794	2.04914	2.20892	2.43907
8	1.18229	1.44761	1.77920	1.97042	2.12351	2.36022

Time of Travel (days) from Lockport Dam to Point Source Waste Load Location (cont.)

Flow Duration %	Point Source River Mile					
	226.50	222.21	218.24	211.19	209.36	190.51
99.8	10.03861	10.55652	10.96233	11.75824	11.96269	14.21006
99	8086790	9.33091	9.69499	10.41204	10.59679	12.64081
98	8.50202	8.93934	9.28243	9.95746	10.13169	12.06636
97	8.18244	8.60263	8.93262	9.58270	9.75064	11.61976
96	7.94453	8.35079	8.66875	9.29363	9.45517	11.25591
95	7.73290	8.12695	8.43557	9.04259	9.19959	10.95176
90	6.98675	7.34808	7.63352	8.19612	8.34129	9.95493
85	6.55408	6.89737	7.16895	7.70515	7.84367	9.38709
80	6.18388	6.51418	6.77453	7.28579	7.41746	8.87590
75	5.98399	6.30439	6.55780	7.05519	7.18309	8.59688
70	5.74070	6.05453	6.30218	6.78644	6.91077	8.28307
65	5.54538	5.85074	6.09113	6.55955	6.67962	8.00268
60	5.33157	5.62638	5.86078	6.31966	6.43720	7.73794
55	5.14355	5.42994	5.65928	6.10978	6.22533	7.51516
50	5.03634	5.31307	5.53621	5.97526	6.08785	7.35015
45	4.81686	5.08107	5.29561	5.71852	5.82698	7.04856
40	4.61280	4.86180	5.06567	5.46912	5.57249	6.73581
35	4.36590	4.59841	4.78959	5.16910	5.26644	6.36597
30	4.09958	4.31412	4.49199	4.84640	4.93724	5.96238
25	3.82120	4.01838	4.18287	4.51108	4.59516	5.54632
20	3.49674	3.68991	3.85164	4.17238	4.25459	5.19278
17	3.33105	3.53470	3.70880	4.04904	4.13488	5.08002
15	3.18035	3.39666	3.58283	3.93990	4.02894	4.97474
14	3.10847	3.32007	3.50294	3.85409	3.94178	4.87548
13	3.00563	3.21167	3.39043	3.73391	3.81979	4.73562
12	2.91574	3.11557	3.28903	3.62353	3.70755	4.61274
11	2.83298	3.03192	3.20388	3.53367	3.61653	4.50706
10	2.75037	2.94794	3.11829	3.44383	3.52580	4.40853
9	2.62973	2.81586	2.97864	3.29315	3.37329	4.25282
8	2.56298	2.75698	2.92651	3.25133	3.33380	4.22414

Time of Travel (days) from Lockport Dam to Point Source Waste Load Location (cont.)

Flow Duration	Point Source River Mile				
%	179.51	174.79	165.65	160.42	158.06
99.8	15.68171	16.92263	19.37045	20.52188	20.80044
99	13.98961	15.13155	17.39019	18.45536	18.71348
98	13.34869	14.43686	16.59267	17.61088	17.85786
97	12.86466	13.93719	16.06408	17.06423	17.30418
96	12.45793	13.49480	15.55280	16.52135	16.75384
95	12.12330	13.13477	15.14362	16.08958	16.31673
90	11.03922	11.97305	13.84367	14.72969	14.94270
85	10.42481	11.30738	13.07736	13.92099	14.12631
80	9.85700	10.67623	12.33268	13.12790	13.32247
75	9.54648	10.32875	11.91237	12.67616	12.86472
70	9.20614	9.96785	11.51176	12.25596	12.43919
65	8.89159	9.61520	11.08396	11.79538	11.97215
60	8.61637	9.37400	10.89271	11.61546	11.79079
55	8.38994	9.18926	10.76550	11.50067	11.67508
50	8.21139	9.03736	10.65309	11.39547	11.56797
45	7.88759	8.72935	10.36543	11.10685	11.27587
40	7.53366	8.31839	9.84418	10.53990	10.70030
35	7.11892	7.84780	9.25842	9.90362	10.05421
30	6.66345	7.32801	8.61460	9.20681	9.34679
25	6.20266	6.84555	8.09038	8.66099	8.79470
20	5.82761	6.48883	7.70547	8.24011	8.36381
17	5.70516	6.38363	7.60092	8.12152	8.24012
15	5.58960	6.27836	7.49643	8.00729	8.12190
14	5.48764	6.20094	7.46578	7.98948	8.10387
13	5.33885	6.06180	7.34392	7.87030	7.98383
12	5.21836	5.98659	7.35711	7.90773	8.02117
11	5.10370	5.87365	7.24572	7.79381	7.90620
10	5.00237	5.78762	7.18515	7.73778	7.84976
9	4.85104	5.67565	7.13784	7.70389	7.81595
8	4.82733	5.68979	7.21549	7.79464	7.90696

Appendix F

Ultimate Carbonaceous and Nitrogenous Inputs at Lockport on the Main Stem and Eight Tributaries

Ultimate BOD Loads at Lockport

$L_{ac} = 25.572\ Q_L - 5818$

$L_{an} = 86.970\ Q_L - 74618$

Flow Duration %	Ultimate Carbonaceous BOD, L_{ac} (lbs/day)	Ultimate Nitrogeneous BOD, L_{an} (lbs/day)
99.8	39215	78537
99	45020	98280
98	48907	111498
97	51720	121065
%	53510	127153
95	55811	134980
90	62972	159332
85	68342	1775%
80	72945	493250
75	75502	201948
70	79594	215852
65	81639	222820
60	84964	234126
55	87521	242823
50	88544	246302
45	90078	251520
40	92124	258478
35	95193	268914
30	99029	281960
25	101842	291527
20	107467	310660
17	111303	323706
15	113851	332403
14	114883	335882
13	118208	347188
12	122044	360234
11	127158	377628
10	132273	395021
9	139944	421112
8	147616	447204

Note: Q_L is the flow at Lockport for a given flow duration percent (see Appendix C)

Ultimate Tributary Carbonaceous (L_{ac}) BOD Load (lbs/day)

$$L_{ac} = A + BQ_T$$

	Des Plaines	Du Page	Kankakee	Mazon	Fox	Vermilion	I & M Canal	Bureau Creek
Coef								
A	6272.1	604.8	25384.1	566.8	22228.2	566.8	566.8	566.8
B	16.010	30.177	10.218	18.648	25.923	18.648	18.648	18.648
Flow Duration %								
99.8	6400	1480	29471	641	32598	772	585	604
99	6528	1631	30646	660	35579	791	585	604
98	6592	1721	31310	660	37264	809	585	604
97	6672	1812	31719	660	38301	809	585	604
96	6720	1842	32077	679	39208	828	585	604
95	6768	1902	32281	679	39727	847	604	623
90	6961	2144	33252	697	42189	902	604	623
85	7169	2385	34478	753	45300	1014	604	641
80	7377	2627	35398	809	47633	1145	623	660
75	7633	2898	36624	865	50744	1313	641	697
70	7921	3140	37850	958	53855	1518	660	735
65	8193	3381	39076	1070	56966	1798	697	772
60	8530	3713	40609	1219	60854	2171	735	847
55	8914	4015	42244	1462	65002	2767	791	940
50	9346	4407	44389	1686	70446	3308	847	1033
45	9858	4830	46842	2003	76667	4110	921	1164
40	10435	5282	50214	2469	85222	5229	1033	1350
35	11155	5946	53483	3233	93518	7094	1219	1667
30	12116	6731	57775	3830	104405	8586	1369	1928
25	13477	76%	61147	4613	112960	10450	1555	2226
20	15238	9054	65234	5583	123330	12875	1798	2637
17	16439	10262	72897	6739	142772	15672	2077	3122
15	17479	11318	79028	7653	158326	17910	2301	3495
14	18120	11770	80561	8269	162215	19401	2450	3756
13	18840	12314	82604	8791	167399	20707	2581	3961
12	19561	12977	85159	9238	173880	21826	2693	4147
11	20441	13732	88735	10021	182953	23691	2879	4464
10	21482	14486	93844	11084	195915	26301	3140	4912
9	22283	15241	99464	12222	210173	29099	3420	5229
8	23563	16448	104062	13136	221839	31336	3644	5770

Note: Q_T is the tributary flow for a given flow duration percent (see Appendix C); A and B are statistically derived regression coefficient

Ultimate Tributary Nitrogeneous (L_{an}) BOD Load (lbs/day)

$$L_{an} = A + BQ_T$$

	Des Flaines	Du Page	Kanka-kee	Mazon	Fox	Vermil-ion	I & M Canal	Bureau Creek
Coef								
A	1249.3	147.8	26198.0	1450.2	2430.6	1450.2	1450.2	1450.2
B	34.820	37.031	6.745	12.586	43.030	12.586	12.586	12.586
Flow Duration %								
99.8	1528	1222	288%	1501	19643	1589	1463	1475
99	1806	1407	29672	1513	24591	1601	1463	1475
98	1946	1518	30110	1512	27388	1614	1463	1475
97	2120	1629	30380	1513	29109	1614	1463	1475
96	2224	1666	30616	1526	30615	1626	1463	1475
95	2329	1740	30751	1526	31476	1639	1475	1488
90	2747	2036	31391	1538	35564	1677	1475	1488
85	3199	2333	32201	1576	40727	1752	1475	1501
80	3652	2629	32808	1614	44600	1840	1488	1513
75	4209	2962	33617	1652	49764	1964	1501	1538
70	4836	3258	34427	1715	54927	2092	1513	1563
65	5428	3555	35236	1790	60091	2281	1538	1589
60	6159	3962	36248	1891	66545	2533	1563	1639
55	6995	4332	37327	2054	73430	2935	1601	1702
50	7935	4814	38743	2205	82466	3300	1639	1765
45	9049	5332	40362	2419	92794	3842	1689	1853
40	10303	5888	42588	2734	106993	4597	1765	1979
35	11869	6702	44746	3250	120763	5855	1891	2193
30	13959	7665	47579	3653	138836	6862	1991	2369
25	16918	8850	79805	4181	153035	8121	2117	2570
20	20749	10516	52503	4836	170247	9757	2281	2847
17	23360	11998	57561	5616	202520	11645	2470	3175
15	25623	13294	61608	6233	228338	13156	2621	3426
14	27016	13849	62620	6648	234792	14163	2721	3602
13	28583	14516	63969	7001	243398	15044	2810	3741
12	30150	15330	65655	7303	254156	15799	2885	3867
11	32065	16256	68016	7832	269216	17057	3011	4081
10	34328	17182	71388	8549	290731	18820	3187	4383
9	36069	18108	75098	9317	314398	20707	3376	4597
8	38855	19589	78133	9933	333761	22218	3527	4962

Note: Q_T is the tributary flow for a given flow duration percent (see Appendix C); A and B are statistically derived regression coefficient

Appendix G

Tributary DO Concentrations Used in Conjunction with the Various Flow Duration Percents

Tributary DO Concentrations (mg/l)

$DO_T = A + BQ_T$

	Des Plaines	Du Page	Kankakee	Mazon	Fox	Vermilion	I & M Canal	Bureau Creek
Coef								
A	11.724	8.642	8.797	9.311	11.395	9.311	9.311	9.311
8	0.00679	0.00455	0.00015	0.00067	0.00075	0.00067	0.00067	0.00067
Flow Duration %								
99.8	11.67	8.51	8.74	11.27	9.30	9.31	9.31	9.31
99	11.62	8.49	8.72	11.22	9.30	9.31	9.31	9.31
98	11.59	8.47	8.71	11.19	9.30	9.31	9.31	9.31
97	11.55	8.46	8.70	11.18	9.30	9.31	9.31	9.31
96	11.53	8.46	8.70	11.17	9.30	9.31	9.31	9.31
95	11.51	8.45	8.70	11.16	9.30	9.31	9.31	9.31
90	11.43	8.41	8.68	11.12	9.30	9.31	9.31	9.31
85	11.34	8.37	8.66	11.08	9.30	9.30	9.31	9.31
80	11.26	8.34	8.65	11.05	9.29	9.30	9.31	9.31
75	11.15	8.30	8.63	11.01	9.28	9.30	9.31	9.31
70	11.02	8.26	8.61	10.97	9.28	9.30	9.31	9.31
65	10.91	8.22	8.60	10.93	9.27	9.29	9.31	9.30
60	10.77	8.17	8.57	10.88	9.25	9.29	9.31	9.30
55	10.60	8.13	8.55	10.82	9.23	9.28	9.30	9.30
50	10.42	8.07	8.52	10.75	9.21	9.27	9.30	9.29
45	10.20	8.00	8.48	10.67	9.18	9.26	9.30	9.29
40	9.96	7.94	8.43	10.57	9.14	9.24	9.29	9.28
35	9.65	7.84	8.38	10.44	9.08	9.22	9.29	9.27
30	9.25	7.72	8.32	10.31	9.02	9.19	9.28	9.26
25	8.67	7.57	8.27	10.11	8.96	9.17	9.28	9.25
20	7.92	7.37	8.21	9.83	8.87	9.13	9.27	9.24
17	7.41	7.19	8.10	9.64	8.77	9.09	9.26	9.22
15	6.97	7.03	8.01	9.46	8.69	9.06	9.25	9.21
14	6.70	9.96	7.99	9.35	8.63	9.03	9.24	9.20
13	6.39	6.88	7.96	9.26	8.59	9.02	9.24	9.19
12	6.09	6.78	7.92	9.14	8.55	9.00	9.23	9.18
11	5.72	6.66	7.87	9.03	8.48	8.97	9.23	9.17
10	5.27	6.55	7.79	8.89	8.39	8.93	9.22	9.16
9	4.93	6.44	7.70	8.75	8.29	8.89	9.21	9.14
8	4.39	6.25	7.64	8.56	8.21	8.86	9.20	9.12

Note: Q_T is the tributary flow for a given flow duration percent (see Appendix C); A and B are statistically derived regression coefficients

Appendix H

Carbonaceous and Nitrogenous BOD Usage Rates Used with Various Flow Duration Percents

Carbonaceous BOD Usage Rates(K_c, l/days) for
Various Flow Duration Percents

$\log K_c = A\log Q_L + B\log Q_M + C\log Q_H + D$

	291.0- 288.7	288.7- 278.0	278.0- 270.6	270.6- 231.0	231.0- 222.6	222.6- 179.0	179.0- 167.0	167.0- 157.0
Coef								
A	-2.8988	-6.5026	-5.8225	-4.2911	-4.3514	**	-5.7437	-5.7437
B	0.6646	1.9881	1.9784	1.1448	1.1791	**	1.5449	1.5449
C	0.1279	0.1578	0.1239	0.1495	0.1078	**	0.1169	0.1169
D	6.3309	13.7544	11.5074	9.1577	9.4027	**	12.9137	12.9137
Flow Duration %								
99.8	.3500	.6070	.4400	.3350	.3430	.4455	.5480	.5480
99	.3500	.6070	.4400	.3350	.3430	.4455	.5480	.5480
98	.3345	.5919	.4253	.3203	.3279	.4305	.5330	.5330
97	.3001	.4703	.3491	.2736	.2793	.3550	.4306	.4306
%	.2839	.4247	.3213	.2542	.2590	.3241	.3893	.3893
95	.2610	.3566	.2765	.2255	.2293	.2082	.3310	.3310
90	.2040	.2130	.1774	.1585	.1601	.1828	.2055	.2055
85	.1710	.1463	.1280	.1230	.1235	.1346	.1457	.1457
80	.1504	.1125	.1022	.1025	.1027	.1083	.1139	.1139
75	.1412	.0991	.0920	.0938	.0938	.0974	.1009	.1009
70	.1261	.0779	.0746	.0796	.0794	.0802	.0809	.0809
65	.1218	.0734	.0713	.0761	.0758	.0759	.0760	.0760
60	.1130	.0648	.0627	.0685	.0680	.0669	.0658	.0658
55	.1076	.0574	.0552	.0640	.0635	.0618	.0600	.0600
50	.1081	.0590	.0601	.0648	.0643	.0626	.0608	.0608
45	.1080	.0603	.0619	.0652	.0646	.0629	.0611	.0611
40	.1061	.0592	.0615	.0640	.0633	.0614	.0594	.0594
35	.1026	.0565	.0598	.0615	.0606	.0583	.0560	.0560
30	.0979	.0524	.0568	.0579	.0570	.0543	.0515	.0515
25	.0976	.0540	.0593	.0584	.0574	.0546	.0517	.0517
20	.0925	.0501	.0567	.0547	.0536	.0504	.0471	.0471
17	.0889	.0471	.0543	.0521	.0509	.0474	.0438	.0438
15	.0875	.0465	.0543	.0512	.0500	.0464	.0427	.0427
14	.0876	.0471	.0553	.0515	.0502	.0466	.0429	.0429
13	.0834	.0429	.0512	.0482	.0469	.0431	.0392	.0392
12	.0787	.0382	.0464	.0444	.0431	.0390	.0350	.0350
11	.0723	.0320	.0399	.0393	.0381	.0339	.0297	.0297
10	.0666	.0270	.0345	.0350	.0338	.0296	.0253	.0253
9	.0591	.0201	.0278	.0294	.0284	.0243	.0201	.0201
8	.0527	.0165	.0226	.0250	.0240	.0201	.0161	.0161

Note: Q_L, Q_M, and Q_H are flows at the Lockport, Marseilles, and Henry gaging stations (see Appendix B)

** Regression analysis produced nonsensical results for the carbonaceous coefficients in this reach. The listed K-values are the averages of the up and downstream reach values

Nitrogeneous BOD Usage Rates(K_n, l/days) for
Various Flow Duration Percents
$\log K_n = A\log Q_L + B\log Q_M + C\log Q_H + D$

	291.0-288.7	288.7-278.0	278.0-270.6	270.6-231.0	231.0-222.6	222.6-179.0	179.0-167.0	167.0-157.0
Coef								
A	-3.4327	-2.3518	-3.5379	-6.0539	-6.0539	-4.2870	-1.6308	-1.3521
B	1.4361	1.4252	1.3600	2.5272	2.5272	2.5476	1.2887	0.6307
C	0.0000	-0.1558	0.0127	0.0000	0.0000	-0.1553	-0.1153	0.0602
D	5.4217	2.3569	6.1634	10.6574	10.6574	4.9337	0.2182	0.9829
Flow Duration %								
99.8	.1877	.1271	.2857	.4110	.4110	.2016	.0956	.1022
99	.1482	.1126	.2209	.4110	.4110	.1625	.0912	.0944
98	.1274	.1038	.1875	.3149	.3149	.1409	.0881	.0897
97	.1145	.0979	.1671	.2609	.2609	.1269	.0858	.0864
96	.1101	.0968	.1597	.2434	.2434	.1224	.0862	.0855
95	.1015	.0925	.1463	.2109	.2109	.1149	.0845	.0832
90	.0797	.0808	.1129	.1376	.1376	.0902	.0791	.0764
85	.0665	.0726	.0931	.1000	.1000	.0744	.0745	.0716
80	.0590	.0682	.0818	.0809	.0809	.0666	.0727	.0688
75	.0559	.0665	.0814	.0735	.0735	.0637	.0722	.0676
70	.0498	.0621	.0681	.0599	.0599	.0564	.0692	.0649
65	.0489	.0622	.0661	.0573	.0573	.0568	.0702	.0645
60	.0458	.0602	.0618	.0520	.0520	.0536	.0700	.0634
55	.0441	.0595	.0592	.0484	.0484	.0526	.0702	.0627
50	.0455	.0616	.0608	.0510	.0510	.0562	.0729	.0639
45	.0468	.0640	.0623	.0537	.0537	.0605	.0762	.0651
40	.0472	.0655	.0624	.0544	.0544	.0632	.0787	.0657
35	.0471	.0668	.0618	.0542	.0542	.0659	.0815	.0662
30	.0464	.0678	.0603	.0528	.0528	.0680	.0843	.0665
25	.0485	.0720	.0626	.0572	.0572	.0763	.0903	.0684
20	.0485	.0745	.0616	.0569	.0569	.0819	.0958	.0693
17	.0480	.0756	.0605	.0559	.0559	.0846	.0989	.0697
15	.0485	.0776	.0608	.0570	.0570	.0889	.1025	.0705
14	.0494	.0793	.0617	.0588	.0588	.0928	.1050	.0712
13	.0476	.0782	.0592	.0551	.0551	.0906	.1053	.0706
12	.0453	.0764	.0559	.0504	.0504	.0872	.1047	.0695
11	.0417	.0730	.0512	.0436	.0436	.0804	.1026	.0676
10	.0385	.0699	.0470	.0379	.0379	.0744	.1005	.0658
9	.0342	.0654	.0414	.0308	.0308	.0661	.0973	.0632
8	.0306	.0614	.0367	.0253	.0253	.0591	.0944	.0608

Note: Q_L, Q_M, and Q_H are, respectively, the flows at the Lockport, Marseilles, and Henry gaging stations (see Appendix B); the regression equations produced unrealistically high values for flows for the 99.8 and 99 percent durations

Appendix I

Examples of BOD-DO Model Runs for 99.8 Percent Flow Duration at 12°C and 28°C and for 8 Percent Flow Duration at 12°C and 28°C

(River mile points represent SWS designations)

FILE = A:998PCEN.DAT
Ts = 12

MP	DO
291.00	0.50
290.99	0.50
290.68	0.49
289.94	0.47
289.94	0.52
288.66	0.29
287.23	0.02
286.25	0.00
286.25	7.89
286.21	7.88
285.82	7.91
285.33	7.85
284.39	7.61
284.01	7.50
283.72	7.43
281.09	6.76
280.47	6.65
278.30	6.43
278.12	6.40
277.82	6.36
276.96	6.21
276.96	6.24
276.22	5.92
273.56	4.99
272.90	4.85
272.90	5.47
272.41	5.19
272.19	5.07
271.67	4.69
271.52	4.57
271.52	9.27
270.64	9.15
270.23	9.08
267.09	8.43
265.00	7.99
263.67	7.72
263.52	7.70
263.52	7.70
262.75	7.57
261.58	7.40
257.97	6.9B
256.00	6.76
254.35	6.60
252.97	6.45
252.42	6.40
250.01	6.24
248.65	6.16
247.08	6.07
246.78	6.05
246.75	6.07
245.90	6.25
243.73	6.51
243.42	6.51
242.68	6.49
239.45	6.45
239.17	6.44
239.17	6.68
238.63	6.61
236.97	6.47
236.29	6.38
234.30	6.22
231.06	6.06
231.02	6.05
231.02	8.71
229.63	B.71
228.85	8.65
226.50	8.49
226.50	8.49
224.89	8.40
223.35	8.30
222.60	8.27
222.21	8.26
220.10	8.19

FILE = A:99BPCEN.DAT
Ts = 28

MP	DO
291.00	0.50
290.99	0.50
290.68	0.46
2B9.94	0.33
289.94	0.39
288.66	0.00
287.23	0.00
286.25	0.00
286.25	6.20
286.21	6.18
285.82	6.18
285.33	6.03
284.39	5.49
284.01	5.27
283.72	5.12
281.09	3.73
280.47	3.54
278.30	3.20
278.12	3.16
277.82	3.10
276.96	2.89
276.96	2.97
276.22	1.85
273.56	2.31
272.90	0.00
272.90	0.20
272.41	0.00
272.19	0.00
271.67	0.00
271.52	0.00
271.52	6.37
270.64	5.91
270.23	5.66
267.09	3.75
265.00	2.74
263.67	2 23
263.52	2.18
263.52	2.20
262.75	1.80
261.58	2.18
257.97	0.39
256.00	2.43
254.35	0.00
252.97	2.82
252.42	0.00
250.01	0.24
248.65	0.42
247.08	0.5B
246.78	0.62
246.75	0.6B
245.90	1.26
243.73	2.06
243.42	1.94
242.68	2.13
239.45	1.76
239.17	2.36
239.17	2.81
238.63	2.58
236.97	2.15
236.29	1.92
234.30	2.57
231.06	1.28
231.02	2.70
231.02	6.00
229.63	4.60
228.85	4.51
226.50	4.28
226.50	4.30
224.89	4.07
223.35	3.83
222.60	3.77
222.21	3.74
220.10	3.63

```
FILE = A:8PCEN.DAT
Ts =  12

   MP      DO

291.00   0.50         248.65   9.78
290.99   0.50         247.08   9.77
290.68   0.51         246.78   9.76
289.94   0.53
                      246.78  10.20
289.94   1.12
                      246.75  10.20
288.66   1.13         245.90  10.20
287.23   1.15         243.73  10.19
286.25   1.18         243.42  10.19
                      242.68  10.18
286.25   8.20         239.45  10.15
                      239.17  10.15
286.21   8.20
285.82   8.20         239.17   9.84
285.33   8.20
284.39   8.17         238.63   9.84
284.01   8.15         236.97   9.83
283.72   8.14         236.29   9.83
                      234.30   9.B3
281.09   B.04         231.06   9.83
2B0.47   8.02         231.02   9.83
278.30   7.98
278.12   7.97         231.02  10.42
277.82   7.96         229.60  10.42
276.96   7.92         228.85  10.41
                      226.50  10.39
276.96   7.81
                      226.50  10.21
276.22   7.77
273.56   7.69         224.89  10.20
272.90   7.68         223.35  10.18
                      222.66  10.17
272.90   7.66         222.21  10.17

272.41   7.66         220.10  10.12
272.09   7.66
271.67   7.67
271.52   7.67

271.52  10.02

270.64  10.02
270.23  10.02
267.09   9.98
265.00   9.96
263.67   9.95
263.52   9.95

263.52   9.90

262.75   9.90
261.58   9.89
257.97   9.86
256.00   9.85
254.35   9.83
252.97   9.82
252.42   9.82

250.01   9.80
```

```
FILE = A:BPCEN.DAT
Ts =  28

   MP      DO

291.00   0.50         248.65   7.06
290.99   0.50         247.08   7.02
290.68   0.50         246.78   7.01
289.94   0.52
                      246.78   7.40
289.94   1.11
                      246.75   7.40
288.66   1.09         245.90   7.39
287.23   1.06         243.73   7.38
286.25   1.03         243.42   7.38
                      242.68   7.36
286.25   6.40         239.45   7.29
                      239.17   7.28
286.21   6.40
285.82   6.40         239.17   7.53
285.33   6.38
284.39   6.30         238.63   7.52
284.01   6.25         236.97   7.49
283.72   6.22         236.29   7.48
                      234.30   7.44
281.09   5.94         231.06   7.41
280.47   5.88         231.02   7.41
278.30   5.78
278.12   5.76         231.02   7.64
277.82   5.74         229.60   7.63
276.96   5.63         228.85   7.60
                      226.50   7.52
276.96   5.67
                      226.50   7.58
276.22   5.58
273.56   5.34         224.89   7.53
272.90   5.32         223.35   7.48
                      222.66   7.46
272.90   6.49         222.21   7.45

272.41   6.47         220.10   7.30
272.09   6.46
271.67   6..43
271.52   6.42

271.52   7.50

270.64   7.49
270.23   7.48
267.09   7.40
265.00   7.35
263.67   7.31
263.52   7.31

263.52   7.38

262.75   7.36
261.58   7.33
257.97   7.26
256.00   7.22
254.35   7.19
252.97   7.16
252.42   7.15

250.01   7.09
```

Appendix J

The BOD-DO Model Program Written in BASIC

DOBOD MODEL PROGRAM

The DOBOD program is a direct translation from the original program to the BASIC program language. The original was written by T. A. BUTTS for the Wang 720C. The translated program differs from the original in that:

1. the input data is read from sequential files stored on disks
2. The check of the height of dam has been changed to 4.55<step 1110)
3. The various data manipulations required in the Wang program to prevent loss of data and computations have been eliminated.
4. The check value in the series expansion has been set at 0.0000005 (step 650).
5. The results are sent to the printer instead of the terminal.

There are two versions of the DOBOD program--l) uncompiled and 2) compiled. Both versions reside in the subdirectory PROGRAM as DOBOD.BAS (uncompiled) and DOBOD.EXE (compiled). The compiled version runs several times faster than the uncompiled. However, the user must be familiar with IBM PC operation to run either program. The hardware system used in the development of the program was an IBM XT and an EPSON LX-80 printer. The program should work on any equipment compatible to the IBM and EPSON.

To run the compiled program do:

1) Boot-up the IBM in the usual manner.
2) Turn on printer.
3) Change to the subdirectory PROGRAM by CD\PROGRAM (enter)
4) Insert data disk into floppy slot.
5) Type DOBOD (enter).
6) Enter the data asked for at the prompts.
   Note; The data filename must be entered as A:filename.ext
   ____NO SPACES ALLOWED!!!!
7) Repeat steps 4 (when necessary), 5 and 6 for all sets of data.

Following is a copy of the DOBOD program:

```
10 REM________________________________DOBOD MODEL____________________________________________
20 REM  The following is a list of the parameters used and their definitions.
30 REM Initial Input            Sub-section Input       Re-initialization
40 REM
50 REM MP=river mile @ start    MP=river mile @ end
60 REM tl=T0T @ start (days)  t2=TOT  @  end (days)
70 REM DOac=DO @ start  (mg/l)  H=Avg. depth (feet)
80 REM Ql=Flow @ start (cfs)    Qa=Avg. flow (cfs)
90 REM Lac = ult.carb. (lbs/day) G20=SOD rate (gm/sqm/d) Lac
100 REM Lan=ult nitro(lbs/day)  PR=Algae +/- (gm/sqm/d) Lan
110 REM Kc=carb rate (/day)     02=Flow @ end (cfs)     Kc
120 REM t0=Nit lag time (days)  Qt=Trib flow (cfs)
130 REM Kn=Nitro rate (/day)   DOtc=Trib  DO (mg/l)     Kn
140 REM Tr=Ref temp (deg Cel)   A=WQ factor S dam
150 REM                         B=Dam aeration factor
160 REM                         HD=Height of dam (feet)
170 REM                         C0DE= 1 input more data; 2 re-initialize
180 REM_______________________________DEFINE THE FUNCTIONS USED___________________________
190 DEF FNKC20(T) =           1.047^(T-20)          'convert carbonaceous rate
```

```
200 DEF FNKN20(T) =  1.097^(T-20)  convert nitrogenous rate 10-22 deq Celsius
210 DEF FNKN22(T) = 1.203*(.877^(T-22)) 'convert nitro rate 22-30 deq Celsius
220 DEF FNKA20(T) =          1.024^(T-20)          'convert reaeration rate
230 DEF  FNL20(T) = .02*T+.6                                'convert ultimate
240 DEF FNDOSAT(T) = 14.652-.41022*T+.007991*T^2-7.7774E-05*T^3 'compute DOsat
250 DEF FNMGE3(H) = 13.94*(LOG(H))-7.45               'compute M for H>=3 feet
260    DEF    FNMLT3(H)    =    .721*H    +    2.279    'compute M for H<3 feet
270 DEF FNK(H,N,T) = (6.291BE-05/H^2)*M*(1.1^(T-20)) 'compute K for series e>:p
280 REM__________________________DATA INPUT FROM DISK___________________________
290 ON ERROR GOTO 1270
300 INPUT "Enter A: (f i 1 ename. ext) of datafile used"; NAM$
310 INPUT "Enter Simulation Temperature--Ts";TS
320 LPRINT "FILE = ";NAM$
330 LPRINT "Ts = ";TS:LPRINT
340 LPRINT "MILEP0iNT","DO":LPRIMT
350 OPEN "I", #1,                    NAM$                      'open data file
360 INPUT#1,MP.,T1,DOAC,Q1,LAC,LAN,KC,T0,KN,TR                      'Initialize
370 LPRINT USING "####.##";MP, DOAC
380 AAA =              T1                      'Set variable for SOD & ALGAE
390 INPUT#1,MP,T2,H,QA,G20,PR,Q2,QT,DOTC,A,B,HD,CODE               'data input
400 REM__________________________COMPUTATIONS___________________________________
410 KC20=KC/FNKC20<TR)             'Convert KC (reference temperature) to KC20
420 KCS = KC20*FNKC20(TS)       'Convert KC20 to KCS (simulation temperature)
430 REM —________Convert KN (reference temperature) to KN20_____________________
440 IF TR>=22 THEN KN20 = KN/FNKN22(TR) ELSE KN20 = KN/FNKN20 (TR)
450 REM__________Convert KN20 to KNS (simulation temperature)___________________
460 IF TR>=22 THEN KNS=KN20*FNKN22(TS) ELSE  KNS = KN20*FNKN20(TS)
470 LACS = LAC*FNL20(TS)      'convert ultimate § 20 to ultimate § simulation
480 REM__________check for nitrogenous demand and adjust variables if needed____
490 IF KNS <=0 THEN 500 ELSE IF (DOA-2)>0 THEN 500 ELSE T0=T2
500 KCT = KCS*(T2-T1)                             'compute carbonaceous exponent
510 LCUSED = LAC*(1-EXP(-KCT))              'carbonaceous use between Tl and T2
520 KNT = KNS*(T2-T1-T0)                            'compute nitrogenous exponent
530 IF KNT <0 THEN KNT = 0                       'nitrogenous lag time > (T2-T1)
540 LNUSED = LAN*(1-EXP(-KNT))               'nitrogenous use between Tl and T2
550 DOU = LCUSED + LNUSED                            'biological use in sub-reach
560 REM__________calculate mix time time (M) for depth (H)______________________
570 IF H > = 3 THEN M = 13.94*L0G (H) -7.45 ELSE M = .721*H + 2.279
580 MIXES = 1440*(T2-T1)/M                    'number of mixes between Tl and T2
590 REM__________compute K for (H) in feet and (M) in minutes___________________
600 K = (6.2918E-05/(H*H))*(1.1^(TS-20))*M
610 REM__________series expansion of e^(-K(2N-1)^2)/(2N-1)^2____________________
620 SUM = 0
630 FOR I = 1 TO 1000
640 AA = (2*1-1)^2:BB = EXP (-K*AA):CC = BB/AA:SUM = SUM+CC
650 IF CC <.0000005 GOTO 670
660 NEXT I
670 SATDO = FNDOSAT(TS)          'saturation DO @ simulation temperature--mg/l
680 R0 = 100-81.06*SUM                      "/. DO absorbed/mix @ zero initial DO
690 R = R0/100                                 'DO absorbed/mix @ zeroinitial DO
700 E = 5.39136*QA*SATDO                   'avg.saturation DO in reach--lbs/day
710 F = E*MIXES*R                      'partial computation of Gannon's equation
720 DOA = 5.39136*Q1*DOAC                      'convert DOA (mg/l) to (lbs/day)
730 REM__________________________SOD USE________________________________________
740 GS = G20*FNKC20(TS)                        'SOD rate @ simulation temperature
750 GPRIME = 3.28*GS*(T2-AAA)/H                                     'SOD in reach
760 SODUSED = GPRIME*QA*5.39136                          'SOD in reach--lbs/day
770 DOU = DOU + SODUSED                                   'use in reach—lbs/day
```

```
780 REM____________________________ALGAE USE____________________________________
790 PRS = PR*FNKC20(TS)                       'Algae rate § simulation temperature
800 PRPRIME = PRS*(T2-AAA)/H                                     'Algae use in reach
810 PRUSED = 5.39136*QA*PRPRIME                        'Algae use in reach--lbs/day
820 REM__________________________Add algae use if respiring; subtract if producing
830 IF PR <0 THEM DOU=DOU+PRUSED ELSE DOU=DOU-PRUSED
840 REM ________________________________________________________________________
850 D =     DOA-DOU/2     'DO remaining @ end of reach--no reaeration--lbs/day
860 X = 0
870 DEFICIT = (1-D/E)                                               'Oxygen deficit
880 DOR = DEFICIT*F           'amt of oxygen absorbed in reach — Gannon equation
890 DON =                DOA+DOR-DOU                'net DO @ end of reach--lbs/day
900 DONC = DON/(5.39136*01)                            'net DO @ end of reach—mg/l
910 IF DONC <0 THEN DONC=0
920 X = X+i
930 IF X >1 GOTO 970
940 0 = <DOA+DON)/2            'replace (DOA-DOU/2) with (DOA+DON)/2--lbs/day
950 DOAC = DONC              'replace initial DO in reach with DOnet — lbs/day
960 GOTO 870
970 IF ABS(DONC-DOAC)>.05 GOTO 940       'compute DOnc until difference <0.05
980 Y = 5.39136*(Q2-Q1)*DONC+DON                        'dissolved oxygen—lbs/day
990 DOAC = DONC
1000 LPRINT USING "####.##";MP,DOAC
1010 REM________________________----INFLUENCE OF TRIBUTARY_______________________
1020 IF QT = 0 GOTO 1090
1030 DOTL =          5.39136*GT*DOTC           'convert tributary DO to lbs/day
1040 IF Y <0 THEN DON=0
1050 DOXC = (DOTL+Y)/(5.39136*(Q2+QT))      'DO concentration after trib—mg/l
1060 IF DOXC =< 0 THEN DOAC = DOAC ELSE DOAC = DOXC
1070 LPRINT:LPRINT USING "####.##";MP, DOAC
1080 REM____________________________INFLUENCE OF DAM_____________________________
1090 IF HD = 0 GOTO 1160
1100 HD = HD/3.28083                        'convert dam height from feet to meters
1110 IF HD >4.55 THEN HD=4.55
1120 DR =          1+.38*A*B*HD*(1-.11*HD)*(i+.046*TS)           'Deficit ratio
1130 DOXD =  SATDO-((SATDO-DONO/DR)  'DO concentration downstream of dam--mg/l
1140 IF HD =0 THEN DOAC=DOAC ELSE DOAC=DOXD
1150 LPRINT:LPRINT USING "####.##";MP,DOAC
1160 AAA = T2
1170 IF C0DE=2 THEN GOTO 1190 ELSE GOTO 390
1180 REM____________________________RE-INITIALIZE________________________________
1190 INPUT#1,LAC,LAN,KC,KN
1200 T1=T2
1210 AAA=T1
1220 Q1=Q2
1230 T0=T2
1240 LPRINT
1250 GOTO 390
1260 REM____________________________CLOSE DATA FILE; TERMINATE___________________
1270 IF ERR = 62 THEN CLOSE #1:LPRINT CHR$(27)CHR$(12)
1280 END
```

CREATION OF SEQUENTIAL DATA FILES

There are two common methods of storing information on a diskette. The packed binary format is used to store (code) information for random access files.. These are the type of files used in spreadsheets and relational data base management programs. ASCII (American Standard

Code for Information interchange) format is used to store (code) information for sequential files.

The DOBOD program was written to read data stored (coded) on a diskette as a sequential file. This requires that the data files be generated by a program that stores data in the ASCII format. Word Processing programs are programs whose output is in the ASCII format.

PC-WRITE is such a word processing program and is located in the subdirectory PCW. It can be accessed from the root directory with the command CD\PCW <enter>. The Tutorial and Quick Guide for the PC-WRITE program are available within the Water Quality Section. No discussion of how to use this program will be presented here. It is assumed the user will be skilled in PC-WRITE.

Data for the DOBOD program is of three catagories; 1) Initialization (one record), 2) Input (one or more records) and 3) Re-initialiration (one record). Individual inputs of each record must be separated by a comma and no blank spaces are allowed.

For the Initialization data record the following individual inputs are:

Data Types	Symbol
River Mile @ start of sub-section	MP
Time-of-travel (days)	t_1
Dissolved Oxygen (mg/L)	DO_{ac}
Discharge of river (cfs)	Q_1
Ultimate Carbonaceous (lbs/day)	L_{ac}
Ultimate Nitrogenous (lbs/day)	L_{ac}
Carbonaceous rate (/day)	K_c
Nitrogenous Lag Time (days)	t_0
Nitrogenous rate (/day)	k_n
Reference temperature °Cel	$T_?$

For the Input record(s) the following individual inputs are:

Data Types	Symbol
River Mile S end of sub-section	MP
Time-of-travel @ end	t_2
Avg. depth of river (feet)	H
Avg. discharge in sub-sect. (cfs)	$Q_?$
SOD rate (gm/m^2/day)	G_{20}
Algae +/- (gm.m^2/day)	PR
Discharge of river @ end (cfs)	Q_2
Tributary discharge (cfs)	Q_t
Tributary DO (mg/L)	DO_{tc}
Water Quality Factor § dam	A
Dam aeration factor	B
Height of dam (feet)	HD
Program control (1 = input more data; 2 = re-initialization)	CODE

For the Re-initialization record the following individual inputs are:

Data Types	Symbol
Ultimate Carbonaceous (lbs/day)	L_{ac}
Ultimate Nitrogenous (lbs/day)	L_{an}
Carbonaceous rate (/day)	k_c
Nitrogenous rate (/day)	k_n

Following is a copy of the file 70PCEN.DAT showing the format of the data entry:

```
291.00,0,.5,3340,79594,215862,.126,0,0,20
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123478,222033,.078,0
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286.25,.51969,12.43,3515,3.5,0,3521,0,0,1.1,1.87,33.6,2
128895,231859,.078,0
286.21,.52217,2.52,3522,3.5,0,3522,0,0,0,0,0,1
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126949,231882,.078,0
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278.12,1.44391,13.04,3654,3.0,0,3654,0,0,0,0,0,1
277.82,1.48455,11.39,3658,3.0,0,3659,0,0,0,0,0,1
276.96,1.60699,8.02,3668,3.5,0,3673,84,8.26,0,0,0,2
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161597,271826,.075,0
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272.19,2.26605,15.64,5056,3.0,0,5056,0,0,0,0,0,1
271.67,2.36944,15.07,5060,3.0,0,5064,0,0,0,0,0,1
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150894,271826,.08,0
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263.67,2.95816,10.30,5184,1.5,0,5195,0,0,0,0,0,1
263.52,2.96947,10.81,5198,1.5,0,5198,21,9.3,0,0,0,2
145702,273779,.08,.06
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257.97,3.37550,10.10,5279,1.5,0,5310,0,0,0,0,0,1
256.00,3.53408,10.22,5325,1.5,0,5342,0,0,0,0,0,1
254.35,3.66370,9.78,5355,1.5,0,5369,0,0,0,0,0,1
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136548,259361,.08,.06
250.01,4.06617,11.22,5422,1.5,0,5441,0,0,0,0,0,1
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```

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247.08,4.36399,11.96,5476,1.5,0,5489,0,0,0,0,0,1
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130686,252685,.08,.06
246.75,4.40465,.86,5494,.5,0,5494,0,0,0,0,0,1
245.90,4.41578,1.32, 5502,.5,0,5508,0,0,0,0,0,1
243.73,4.45748,2.96,5553,.5,0,5593,0,0,0,0,0,1
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242.68,4.52874,9.26,5614,1.5,0,5630,0,0,0,0,0,1
239.45,4.75018,10.03,5684,1.5,0,5742,0,0,0,0,0,1
239.17,4.77623,10.76,5752,1.5,0,5752,565,10.97,0,0,0,2
182050,302260,.08,.06
238.63,4.82620,12.49,6328,1.5,0,6336,0,0,0,0,0,1
236.97,4.94727,10.73,6367,1.5,0,6394,0,0,0,0,0,1
236.29,5.02208,12.42,6408,1.5,0,6418,0,0,0,0,0,1
234.30,5.19454,10.33,6454,1.5,0,6487,0,0,0,0,0,1
231.06,5.47399,11.27,6549,1.0,0,6600,0,0,0,0,0,1
231.02,5.48212,15.99,6602,1.0,0,6602,0,0,1.25,.914,17.7,1
229.63,5.55401,5.98,6624,.5,0,6650,0,0,0,0,0,1
228.85,5.60122,10.81,6665,2.0,0,6677,0,0,0,0,0,1
226.50,5.74070,10.09,6718,2.0,0,6759,51,9.28,0,0,0,2
171829,287357,.079,.06
224.89,5.85693,11.61,6839,1.5,0,6867,0,0,0,0,0,1
223.35,5.98877,14.77,6869,1.5,0,6920,0,0,0,0,0,1
222.66,6.03242,14.02,6935,1.5,0,6944,0,0,0,0,0,1
222.21,6.05453,11.38,6953,1.5,0,6960,0,0,0,0,0,2
166259,282198,.08,.056
220.10,6.17843,10.12,7000,1.5,0,7034,0,0,0,0,0,1
```

After the sequential data file has been generated by the word processing program the file is copied to the diskette using the command:

```
COPY (filename.ext)/V A:
```

Naming the file (filename. ext) uses the conventions listed in the DOS manual. It is suggested that the (ext) be .DAT signifinq that the file is a data file. The /V portion of the copy command is an instruction that causes the IBM XT to verify that the file is copied correctly to the diskette.

This program description and instructions were written using PC WRITE and is stored in the PCW subdirectory as the file DOB0D.TXT.

--D. H. SCHNEPPER

Appendix K

Data Used to Develop Stepwise Regression Relationships

Data Collected at Dresden Island Which Was Used to Develop Stepwise Regression Equations Relating Either the DO Percent Saturation Below the Dam, the Deficit Ratio (r), the Dam Aeration Coefficient (b), or the Beta-factor (3) to Various Physical and Water Quality Parameters

1986	Gates open		Head (ft.)		Discharge	a	COD	MBAS	SS	Aleae (no/ml)		Temp	DO C% sat.)		r	b	
Date	No.	ft/gate	Total	@ Sill	cfs	(eg. 2)	mg/l	mg/l	mg/l	Above	Below	°C	Above	Below	(eg. 1)	(ea. 2)	β
7/08 a.m.	4	2	17.49	3.72	11,419	1.50	25.7	0.04	53	391	1071	28.1	81.4	102.6	6.64	1.89	1.03
7/15 a.m.	6	2	15.69	1.92	15,323	1.81	18.4	0.10	79	296	128	25.7	78.0	108.1	5.94	1.44	1.04
7/15 p.m.	5	2	16.57	2.91	12,720	1.71	15.2	0.09	15	634	208	27.9	80.3	101.6	5.52	1.34	0.99
7/22 a.m.	2	3	19.33	5.34	7,534	1.08	17.8	0.10	32	452	716	29.7	97.2	109.3	4.60	1.63	1.04
7/22 p.m.	2	3	19.06	5.24	7,523	1.40	19.0	0.08	26	260	956	29.6	102.9	110.7	5.31	1.51	1.01
7/28 a.m.	2	3	19.28	5.56	7,440	1.23	24.8	0.07	31	389	645	28.9	90.3	107.4	4.94	1.59	1.05
7/28 p.m.	2	3	19.30	5.74	7,477	1.59	25.5	0.09	28	1109	1147	29.3	104.6	112.0	6.00	1.55	1.07
8/12 a.m.	4	1	20.09	6.32	5,169	2.05	20.7	0.08	41	1107	1747	26.4	75.4	100.4	7.17	1.57	0.98
8/12 p.m.	4	1	20.31	6.50	5,179	1.39	19.7	0.07	37	412	756	27.8	95.1	110.5	4.80	1.40	1.06
8/13 a.m.	5	1	20.03	6.24	6,465	1.68	23.2	0.06	39	132	1035	26.4	79.9	102.2	4.78	1.18	1.00
8/13 p.m.	3	1	20.54	6.87	3,863	1.56	22.2	0.08	39	307	510	27.0	81.2	103.4	5.22	1.33	1.01
8/18 a.m.	1	4	20.41	6.64	4,873	2.16	19.3	0.07	27	116	844	27.7	85.1	101.0	8.53	1.78	0.98
8/18 p.m.	1	4	20.46	6.81	4,856	1.53	19.2	0.06	21	496	210	27.7	91.0	97.0	4.90	1.30	0.97
8/19 a.m.	1	4	20.31	6.53	4,878	2.69	22.1	0.06	28	636	779	27.0	86.0	101.2	7.87	1.32	0.98
8/19 p.m.	1	4	21.26	6.56	4,864	1.46	20.5	0.06	26	651	1208	27.4	101.4	105.3	5.67	1.64	1.00
8/20 p.m.	2	2	20.29	7.51	5,106	1.11	31.3	0.07	26	542	764	27.5	100.7	101.5	4.00	1.38	0.96
8/27 p.m.	4	1	20.11	6.35	5,166	1.44	19.5	0.06	28	632	930	25.1	74.4	98.8	4.14	1.18	0.98

Note: "Above" and "Below" refer to above and below the dam. DO (% sat.) are DO saturations corrected for elevation by multiplying equation 6 values by 0.982.