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AERATION CHARACTERISTICS OF FLOW RELEASE CONTROLS ON ILLINOIS WATERWAY DAMS

by Thomas A. Butts and Ralph L Evans

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ABSTRACT

The main stem of the Illinois Waterway from Grafton at its confluence with the Mississippi River to Lockport below Chicago, a length of approximately 300 miles, consists of seven navigation locks and dams and attendant navigation pools. Each pool has historically experienced dissolved oxygen (DO) concentrations that fall below Illinois EPA water quality standards. The levels to which the DOs fall in the pools are greatly influenced by the aerating characteristics of the dams that form the pools.

These aeration characteristics were studied during the summers of 1978 and 1979 to 1) calibrate the dams with the British weir equation as a model and 2) evaluate the effects of increased Lake Michigan diversion water on the dam aeration characteristics. The dam aeration coefficients derived varied significantly within a dam, depending upon the mode of operation, and varied greatly between dams. As an example, the aeration coefficient at Dresden Island with the Tainter gates open 1 foot was approximately 2.0, but with 2-foot openings, it dropped to a level of 1.0. However, for openings of 1.5 feet or less at Starved Rock the coefficient averaged only 0.8. Increasing diversion up to 10,000 cfs will not enhance the aeration capabilities of the flow release structures at the dams. On the contrary, under current operating modes, the aeration capability of these structures at the dams above the LaGrange and Alton pools will be significantly lowered by increased flows.

INTRODUCTION

This study was performed for the Chicago District Office of the U. S. Army Corps of Engineers to provide data for input into a comprehensive water quality model being developed by the Corps in conjunction with their study on the effects of increased Lake Michigan diversion to the Illinois Waterway.

The diversion study is being carried out under Section 166 of the Water Resources Development Act of 1976 (P. L. 94-587) as a five-year demonstration program under the authority of the Secretary of the Army, acting through the Chief of Engineers. Diversion limits are to range between the present limit of 3200 cubic feet per second (cfs) annual average up to 10,000 cfs. The effects of increased diversion on Great Lakes water levels, on Illinois Waterway water quality, and on Waterway flooding are to be demonstrated.

This study is one of three separate water quality studies being conducted by the Water Quality Section of the Illinois State Water Survey related to the water quality phase of the demonstration project. It was designed to produce, within certain constraints, a maximum amount of data of sufficient quality to be used with confidence in a general water quality model.

Effects of Dams

Dams are built across streams for a multiplicity of reasons ranging from aesthetics (as exemplified by small channel dams in parks) to flow and navigation control. Regardless of the purpose of a dam, all affect water quality to some degree. The manifestations can be both positive and negative; 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 (DO) concentrations. This study was concerned primarily with this phenomenon in a generalized way. The purpose was to define the aeration characteristics of spillways and flow release structures designed into navigation locks and dams.

To fully appreciate the need for an efficient aeration design or operating procedure at a dam site, an understanding of the basic ecological and environmental consequences dams have on aquatic systems is needed. 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.[1] 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 relative to 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 aforementioned 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 (SOD) is directly related to the detention time and inversely related to depth, as shown by Butts et al.[2] 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 supersaturated levels of DO at the same rate at which aeration occurs 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[3] found that for highly productive streams like 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.

Sharp drops in DO concentrations often occur immediately below some dams which spill directly onto shallow rocky scarps. Since the dams sustain relatively stable, high DO levels and the rocks provide ideal substrates, zoogleal growths are promoted (similar to that which persists on trickling filter rocks) when dissolved biochemical oxygen demand

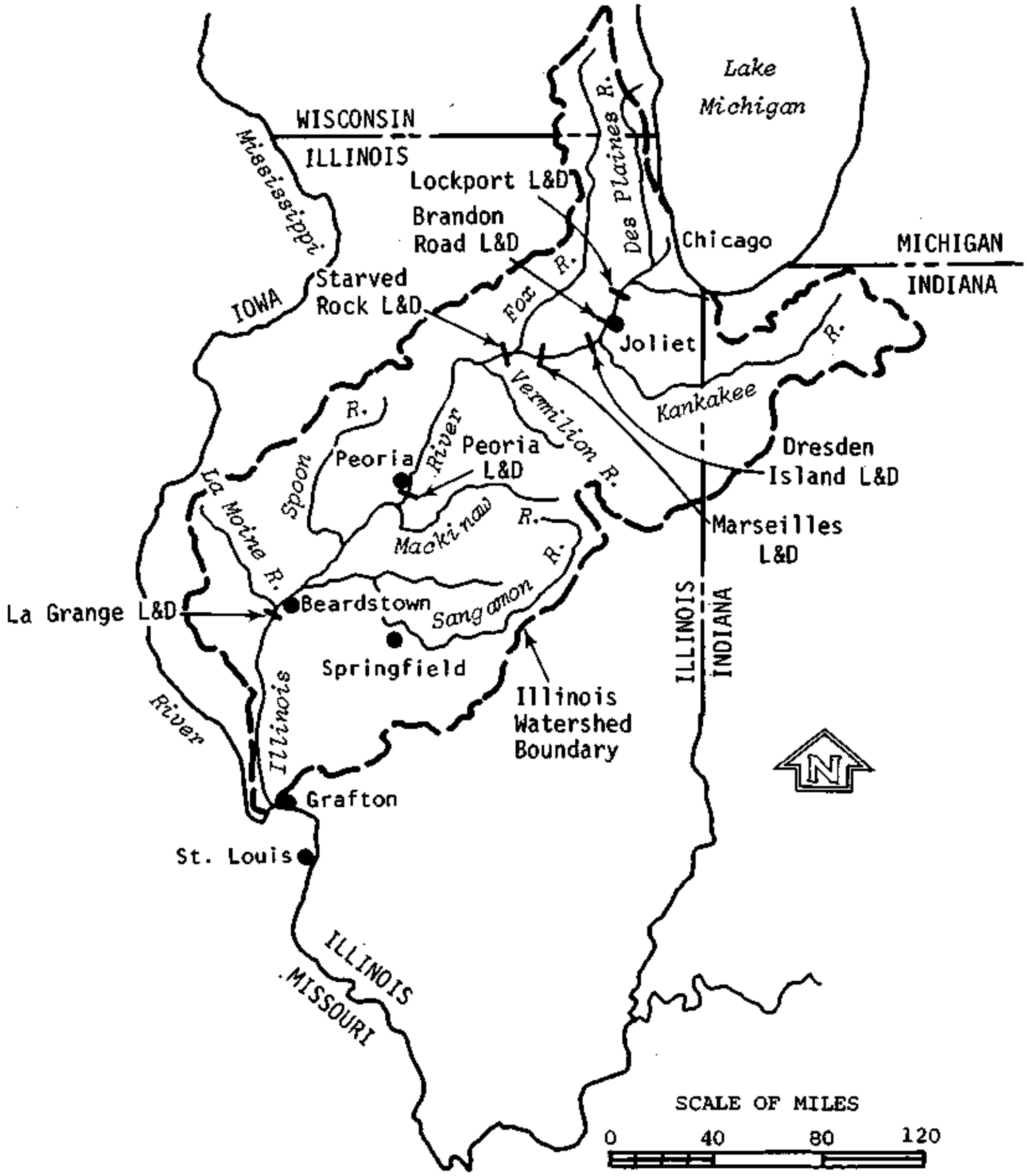


Figure 1. Illinois Waterway

(BOD) exists in stream waters. These DO drops are especially pronounced in streams having a high second stage BOD, i.e., a high ammonia concentration. Butts et al.[4] observed large immediate decreases in DO below the navigation dams in the Illinois Waterway, a waterway system which historically has been subjected to relatively high ammonia loads. Holm[5] has experimentally shown that the highest ammonia oxidation rates occur at the heads of channels. Nitrifying bacteria were found to proliferate in shallow areas having an environment similar to that found below the spillway of many dams.

The principal objective of this study was to gather physical and chemical data for use in a dam aeration calibration procedure based on the use of a weir formula developed in Great Britain.[6] This entailed making on site DO and temperature measurements above and below flow release structures at the dams and in a calibrated weir box, and collecting chemical and biological samples for laboratory analysis.

Dams Studied

Seven dams from Lockport to LaGrange were studied. The areal locations are given in figure 1,

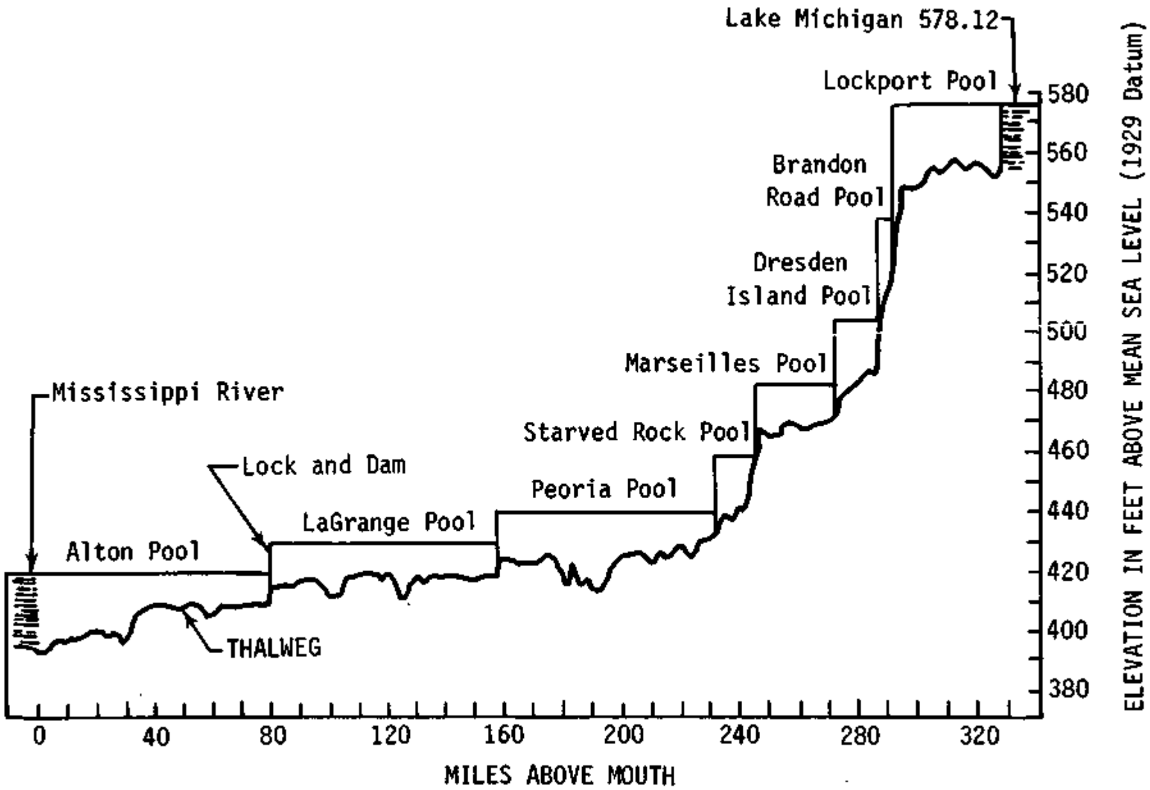


Figure 2. Illinois Waterway profile

and their profiles are shown in figure 2. The direct diversion control structures near or at Lake Michigan were not sampled. These include the O'Brien Lock & Dam, the Chicago River Lock, and the Wilmette Pumping Station. All the dams studied are federally owned except Lockport; it is owned and operated by the Metropolitan Sanitary District of Greater Chicago. General information relative to each dam is given in table 1. Each dam, with the possible exception of Peoria and LaGrange, has distinguishing physical and operating characteristics. Consequently, each had to be studied and sampled individually, i.e., a concentrated analysis could not be made of one or two and extrapolated to the others.

Report Format

Dam aeration theory is briefly reviewed and discussed first. Then the methods and procedures utilized to collect field data and to reduce it to usable form are presented. Laboratory methods used to calibrate a weir box designed for field use at the dam site are given. Under a results section, the weir box calibration data are given along with the field collected data. Similarly, under a discussion section the significant results of both the laboratory and field work are examined in detail. Finally, brief comments are made concerning the need for additional related studies. Three appendices are included so that raw data, statistical summaries, and schematic drawings of the dams could be incorporated into the report.

Acknowledgments

This study was conducted as part of the work of the Water Quality Section of the Illinois State Water Survey, Stanley A. Changnoh, Jr., Chief. The data collection was labor intensive, and at various times almost everyone in the Water Quality Section participated. Therefore, collective thanks are given to those who participated. Thanks also go to Jim Williams and Scott Bell for their work toward data collection. Special thanks are extended to all the

Table 1. General Information on Illinois Waterway Locks and Dams

Lock & dam name	*Mile point designation*	*Year completed*	*Flow release devices Type*	*No.*	*Flat pool head loss (meters)*
Lockport	291.1	1905	Sluicegates	3	11.87
Brandon Road	286.0	1933	Tainter gates	21	10.36
			Head gates	16	
			Sluice gates	?	
Dresden Island	271.5	1933	Tainter gates	9	6.63
			Head gates	15	
Marseilles	247.0	1933	Tainter gates	8	4.34
			Head race gates	3	
Starved Rock	231.0	1933	Tainter gates	10	5.70
			Head gates	10	
Peoria	157.7	1939	Chanoine wickets	134	3.35
			Butterfly valves	6	
LaGrange	80.2	1939	Chanoine wickets	135	3.05
			Butterfly valves	12	

Corps of Engineers lock masters who were receptive to our presence and provided advice and information when needed. Also, special thanks are extended to Norman Neidergang and other Corps personnel in Chicago and Joliet who supplied information and advice as requested. Illustrations were prepared under the supervision of John W. Brother, Jr., final editing was done by J. Loreena Ivens and Tony Fitzpatrick, and the camera-ready copy was prepared by Marilyn Innes.

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 it 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[7] and by Foree.[8] Crevenston and Stoddard derived an empirical expression from field observations 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 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.[9] for the Hastings Dam on the Mississippi River below Minneapolis, Minnesota, and the other was the work reported by Preul and Holler[10] 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 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 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) unsubmerged Tainter gate tailwater, 2) submerged Tainter gate tailwater, and 3) replacement of Tainter gates with bulkheads thereby creating 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.

The evaluations cited above essentially require discharge rating information on flow releases through gates. At the onset of this study, only the gates of the Marseilles dam had been thoroughly rated; consequently, this precluded taking a direct quantitative approach in assessing the reaeration capacity of Illinois Waterway dam flow release structures. An indirect approach had to be taken which would yield reliable results with a minimal amount of sampling. A statistical approach was ruled out because of the need for a large number of repetitive sampling dates under a wide variety of water quality and hydraulic conditions. An option that was available was the use of the British weir equation which was originally conceived by Gameson.[11]

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[6] 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 for water falling into a deep, quiet pool. Preul and Holler[10] showed that the size of the hydraulic jump created in Tainter gate stilling basins was the most important factor regulating reaeration on 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 the gate discharging into stilling basins.

Velz[12] 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. Kothandaraman,[13] in making a literature review on the effects of contaminants on reaeration rates, reports 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[10] 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.[9] used alpha values ranging from 0.9 to 1.0.

The British, probably spurred on by the fact that their homeland streams are heavily bisected with weirs and spillway type structures, have made extensive studies concerning dam aeration. The dam aeration equation, as finally formulated by the British, has definite limitations when applied to some of the relatively high head structures found along the Illinois Waterway. However, by making slight mathematical adjustments to handle any aberrations in the physical makeup of the waterway dams, the British weir equation can be used with some degree of confidence.

Gameson[6] in some original 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:

$$r = (C_S - C_A)/(C_S - C_B) \tag{1}$$

where C_S is the D_O 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[6] and Gameson et al.[14] found in laboratory experiments that the ratio is independent of above-dam DO concentrations of $C_s \pm 10$ mg/l. However, data collected by Barrett et al.[15] indicate that this independence may be reduced to $C_S \pm 4$ mg/1 for full-sized field structures. The latter figure may be of significance in this study because some DOs in the waterway, particularly those above the Brandon Road and Lockport dams, fall well below C_S - 4 mg/1.

Gameson's original dam aeration formula[6,14] 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 form[11] :

$$r = 1 + 0.38\,abh\,(1 - 0.11h)\,(1 + 0.046T) \tag{2}$$

where a is the water quality factor; b is the weir, spillway, or gate 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[11]; however, actual field measured values are usually lower.

The formula was developed by the 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,[11] the maximum height of the dams at which data collections were made during development. In addition, close examination of the equation reveals that the factor (1 — 0.11 h) mathematically restrains the use of the equation to heights slightly less than 9.1 meters. Unfortunately, the Lockport and Brandon Road dam elevations both exceed 10 meters. To circumvent this height constraint, the factor (1 — 0.11h) can be limited to a value of 0.01 when h exceeds 9.0 meters. Equation 2 is then reduced to:

$$r = 1 + 0.0038\,abh\,(1 + 0.046\,T) \tag{3}$$

For high dams exhibiting good reaeration capacities, inordinately high weir coefficients result from this equation. However, independent checks with these generated values show that very good agreements between computed and observed values are achieved.

The water quality factor, a, has to be evaluated experimentally in the field or estimated from published criteria. The following generalized values can be used in the absence of direct determinations.

Polluted state	*a*
Gross	0.65
Moderate	1.0
Slight	1.6
Clean	1.8

These values are based on a minimal amount of field and laboratory data and are refinements of those originally published by Gameson.[6] The direct applications of these values are subjective, and since considerable latitude exists numerically between values, significant errors can result. With this in mind, measures were taken to design into this study a means of indirectly determining the water quality factor at the dam sites during each field trip.

To attain the objective of this study the basic elements for which assessments were required included determining a rational weir or gate aeration coefficient by directly measuring differential water levels, above and below dam DOs, and water temperatures, and by indirectly measuring the water quality of the waterway coincident with direct measurements.

METHODS AND PROCEDURES

The methods and procedures utilized are presented under "laboratory" and "field" subheadings. The laboratory work was done in conjunction with developing a methodology and procedure for determining the water quality factor in the field.

Data Collection

Laboratory

A methodology patterned after suggestions presented by Gameson[11] was developed to estimate the water quality factor in the field. A weir box and a receptacle trough were constructed as shown in figures 3 and 4. Experimental laboratory data were collected to verify that the product 'ab' in equation 2 equals 1.8 for a sharp crested weir (b = 1.0) discharging clean water (a = 1.8). A verification that the standard weir has a coefficient of unity would enable the water quality to be computed with the weir box in conjunction with river water at the dam sites.

The experimental design was developed around analysis of variance (ANOVA) statistical concepts. This was done to gain some insight into what factors may cause 'a' to deviate from unity if, by chance, it did so. Four parametric inputs were monitored and varied. They are 1) flow, 2) weir box DO, 3) water level differential, and 4) receptacle box depth h'. Four different ranges of flow, DO, and receptacle box depths were used, while only three water level differentials were investigated. The values of ranges utilized during the experimental runs are given in table 2. Each parameter was set at a particular value, within the stated range, while all the others were varied. This resulted in a total of 192 data sets.

The source of experimental water was from the tap. This particular water has several qualities which make it ideal for use in an aeration experiment. The Peoria Water Company supplies the SWS Peoria laboratory with shallow well water which has a relatively constant temperature throughout the year and a DO content generally less than 1.5 mg/l. The latter is significant in that no chemical additions are needed for deoxygenation. Also, the water receives no treatment before distribution except for chlorination. The range of flow rates over which observations could be made was limited (twofold) by distribution main pressure.

Dissolved oxygen levels were controlled reasonably well within a setting (within 1.0 mg/l) and over the overall range of all settings by using an as-

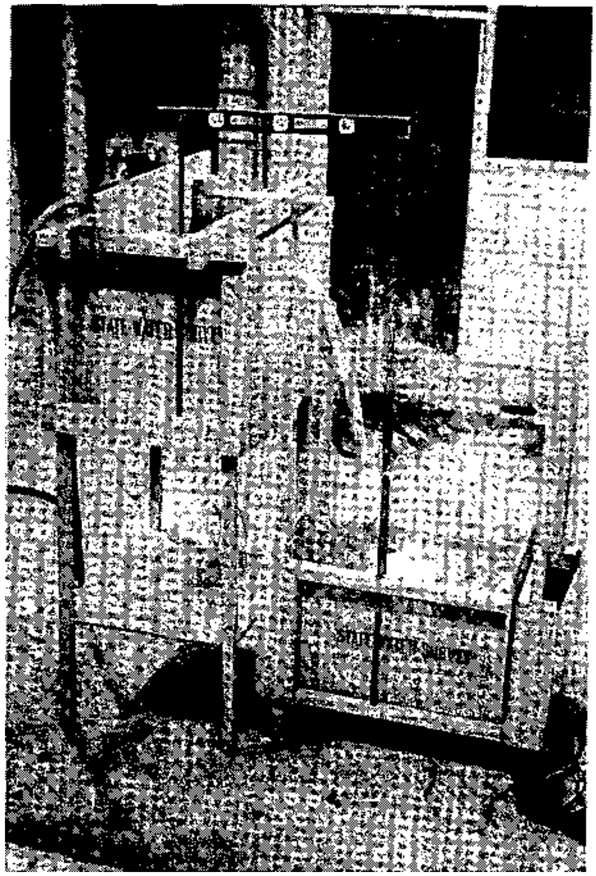


Figure 3. Weir box and receptacle trough

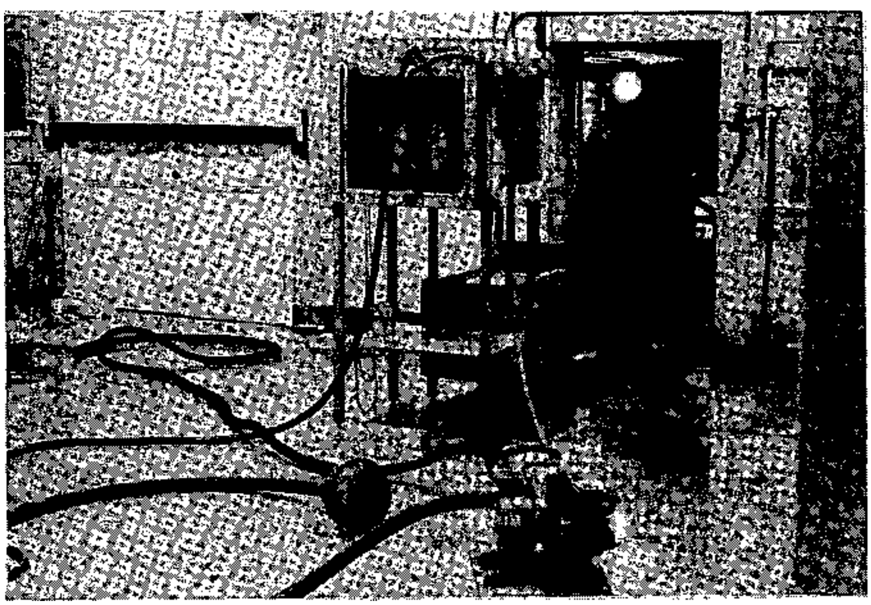


Figure 4. Weir box setup with pump and waste system used in the field

Table 2. Weir Box Parameter Setting for Laboratory Experiment

Parameter	*Setting ranges of variables* 1	2	3	4
Flow, Q (liters/sec)	**0.45-0.55**	**0.55-0.65**	**0.70-0.80**	**0.85-0.95**
Dissolved oxygen, DO (mg/l)	**<1.5**	**2.5-3.5**	**4.5-5.5**	**7.5-8.5**
Receptacle depth, h (m)	**0.015-0.03**	**0.10-0.12**	**0.23-0.25**	**0.37-0.38**
Water fall height, h (m)	**0.27-0.37**	**0.59-0.68**	**0.97-0.99**	

pirator working on the Venturi principle (see figure 5a and 5b). Air intake, and therefore oxygen concentration, was controlled by a pinch clamp attached to the rubber suction tubing shown in figure 5a.

Discharge depths were controlled by adjusting a false bottom fitted for movement within the receptacle box. Water fall heights were varied by moving the receptacle box up or down on extended legs. The leg bottoms on both boxes were fitted with adjustable leveling screws. The inlet end of the weir box and outlet end of the receptacle trough required baffles to dissipate energy and to facilitate dissolution of air bubbles. Water surface elevation differentials were determined with a hook gage fitted to slide upon rods leveled between the weir and receptacle boxes as shown in figure 3.

All DO concentration values used for computational purposes were determined by the standard Winkler method. For each setting, four above and below, water samples were siphoned into DO bottles with rubber tubing. Analyses were run on two, and if differences exceeding 0.2 mg/1 occurred, the other set was run. Temperature measurements were made above and below with industrial grade mercury thermometers having ½°C graduations falling between —5 to 45°C.

A YSI Model 57 DO-temperature meter and probe was used, but only to monitor the weir box DO levels to facilitate attaining DO values within the ranges specified in table 2. Preliminary work indicated that frequent recalibrations of the meter would be needed to maintain desired experimental accuracy; consequently, its use as a rapid and easy means of making DO and temperature measurements was abandoned.

Field Studies

The field work at a given location consisted of two distinct operations. One was setting up and operating the weir box for gathering data pertinent to the determination of the water quality factor. The other was instream DO and temperature sampling by boat above and below each dam. The weir box data collection was made prior to the instream boat run.

The weir box and appurtenances were set up, with two exceptions, on the upstream nose of guidewalls or on mooring piers above the upstream lock gates. At the Lockport dam, weir box water was pumped from the bar screens at the turbine intakes. At Marseilles the system was set up on a concrete pad located immediately above the Tainter gates on the right bank. These two locations are more ideal than those used at the other five dam sites. The lack of suitable access to the flow release side of the other structures prevented setting up the box and equipment there. Lock-side sampling probably gave representative water quality results at all 1979 sampling sites because barge traffic was heavy, which resulted in a continuous siphoning of water into this area for lockage purposes. However, during the 1978 sampling period the Dresden Island and Starved Rock locks were shut down for repairs, and the resultant 'measured' water quality factor may not have been truly representative of the flowing stream. During direct passages of a barge and tow, the system was shut down and was not restarted until all visual effects of the disturbance had subsided.

A 92 gpm Homelite pump driven by a gasoline engine was used to pump river water into the weir box. The pump capacity was much greater than needed, but it was the smallest gasoline powered unit available commercially. Consequently, most of the flow was wasted via a valve arrangement at the discharge end. The pump and waste system as hooked up for field use is shown in figure 4. A flow in the range of 0.7 to 1.5 liters/sec was maintained through the weir box system.

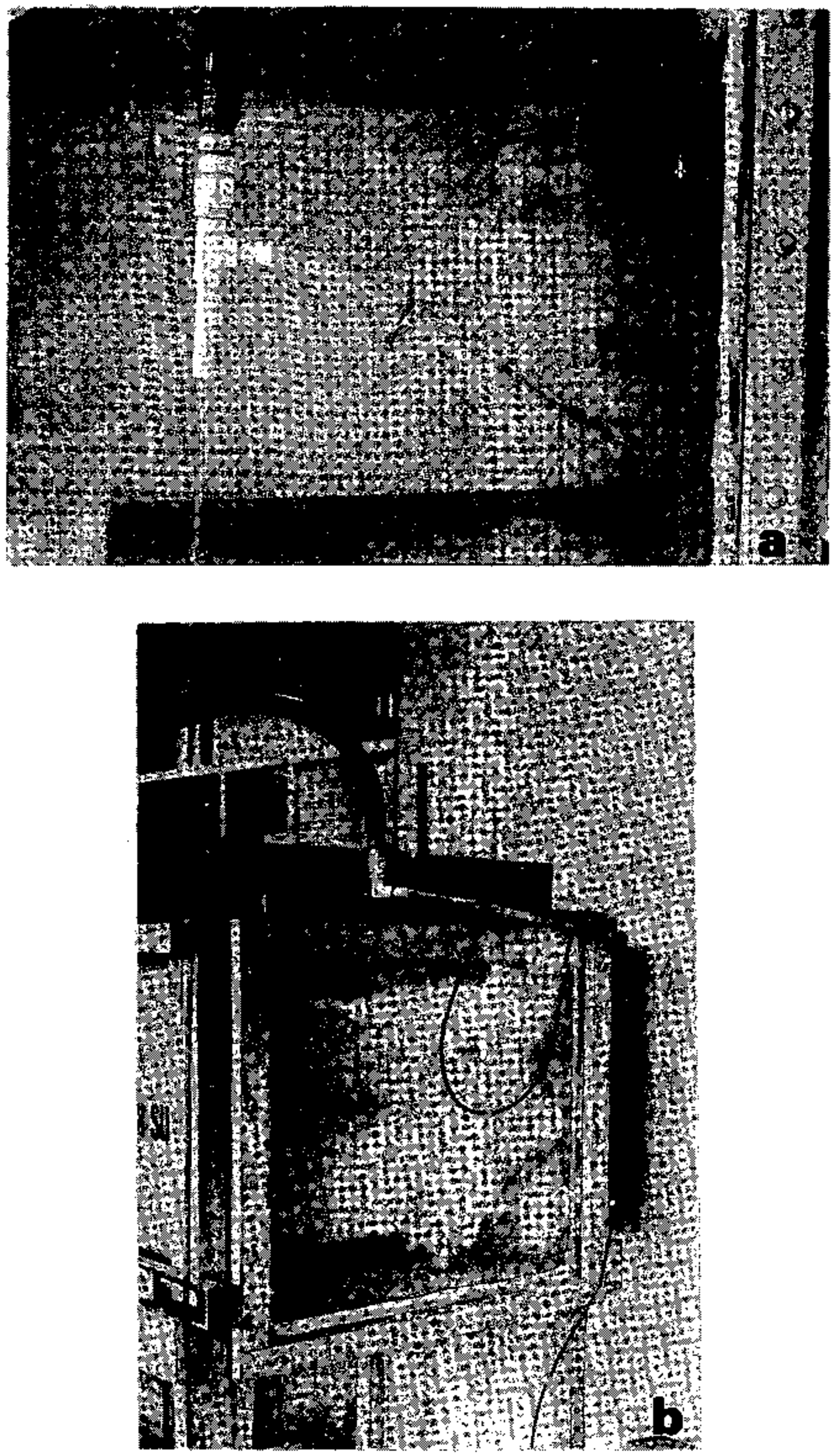


Figure 5. Aspirator equipment

The only physical parameter varied for each setup in the field was the water fall height. Three runs were made with 'h' set at approximately 0.2, 0.6, and 1.0 meters. DO samples were collected above and below in quadruplicate with sets of two being run initially by the Winkler method. For paired results deviating 0.2 mg/l or more, the second set of bottles was run. Temperature measurements were taken only in the weir box.

Special precautions had to be made during very windy weather to limit blowing and scattering of the water falling from the weir box. Such effects appeared to reduce aeration significantly. Care was taken to place the back of the weir box into the wind whenever possible. In addition, a tarpaulin was wrapped around the setup as a wind shield during extremely windy conditions .

Just prior to the instream sampling, the location of operating gates and their openings were provided by the lock master. On the basis of this information, an efficient sampling procedure was quickly determined. As an example, at a dam having 10 Tainter gates with gates 1, 2, and 3 open 1 foot, gates 5 and 6 open 2 feet, gate 7 open 3 feet, and the rest closed, measurements would be taken at the centerlines of gates 2 and 7, and at the centerline of the pier between gates 5 and 6. When a gate was officially listed by the lock master as closed but was observed to be leaking excessively, its centerline would also be chosen as a sampling location.

Two boats with two-men crews were used. Sampling activities between the upstream and downstream crews were coordinated instream by use of long wave (CB) radios. Care was taken so that simultaneous sampling occurred. All samples were taken with a Juday type of sampler and were run by the Winkler method. Water temperatures at various depths were checked from the residual water in the samplers. For depths greater than 10 feet, collections were made at 1 and 3 feet, at mid-depth, and at bottom levels; for depth less than 10 feet, collections were made at the 1 foot, mid-depth, and bottom levels.

One water and one algae sample were collected upstream of each dam during every sampling run. The water samples were examined in the laboratory for suspended solids, chemical oxygen demand, and methylene blue active substances in terms of linear alkylate sulfonate (LAS). The latter chemical parameter reflects upon 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.

Data Reduction

Laboratory Weir Box Data

The primary purpose of collecting data for the weir box under controlled laboratory conditions was to confirm the unity definition of a sharp crested weir. The experiment was designed such that in the event that $b \neq 1.0$, the system could be 'recalibrated' for field use.

Analysis of variance statistical techniques were used to isolate the physical factors which could influence the deficit ratio as defined by equation 1. Because four independent variables (as listed in table 2) were investigated, a four-way ANOVA technique had to be developed. Such a development is procedural as opposed to theoretical or basic. The methodology outlined by Crow et al.[16] for performing a three-way ANOVA was used as a guide. Basically, the data had to be broken down and regrouped into a number of independent two-way tables. A four-way ANOVA for the parameters investigated in this work required the development of six two-way ANOVA tables formulated according to the criteria presented in table 3. A 95 percent confidence level was used in the analysis to determine the significance of each variable relative to weir aeration.

Field Data

Because sufficient time was not available to reduce the laboratory weir box data to meaningful terms for verification and/or recalibration before field work began, three water fall settings were run in the field to insure adequate data in the final analysis. Equation 2 was solved for 'a' for each set of data generated. The duplicate DO values were averaged for use in the calculations. Where differences in duplicate values exceeded 0.2 mg/1 and a second set of samples was run, the outlier values were eliminated in the averages.

The relationship between the calculated water quality factor and five water quality parameters

Table 3. Two-way ANOVA Table Development Required for Four-way ANOVA Investigation

Evaluation number	*Parameter designation for*		
	Columns	*Rows*	*Cell summation*
1	**DO**	**h**	**Q-h'**
2	**h'**	**DO**	**Q-h**
3	**h'**	**Q**	**DO-h**
4	**h'**	**h**	**DO-Q**
5	**h**	**Q**	**DO-h'**
6	**DO**	**Q**	**h-h'**

was investigated by a stepwise regression statistical technique. The independent variables were DO (% saturation), algae density, suspended solids, chemical oxygen demand, and methylene blue active substances. This statistical procedure produced a predictive equation which can be used to estimate the water quality factor by specifying water quality conditions in the waterway.

The weir aeration coefficient for the flow release structure at each dam was determined by solving equations 2 or 3 for 'b' with the DOs and temperatures observed instream and the water quality factor computed from the weir box observations. The DOs and temperatures were weighted vertically by depth, and the water fall height was determined from official Corps staff gages located immediately above and below each dam. Aeration coefficients were computed separately for the types of flow release combinations described in the field data collection section, i.e., each gate or wicket section was analyzed individually and not collectively.

Some anomalies occurred in the instream field data. Of particular note is the occasional appearance of negative values of b. Also, several values of b computed by equation 2 appeared to be somewhat high compared with that for a theoretical step weir. Negative values observed in this study are principally indicative of an inability to ascertain finite DO readings when the upstream DOs were slightly below or above saturation. Negative values for the expression (r — 1) created by the rearrangement of terms in equation 2 occur in the computational procedure when field data fit one of the following criteria (Cs = DO saturation concentration):

Case I	$C_B < C_A < C_S$
Case II	$C_B > C_S < C_A$
Case III	$C_B > C_A > C_S$
Case IV	$C_A > C_S > C_B$

Theoretically, none of the above can occur. However, they do for a number of reasons as explained by Butts.[3] Only condition 3 did not occur during this study.

Dissolved oxygen saturation values used in this study were computed by the American Society of Civil Engineers' formula[17]:

$$C_S = 14.652 - 0.41022\,T + 0.007991\,T^2 - 0.000077774\,T^3 \qquad (4)$$

An alpha factor of 1.0 was used in conjunction with this formula. No basis for using a smaller value existed nor is justified since the principal causes of negative coefficients encountered during this study are the result of cases 2 and 4 where either C_A or C_B was observed to be greater than saturation values calculated with equation 4.

RESULTS

The overall results of this study were good. Both the laboratory weir box study and the instream study segments at the dam sites produced usable information directly applicable to a DO water quality model of the waterway. In addition, the data generated form a sound basis around which additional studies or experiments related to dam aeration can be designed. A brief discussion of a proposed future study is given later.

Laboratory Weir Box

A total of 520 DO analyses (260 sets) was made for variable conditions during the weir box calibration procedure. The DO and temperature values generated are presented in Appendix A-1. Only that information produced under the constraints specified in table 2 was used in the statistical analyses; this resulted in 192 usable sets of data. The ANOVA tests were performed by converting the raw DOs into deficit ratios; the r values are given in Appendix B-1. The data, grouped to describe the ANOVA modes given in table 3, are presented in tables 4 through 9. A close examination of these tables reveals that two factors, water fall height and receptacle depth, stand out as being the major influences on weir box aeration. This visual observation is verified statistically as shown by the results of the four-way ANOVA summarized by the data presented in table 10. However, what was not clear from a visual inspection of tables 4 through 9 was that the weir box DO concentration has a small but significant influence on expected deficit ratios. The small twofold range of flows used in this experiment had no influence on the aeration at all.

Examination of table 6 shows that the receptacle depth influence on the overall aeration capacity of the system increases slightly with increases in h' with increasing degrees of increase as the water fall height increases. A large break in the slope of these increases appears to occur somewhere between 0.12 and 0.23 meters. For a weir box system this means, contrary to the generally accepted idea, that maximum aeration is not achieved by having a discharge splash into a very shallow surface. However, in the same light, for a given water fall height, only very slight increases in aeration can be expected to occur at receptacle depths greater than 0.2 meters.

Examination of table 4 reveals why a statistical difference, albeit small, existed between the DO levels. A slight but clear break occurs in the r ratio values at DOs somewhere between 3.5 and 4.5 mg/l. This observation supports the previous referenced fact that the deficit ratio is influenced very little over a wide range of upstream DOs in laboratory weir aeration studies since saturation levels exceeded 10 mg/1 during this study.

Table 11 presents a matrix of average 'ab' values for all of the 250 data sets presented in Appendix B-l. These tabular results clearly show that the weir box system truly represents a normal or standard weir (b = 1, a = 1.8) when operated at receptacle depths ranging from 0.3 to 0.4 meters in combination with water fall heights ranging from 0.6 to 1.0 meters. Consequently, when operated under these specifications in the field, estimates of unknown water factors can be confidently and reliably made.

Field Studies

The data generated from running the weir box in the field with an approximate 0.4-meter receptacle depth in conjunction with three water falls of approximately 0.25, 0.6, and 1.0 meters are given in Appendix A-2. The 'a' values calculated with these data are summarized in table 12. Generally, reasonable values of a were derived. As would be expected, relative to the laboratory findings, the 1 meter water fall gave the best overall results. For both the 0.25 and 0.6 meter heights, 9 of the 33 runs had outliers exceeding the expected maximum of 1.8 (clean water) or less than the expected minimum of 0.65 (grossly polluted water), whereas only 8 such outliers occurred for the 1 meter setup. The fact that 8 did occur at 1 meter is not surprising in that the DO concentrations were high for these occurrences. In each case, the saturation percentage of DO exceeded 81 and twice it exceeded 96. Reasonable values have been achieved at saturation levels around 80 percent, but the margin for experimental error is greatly reduced when working with these conditions. Conversely, six observations were made when the DO percent saturation was less than 28 and all six computed a values fell within the expected range.

Table 4. Weir Box Aeration Table for Deficit Ratio (r), Two-Way ANOVA Classification; DO Versus h' with Q-h Cell Summations

DO (mg/l)	*Receptacle depth, h' (m)* .015-.03	.10-.12	.23-.24	.37-.38	*Row values* r-Sum	r-Avg
<1.5	16.60	19.02	20.27	20.11	76.00	1.58
2.5-3.5	16.74	18.60	20.41	20.38	76.13	1.59
4.5-5.5	16.57	18.43	19.48	20.06	74.54	1.55
7.5-8.5	16.40	17.89	19.94	20.33	74.56	1.55
Column r-sum	66.31	73.94	80.10	80.88	301.23	
Column r-avg	1.38	1.59	1.67	1.69		1.57

Table 5. Weir Box Aeration Table for Deficit Ratio (r), Two-Way ANOVA Classification; Q Versus h' with DO-h Cell Summations

Q (l/sec)	*Receptacle depth, h' (m)* .015-.03	.10-.12	.23-.24	.37-.38	*Row values* r-Sum	r-Avg
.45-.55	16.36	18.50	19.49	20.12	74.47	1.55
.55-.65	16.82	19.02	20.28	19.99	76.11	1.59
.70-.80	16.69	18.24	19.95	20.48	75.36	1.57
.85.95	16.44	18.18	20.38	20.29	75.29	1.57
Column r-sum	66.31	73.94	80.10	80.88	30i.23	
Column r-avg	1.38	1.54	1.67	1.69		1.57

Table 6. Weir Box Aeration Table for Deficit Ratio (r), Two-Way ANOVA Classification; h Versus h' with DO-Q Cell Summations

h (m)	*Receptacle depth, h' (m)* .015-.03	.10-.12	.23-.24	.37-.38	*Row välües* r-Sum	r-Avg
.27-.17	19.63	21.02	21.54	21.65	83.84	1.31
.59-.68	22.25	24.14	26.92	27.11	100.42	1.57
.97-.99	24.43	28.78	31.64	32.12	116.97	1.83
Column r-sum	66.31	73.94	80.10	80.88	301.23	
Column r-avg	1.38	1.54	1.67	1.69		1.57

Table 7. Weir Box Aeration Table for Deficit Ratio (r), Two-Way ANOVA Classification; Q Versus h with DO-h' Summations

Q (Usee)	*Water fall height, h (m)* .27-.37	.59-.68	.97-.99	*Row values* r-Sum	r-Avg
.45-.55	21.28	24.75	28.44	74.47	1.55
.55-.65	21.18	25.53	29.40	76.11	1.59
.70-.80	20.70	25.55	29.11	75.36	1.57
.85-.95	20.68	24.59	30.02	75.29	1.57
Column r-sum	83.84	100.42	116.97	301.23	
Column r-avg	1.31	1.57	1.83		1.57

Table 8. Weir Box Aeration Table for Deficit Ratio (r), Two-Way ANOVA Classification; Q Versus DO with h-h' Summations

Q (l/sec)	Dissolved oxygen concentration, DO (mg/l) <1.5	2.5-3.5	4.5-5.5	7.5-8.5	Row values r—Sum	r—Avg
.45-.55	19.00	18.87	18.51	18.09	74.47	1.55
.55-.65	19.13	19.06	18.42	19.50	76.11	1.59
.70-.80	19.07	19.04	18.51	18.74	75.36	1.57
.85-.95	18.80	19.16	19.10	18.23	75.29	1.57
Column r-sum	76.00	76.13	74.54	74.56	301.23	
Column r-avg	1.58	1.59	1.55	1.55		1.57

Table 9. Weir Box Aeration Table for Deficit Ratio (r), Two-Way ANOVA Classification; DO Versus h with Q-h' Summations

h (m)	Dissolved oxygen concentration, DO (mg/l) <1.5	2.5-3.5	4.5-5.5	7.5-8.5	Row values r—Sum	r—Avg
.27-.37	20.94	20.98	21.03	20.89	83.84	1.31
.59-.68	25.60	25.65	24.81	24.36	100.42	1.57
.97-.99	29.46	29.50	28.70	29.31	116.97	1.83
Column r-sum	76.00	76.13	74.54	74.56	301.23	
Column r-avg	1.58	1.59	1.55	1.55		1.57

Table 10. Statistical Summary and Results of Four-Way ANOVA Performed on Deficit Ratios Generated with Sharp Crested Weir

Factor number	Source of variation	Sum of squares	Degrees of freedom	Mean squares	F-ratios Computed	F .05	Significant Yes	No
1	h'	2.85095	3	0.95032	195.94	2.67	X	
2	DO	0.04800	3	0.01600	3.30	2.67	X	
3	Q	0.02809	3	0.00936	1.93	2.67		X
4	h	8.57498	2	4.28749	884.02	3.06	X	
5	h' x DO	0.06058	9	0.00673	1.39	1.95		X
6	h' x Q	0.07153	9	0.00795	1.64	1.95		X
7	h' x h	0.67302	6	0.11217	23.13	2.17	X	
8	DO x Q	0.10684	9	0.01187	2.45	1.95	X	
9	DO x h	0.05245	6	0.00874	1.80	2.17		X
10	Q x h	0.11926	6	0.01988	4.10	2.17	X	
11	Residual	0.65497	135	0.00485				

Table 11. Matrix of ab Values Computed for Laboratory Weir Box Experimental Data

h (m)	Receptacle depth, h' (m) .015-.03	.10-.12	.23-.24	.37-.38	Optimum h' (.1h + .06)
.27-.37	1.03	1.38	1.62	1.67	.087-.097
.59-.68	1.00	1.37	1.76	1.78	.119-.128
.97-.99	0.91	1.43	1.74	1.78	.157-.159

Table 12. Illinois Waterway Water Quality Factor (a) Computed with Weir Box Field Data

Date	*a at waterfall heights of* .2-.3 m	.6-.8 m	1.0 m
Lockport Dam			
9/13/78	1.16	1.27	1.16
10/13/78	1.04	1.39	1.37
8/16/79	1.38	1.37	1.32
Brandon Road			
9/12/78	0.92	1.36	0.95
10/12/78	1.09	1.34	1.18
8/15/79	1.23	1.27	1.35
8/29/79	1.24	1.08	1.28
9/11/79	1.79	1.83	1.32
Dresden Island			
8/25/78	2.01	2.65	2.64
9/14/78	0.67	0.92	0.82
8/08/79	0.48	1.08	0.93
8/14/79	0.75	1.36	0.97
9/05/79	1.02	1.31	1.06
Marseilles			
8/24/78		0.47 0.35	0.11
9/19/78	1.54	0.95	0.81
7/06/79	0.97	0.94	0.98
9/06/79	0.75	1.46	1.30
9/12/79	1.67	1.35	0.94
Starved Rock			
8/23/78	12.16	-45.5	17.19
9/20/78	0.68	0.80	0.80
8/03/79	0.67	1.43	1.44
9/07/79	0	-0.81	0
9/14/79	2.54	2.02	2.09
Peoria			
8/12/78	1.86	0.82	0.56
10/02/78	8.03	2.81	2.58
7/27/79	1.47	2.81	1.02
8/01/79	1.39	0.77	0.82
10/10/79	0	1.15	1.20
LaGrange			
8/22/78	0.27	0.24	0.54
9/21/78	1.28	1.55	1.31
8/07/79	1.30	1.21	0.89
9/18/79	0.33	1.18	1.53
9/26/79	1.66	2.14	1.15

Note: Underlined values indicate values falling outside acceptable maximum (1.8) and minimum (0.65) limits.

The results of the analyses made on water samples for algae, suspended solids, chemical oxygen demand, and methylene blue active substances are tabulated in Appendix B-2 along with DO saturation percentages observed in the weir box for each of the three water fall settings. These five parameter values were equated to the nonshaded (acceptable) a values for each water fall height and also for the average of the three a values from step-wise regression procedures. The multiple correlation coefficients between the independent variables and the water quality factor for the low, mid, and high water fall settings and the average of the three settings are 0.56, 0.75, 0.85, and 0.79, respectively. Not unexpectedly, the 1.0 meter water fall produced the highest correlation and, therefore, the best predictive equation. This expression is presented as equation 5 and the step developments are summarized in table 13.

$$a = 0.036 + 0.223 (\log A) - 0.003 (DO) + 0.8 (M) - 0.0045 (SS) + 0.038 (COD) \quad (5)$$

where a is the water quality factor, A is the algae counts in number per milliliter (no./ml), DO is the dissolved oxygen in percent saturation, M is the methylene blue active substance in mg/1 as LAS, SS is the suspended solids concentration in mg/1, and COD is the chemical oxygen demand in mg/1. A log transform was used in conjunction with algal counts because of the wide range of variability in these data. The intercorrelations generated during the development of equation 5 are given in table 14.

The unreduced temperature and DO data collected instream in the vicinity of the flow release structures at each dam are presented in Appendix A-3. Included are the horizontal and vertical sampling locations; the horizontal locations are merely descriptive whereas the vertical locations are finite in terms of feet.

The data required to calculate the weir coefficients 'b' by equations 1 and 2 or 3 are presented in Appendix B-3. The temperatures and DOs are weighted averages of those given in Appendix A-3. The water quality factors are the nonunderlined values listed in table 12 under the 1.0 m column. The outlier values have been replaced with best estimates calculated by equation 5.

A summary of the results, grouped by specific flow release conditions at each dam, is tabulated in table 15. From the summations presented in table 15, generalized coefficients were derived for the specific flow release conditions and these are presented in table 16. They represent the end product of this study, i.e., they are the coefficients recommended for use in estimating reaeration at a dam site for any water quality model of the waterway involved with DO balances.

Table 13. Stepwise Regression Equations Relating the Water Quality Factor (a) to Five Parameters with "h" at 1.0 Meter

Step No.	*Stepwise regression equation, a =*	*Correlation coefficient*	*Standard error of a*
1	0.235 + 0.311 (log A)	0.64	0.24
2	0.208 + 0.423 (log A) - 0.00 (DO)	0.75	0.22
3	0.110 + 0.363 (log A) - 0.00 (DO) + 2.3 (M)	0.78	0.21
4	0.135 + 0.339 (log A) - 0.00 (DO) + 2.7 (M) - 0.0011 (SS)	0.79	0.21
5	0.036 + 0.223 (log A) - 0.03 (DO) + 0.8 (M) - 0.0045 (SS) + 0.038 (COD)	0.85	0.19

Table 14. Simple Correlation Coefficient Matrix for Variable Inputs to Stepwise Regression Development

Variables	*Log algae nos.*	*DO % saturation*	*MBAS*	*SS*	*COD*	*a*
Log of algae numbers	1	0.53	0.22	0.05	0.50	0.64
DO % saturation		1	-0.24	0.35	0.40	0.02
Surface active agents, MBAS			1	0.08	0.43	0.49
Suspended solids, SS				1	0.70	-0.17
Chemical oxygen demand, COD					1	0.43
Water quality factor, a						1

Table 15. Summary of Usable Dam Aeration Coefficients (b)

Gate or wicket openings	Dam coefficient, b	Group	Group averages Arithmetic	Median
Lockport Dam				
Sluice gates 1 & 2	0.39			
Sluice gates 1 & 2	0.16	all	0.28	
Brandon Road				
Tainter gates @ 0.1 ft	34.43			
Tainter gates @ 0.1	37.36			
Tainter gates @ 0.1	69.91	0.1 ft	47.23	37.36
Tainter gates @ 2	20.50			
Tainter gates @ 2	23.81			
Tainter gates @ 2	26.34			
Tainter gates @ 2	33.62	2 ft	26.07	25.08
Head gates @ 6	79.90			
Head gates @ 8	25.87			
Head gates @ 8 + 4	34.27			
Dresden Island				
Tainter gates @ 0.1 ft	1.16			
Tainter gates @ 0.5	1.71			
Tainter gates @ 1.0	1.45			
Tainter gates @ 1.0	1.60			
Tainter gates @ 1.0	1.86			
Tainter gates @ 1.0	2.03			
Tainter gates @ 1.0	2.19			
Tainter gates @ 1.0	3.08			
Tainter gates @ 1.0	4.95	0.5-1 ft	2.36	1.95
Tainter gates @ 2.0	0.99			
Tainter gates @ 2.0	1.11			
Tainter gates @ 2.0	1.15			
Tainter gates @ 2.0	1.28	2 ft	1.13	1.13
Marseilles				
Tainter gates @ 0.1 ft	0.78			
Tainter gates @ 0.1	0.93			
Tainter gates @ 0.1	2.00			
Tainter gates @ 0.5	0.58			
Tainter gates @ 1	1.02			
Tainter gates @ 1	1.33			
Tainter gates @ 2	0.58			
Tainter gates @ 2	1.08	0.1-2 ft	1.04	0.98
Tainter gates @ 3	0.45			
Tainter gates @ 3	0.48			
Tainter gates @ 4	0.31			
Tainter gates @ 5	0.81	3-5 ft	0.51	0.47
Headrace - weir	0.43			
Headrace - turbine	0.00			
Nabisco - raceway	0.00			
Starved Rock				
Tainter gates @ 0.1 ft	0.38			
Tainter gates @ 0.1	0.74			
Tainter gates @ 0.5	0.42			
Tainter gates @ 0.5	1.22			
Tainter gates @ 1	0.63			
Tainter gates @ 1	1.37			

Continued on next page

Table 15. Concluded

Gate or wicket openings	Dam coefficient, b	Group	Group averages Arithmetic	Median
Tainter gates @ 1.5	0.98	0.1-1.5 ft	0.82	0.74
Tainter gates @ 3	0.23			
Tainter gates @ 3	0.38			
Tainter gates @ 4	0.09			
Tainter gates @ 4	0.61	3-4 ft	0.33	0.31
Peoria				
(1) Wickets up, 20 needles up	0.03			
and no butterfly valves open	0.00			
	0.00	(1)	0.01	0.01
(2) Wickets up, no needles, and	0.21			
2 butterfly valves open	0.13			
	0.15			
	0.16	(2)	0.16	0.16
(3) Wickets up, no needles, and	0.11			
6 butterfly valves open	0.11			
	0.12			
	0.03			
	0.12	(3)	0.10	0.11
(4) Wickets up, 21 needles up,	0.47			
and 6 butterfly valves open	0.40	(4)	0.44	0.44
(5) Wickets up, 62 needles up, and	0.59			
and 6 butterfly valves open	0.95			
	0.97	(5)	0.84	0.95
(6) Wickets down, 6 butterfly				
valves open	0.00			
LaGrange				
(1) Wickets up, no needles, and	0.27			
4 butterfly valves open	0.27			
	0.26			
	0.19	(1)	0.25	0.26
(2) Wickets up, no needles,	0.11			
and 12 butterfly valves open	0.11			
	0.08			
	0.62	(2)	0.23	0.11
(3) Wickets up, no needles and	0.72			
no butterfly valves open	0.65			
	0.55			
	2.14			
	0.56			
	0.58	(3)	0.87	0.62
(4) Wickets down	0.11			
	0.11			
	0.19	(4)	0.13	0.11
(5) Butterfly valves	0.02			
			1.16	

Table 16. Best Estimate Dam Aeration Coefficients (b) Based on Table 15 Data

Gate, wicket, or valve conditions	*b*
Lockport Dam	
Power generation sluice gates open	0.3 *
Brandon Road	
Tainter gates leakage	35 *
Tainter gates open 2 ft	25 *
Head gate open 6 ft	80 *
Head gate open 8 ft	25 *
Head gates open 8 & 4 ft	35 *
Dresden Island	
Tainter gates open 0.5-1 ft	2.0
Tainter gates open 2 ft	1.0
Marseilles	
Tainter gates open 0.1-2 ft	1.0
Tainter gates open 3-5 ft	0.5
Headrace weir at power plant	0.4
Headrace turbine discharge	0
Nabisco raceway discharge	0
Starved Rock	
Tainter gates open 0.1-1.5 ft	0.8
Tainter gates open 3-4 ft	0.3
Peoria	
Wickets down, 6 valves open	0
Wickets up, no needles, 6 valves open	0.2
Wickets up, 15% needles, 6 valves open	0.5
Wickets up, 100% needles up	1.0
LaGrange	
Wickets down, 12 valves open	0.1
Wickets up, no needles, 12 valves open	0.1
Wickets up, no needles, 4 valves open	0.3
Wickets up, no needles, no valves open	0.6
Butterfly valves	0

** To be used in conjunction with equation 3 only*

DISCUSSION

General

The information presented in this report has been derived out of immediate engineering and planning needs. Considering the time constraint imposed and the physical obstacles and detriments encountered in the field, good overall results were produced.

One important revelation is that smaller gate openings consistently had greater reaeration capacities than larger openings, i.e., the aeration efficiency is inversely related to opening size. This is readily apparent from the data presented in tables 15 and 16. The smaller gate opening groupings displayed approximately twice the oxygen transfer efficiency as did the wider gate opening groupings.

This means more efficient aeration could be achieved by using the smallest opening possible while maintaining a desired downstream flow. For example, if 8 feet of opening is required at Starved Rock, 8 gates opened at 1 foot would be better than, say, two gates at 4 feet or even two at 3 feet and one at 2 feet.

This fact, superficially, appears contradictory to that reported by Preul and Holler[10] for the Meldahl Ohio River dam, in that 2-foot openings produced deficit ratios twice as large as 1-foot openings. Similarly, they found that 1-foot openings for the Markland dam produced almost 30 percent more aeration than did half-foot openings. The difference in the results of this study and those of Preul and Holler can be resolved by examining figures 6a and 6b, schematic diagrams of the basic gate designs used for each waterway. The Ohio River dam Tainter gates are designed to release flow into submerged stilling basins while all Tainter gates at Illinois Waterway dams release flow onto raised curvilinear surfaces. For the Ohio River dam conditions Preul and Holler state:

> It appears that an increase in gate opening from one ft. to two ft. can increase the amount of oxygen transferred to the flow. This is primarily the result of the great increase in turbulence that results from a two-ft. gate opening. In the case of the one-ft. gate opening, most of the discharging jet remains submerged beneath the tailwater in the stilling basin. The amount of air-water interface and the rate of surface renewal are both small. Increasing the gate opening to two ft. brings the elevation of the discharging jet closer to the surface of the tailwater. More water particles break through the surface and create air-water interfaces and the increased turbulence greatly increases the rate of surface renewal.

Under normal flows, the discharging jets for the Tainter gates at Illinois Waterway dams are always free, as can be seen by examining the basic gate design sections given in Appendix C. The Brandon Road dam, in particular, is an extreme case of setting the gates high above the normal downstream water level. The crest of the concrete ogee-type spillway section is 35.75 feet above the toe and 31.75 feet above the lower pool elevation. The Marseilles gate design is at the other extreme; the seating crest is only 1.25 feet above the downstream toe. However, the downstream receiving channel is a very shallow rocky rapids which limits downstream flooding of the gate releases to periods of extremely high flows. Consequently, for the Illinois dam gates, the smaller openings aerate thin turbulent jets which splash freely on the downstream surface. As the openings increase for a given head differential, smoother, less forceful discharges occur which are less conducive to aeration. The water is literally squirted out for small openings.

An interesting observation made by Susag et al.[9] was that after the building of the Mississippi River lock and dam 3 (L & D 3) below L & D 2, aeration at L & D 2 was reduced by one-third due to Tainter gate flooding by the tailwaters of L & D 3. They found that aeration could be increased significantly by raising the Tainter gates completely and installing bulkheads in the openings.

Table 17 summarizes the aeration characteristics of the Ohio and Mississippi dam Tainter gates. The reaeration capacity is expressed in terms of the dam aeration coefficient as utilized in this report so that relative comparisons can be made. The Ohio River structures are greater than 30 feet, and they therefore can only be compared to the Brandon Road dam using equation 3. The Meldahl dam is a significantly better aerator than its sister structure, the Markland dam, at comparable 1-foot gate openings. The Meldahl gates are somewhat better aerators than the Brandon Road dam gates at 2-foot openings (see table 16); however, 6-foot head gate openings at Brandon Road produce more aeration than do 2-foot openings at Meldahl.

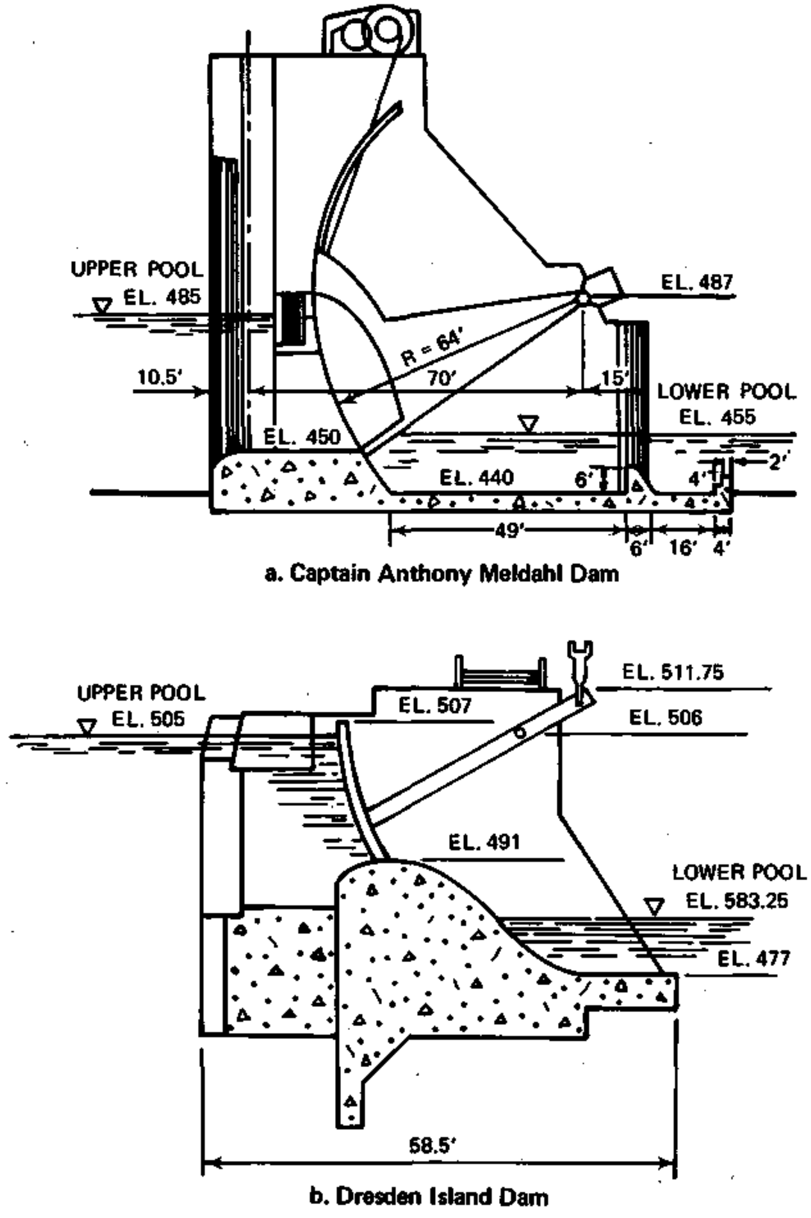


Figure 6. Tainter gate schematics

Table 17. Dam Aeration Coefficients (b) and Attendant Plysical Data for Meldahl and Markland Dams (Ohio River) and Mississippi River Lock and Dam 2

Date	a (est.)	Temp. (°C)	DO (mg/l) Above	DO (mg/l) Below	Pool elevation (MSD Above	Pool elevation (MSD Below	b	Gate settings (ft) 1	2	3	0*
Meldahl Dam											
8/30/67	1.0	25.8	5.52	6.58	485	455	9.5	10			
3/17/69	1.3	6.0	10.40	11.00	485	455	7.1	11			
4/16/68	1.3	14.0	9.30	10.03	485	455	42.4		12		
9/1/67	1.0	25.5	5.43	7.45	485	455	41.3		3	1	
9/28/67	1.0	25.5	5.96	706	485	455	14.0	9	3		
4/22/68	1.3	16.0	8.75	9.55	485	455	38.4	3	9		
12/18/68	1.3	4.5	10.41	11.81	485	455	22.3	4	6	1	
8/29/67	1.0	25.5	5.72	6.88	485	455	12.6	4			5
8/9/67	1.0	27.0	5.79	6.96	485	455	16.4	9	1		2
Markland Dam											
9/28/67	0.9	22.0	3.94	5.04	455	420	4.1	4			
10/1/68	0.9	23.0	3.05	3.45	455	420	1.1	7 at 0.5 ft			
L&D 2 Dam											
1/30/38	0.8	0	1.75	7.50	687.2	669.1	1.2	unsubmerged gates			
1/59	1.0	0	1.04	2.44	687.2	675.0	0.14	submerged gates			
1/64	1.0	0	0.64	4.74	687.2	675.0	0.5	bulkheads			

* *Tainter gates submerged with flow over the top*

The Tainter gates at L & D 2 on the Mississippi River, before the establishment of L & D 3 gate discharges, had aeration coefficients very similar to those observed at the Dresden Island, Marseilles, and Starved Rock dams. After the L & D 2 gate discharges became flooded, the aeration capacity was reduced to less than 12 percent of the preflooded value. Placement of the bulkheads created an overflow condition resulting in considerable improvement of the weir aeration coefficient. The improved b value of 0.5 is, however, below that expected for a sharp crested weir, but it is comparable to those observed for the Peoria and LaGrange dams when the wickets are up without needle placement. The probable cause for the lower than expected values is discussed in more detail later.

Individual Structures

A brief description of conditions observed at each dam during the study period is presented, and the quality of the collected data and the overall quality of the results specific to each structure are discussed. The areal layout of each dam and typical gate sections for each are presented in Appendix C. Unique or unusual characteristics of each dam and/or release structure are discussed and related to dam aeration in the following sections.

Lockport

The Lockport dam is the highest structure located on a commercially navigable stream within Illinois or along its boundaries. The difference in upper and lower flat pool elevations is 39 feet. The dam was built in 1905 by the Metropolitan Sanitary District of Greater Chicago (MSD) for power generation; the locks were added in 1933. The structure is still used for hydroelectric power generation, and as a consequence, it is a very inefficient aerator. The upstream water passes through the intake bays, down into the penstocks and turbines, and then releases through sluice gates without being subjected to a significant amount of turbulence.

Because of the lack of any significant reaeration, the structure was sampled only three times, whereas the other six dams were sampled on five different dates. The data for Lockport in Appendix B-3 show the maximum oxygen uptake observed was 0.42 mg/1, a very small amount considering the upstream DO concentration was a low 1.80 mg/1. When the upstream DO was approximately 2.5 mg/1 on another occasion, no DO uptake at all occurred. The best estimate of b is 0.3; this figure should result in good downstream DO predictions when used in conjunction with equation 3.

Low b values are to be expected when flow is released or controlled by sluice gates. Other studies by Butts and Evans[3] and Gameson[12] found weir coefficients equal to 0.05 or less for sluice gate controlled structures on small rivers and streams.

Brandon Road

This lock and dam is second only to Lockport in height having a difference in flat pool elevations of 35 feet. Consequently, the b value estimates derived for this structure must also be used in conjunction with equation 3.

The design of this structure is rather unusual in that small Tainter gates are set on top of a tall curvilinear spillway. A hydraulic jump is designed into the base at the toe. The gates can be opened to a maximum of only 2.25 feet, and this is the height at which they are always set. This spillway and gate design has allowed tremendous amounts of oxygen-consuming sediments to build up behind the dam. Flows can also be released through head gates (see Appendix C). Also, the gates, when closed, exhibit considerable leakage; thin sheets of 'white water' can be observed sliding over the face of the spillway.

Five different physical conditions were evaluated for this dam as summarized in tables 15 and 16. To distinguish leakage conditions, a gate was arbitrarily assigned an opening of 0.1 foot, i.e., a 0.1 foot designation indicates leakage at a flow release gate at any dam site.

Good aeration is achieved at this dam by various means. The head gates, when opened only 6 feet, produced an exceptionally high aeration coefficient. Increasing the opening to 8 feet, however, reduced the aeration coefficient to less than a third of the 6-foot value, while an 8- and 4-foot opening combination produced an intermediate value. The free surface discharge of the Brandon Road Tainter gates did not appear to promote quite as much aeration as did the submerged 2-foot gates for the Meldahl dam on the Ohio River.

The fact that flow releases at this structure produce high aeration coefficients is important since the upstream DOs are generally very low. During this study values ranged from 0.56 to 3.4 mg/1 while Butts et al.[4] in their study of the upper waterway found that the DO above the dam frequently fell below 2 mg/1. Nevertheless, downstream DO ranged from 6.40 to 7.42 mg/1 during this study. This is a prime example of a dam placement physically aiding in the degradation of upstream waters, and therefore, efficient reaeration at the dam site itself is critical to the maintenance of satisfactory downstream water quality.

Dresden Island

This lock and dam is relatively high, having a flat pool elevation differential of 21.75 feet; however, it can be evaluated by using equation 2. The overall results show that gate openings of 1 foot or less produced a reaeration coefficient twice that for 2-foot openings. The generalized coefficients given in table 16 should provide good reliable downstream DO estimates.

One water quality factor in excess of 2 resulted from the weir box data evaluation for this dam (see Appendix B-2). Table 18 lists this and seven other abnormal values along with realistic replacement values calculated for each by equation 5. The water quality immediately above the dam is probably influenced by the Kankakee River, which empties into the Illinois Waterway about a mile upstream of the dam. Also, the pool area is wide and the water is sluggish providing good habitat for algae which, as was shown earlier, have a big influence on the water quality factor in equation 2.

Marseilles

The Marseilles dam, like the Lockport dam, creates a head which is utilized for hydroelectric power generation. However, unlike at Lockport, a significant portion of the flow not needed for power generation is released through the dam Tainter gates. Butts et al.[4] report that only river flows in excess of 8500 cfs at Marseilles are released through the Tainter gates. They found that for 24 sampling days during 1971 (a relatively dry year) the average DO above the dam was actually 0.14 mg/1 higher than that below. On the other hand, they found that for four days of high flows during 1971, the average downstream DO concentration was 1.75 mg/1 higher than the upstream value.

The weir coefficient data given in tables 15 and 16 for the conditions observed at Marseilles show, characteristically, that the smaller gate opening grouping has an average reaeration coefficient twice as large as that for the wider opening grouping. The outfalls at the power plant and at Nabisco were

Table 18. Outlier Water Quality Factors and Realistic Replacement Values Estimated with Equation 5

Dam	*Date*	*Water quality factor*	
		*Weir box**	*Equation 5*
Dresden Island	8/25/78	2.64	1.03
Marseilles	8/24/78	0.11	1.04
Starved Rock	8/24/78	17.19	1.43
	9/07/78	0.00	1.32
	9/14/79	2.09	1.22
Peoria	8/12/78	0.56	1.15
	10/02/78	2.5S	1.16
LaGrange	8/22/78	0.54	1.12

• *Calculated for 1 meter water fall height*

sampled once. Headrace water wasted over a weir, i.e., not channeled through the turbines, was found to be reaerated at a rate slightly less than that observed for dam gate settings of at least 3 feet but at a rate significantly less than that observed for gate settings less than 2 feet. No detectable aeration occurred in the turbine discharge water nor in the raceway water flowing through Nabisco properties.

The generalized coefficients presented for Marseilles in table 16 should provide very good estimates of downstream DO concentration. The normal upstream and downstream water level difference is only 14.25 feet, which approaches the upper limit of h recommended for use in equation 2. In addition, except for the one outlier noted in table 18, the water quality factor fell within a relatively narrow range (see Appendix B-2).

A comparison of the Marseilles b values with those of Dresden Island, as summarized in table 15, indicates that the Marseilles dam may not have the aeration potential Dresden Island does. One-foot openings or less in the Marseilles gates appear to produce about the same amount of reaeration as do the 2-foot openings, whereas a sharp break occurs between the 1- and 2-foot settingsat Dresden Island. In other words, setting gate openings at 1 foot rather than at 2 feet at Dresden Island will significantly increase DO levels, but doing so at Marseilles will probably not. Increasing the openings to 3 feet or greater, however, will in all probability reduce downstream DO levels.

Unlike flow release structures at other dams along the waterway, the Marseilles gates have been discharge rated by the U. S. Geological Survey.[18] This information allows an evaluation to be made of the actual oxygen transfer loads being achieved for various gate opening heights. The Marseilles Tainter gates are 60 feet wide and have maximum openings of approximately 14.5 feet. The discharge is governed by the headwater elevation, free or flooded tailwater conditions, and opening height. The DO transfer rates for gate openings are given in table 19 for ambient or observed conditions and for standardized conditions specified as: C_A equal to 5 mg/1 at a water temperature of 20°C with water levels at flat pool elevations. The C_B values for standard conditions were derived by calculating the deficit ratio by substituting into equation 2 the observed a and b values listed in table 19 and the standard values as specified. Equation 1 was then used to solve for C_B.The gate opening heights versus transfer rates are plotted and shown as figure 7. Although the correlation for the data is not high, a definite tendency toward higher oxygen transfer rates per foot of gate opening exists for smaller opening sizes. On the basis of the resultant regression equation, very little reaeration would be expected to occur for gate openings in excess of 10 feet. The transfer rates for the three leaking gates (assumed to be open 0.1 foot) are extremely high having values of 51,913, 68,373, and 76,974 lbs/day/ft. Consequently, fractional gate openings less than 0.5 feet should not be extrapolated for use in the given equation.

Starved Rock

This is a moderately high structure with a flat pool elevation differential of 18.7 feet. This allows equation 2 to be used in the evaluation although the water level difference is somewhat higher than desirable for use of the equation. Number 10 Tainter

Table 19. Oxygen Transfer Loads for Marseilles Gate Openings at Ambient and Standard Conditions

(C_A =5mg/l, $T = 20°C$, U. P. Elev. 483.25, L. P. Elev. 471.0)

Date	Gate open (ft)	Observed coefficients a	b	Ambient conditions: Pool elevation Upper	Lower	Temp. (°C) Upper	Lower	DO (mg/l) C_A	C_B	$C_B - C_A$	Standard DO cond. (mg/l) C_B	$C_B - 5$	Flow/gate (cfs)	DO transfer (lbs/day/ft) Ambient	Standard
8/24/78	4	1.04	0.31	482.9	470.9	28.0	27.5	6.60	7.10	0.50	6.37	1.37	4,650	3,139	8,600
9/19/78	5	0.81	0.81	483.2	472.5	25.0	25.0	4.68	6.53	1.85	7.06	2.06	5,730	11,449	12,748
8/06/79	0.5	0.98	0.58	483.1.	471.5	28.9	29.5	4.70	6.13	1.43	6.92	1.92	680	10,502	14,100
	3	0.98	0.45	483.2	471.5	28.9	29.5	4.80	6.13	1.33	6.67	1.67	3,640	8,714	10,942
	3	0.98	0.48	483.2	471.5	29.1	29.0	5.00	6.23	1.23	6.73	1.73	3,640	8,053	11,335
9/06/79	1	1.30	1.33	483.3	470.7	27.5	27.9	5.47	7.20	1.73	7.96	2.96	1,320	12,331	21,099
	2	1.30	0.58	483.2	470.7	27.5	27.8	5.47	6.80	1.33	7.20	2.20	2,530	9,085	15,028
9/12/79	1	0.94	1.02	483.1	470.7	25.3	25.4	6.36	7.47	1.11	7.44	2.44	1,320	7,912	17,392
	2	0.94	1.08	483.1	470.7	25.4	25.3	6.54	7.57	1.03	7.49	2.49	2,530	9,817	17,009
9/19/78	1	0.81	0.78	483.1	472.5	24.7	25.0	4.61	6.43	1.82	6.97	1.97	244	47,961	51,913
9/06/78	1	1.30	0.93	483.3	470.7	27.5	27.9	5.51	7.05	1.54	7.66	2.66	238	39,584	68,373
9/12/78	1	0.94	2.00	483.2	470.7	25.5	25.5	6.33	7.70	1.37	8.02	3.02	236	34,919	76,974

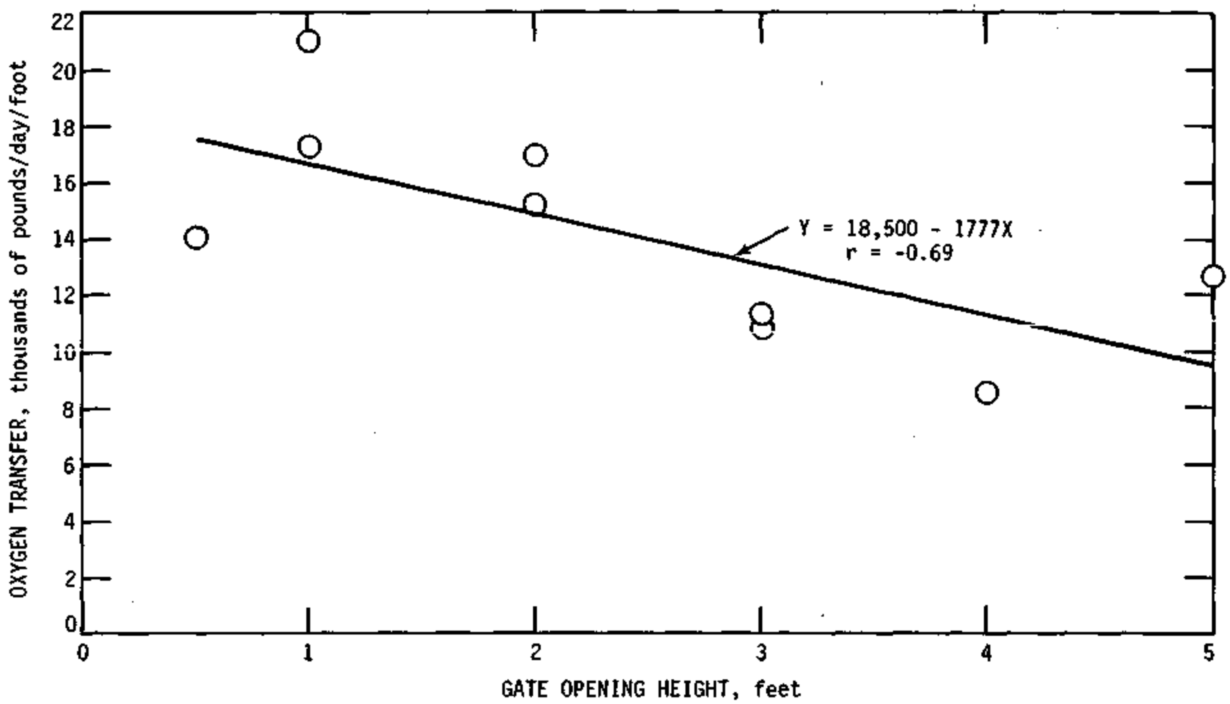


Figure 7. Dissolved oxygen Transfer rates for Marseilles Dam Tainter gate openings (C_A = 5 mg/l, T = 20°C, Upper Pool Elev. 483.25, L.P. Elew. 471.0)

gate (see sketch in Appendix C) is stuck in a down position and is presently inoperative.

The results produced by use of the data collected at this site from instream and weir box sampling are not very good. Unfortunately, during three of the five sampling days, DO concentrations above the dam were high ranging from 86.5 to 100 percent of saturation. These conditions prevent making accurate evaluations by use of the raw data for the reasons presented and discussed earlier. Ten different upstream and downstream stations were sampled in tandem. Of these, seven produced negative b values, six of which were the result of 'Case II' conditions and one the result of a 'Case IV condition. The other three b values came out positive but were unacceptably high because $C_S - C_A$ and $C_S - C_B$ were both numerically small, though in terms of absolutes, $C_S - C_B$ was much smaller than $C_S - C_A$.

As an example, at one station on August 23, 1978, the upstream saturated and observed DOs were 7.95 and 7.21 mg/l, respectively, while the corresponding downstream values were 7.84 and 7.80 mg/l. Consequently, C_S - C_A = 0.74 mg/l and C_S - C_B = 0.04 mg/l resulting in an observed deficit ratio of 18.5. This in turn yielded a b value of 6.13.

However, if the contaminated river water DO saturation level was as little as 0.3 mg/l greater than that for distilled water (equation 4 was developed for distilled water) as has been observed by Kothandaraman,[13] then the deficit ratio would be only 3.05 (1.05/0.34) a realistically usable figure. When the observed C_A or C_B is much below Cs, errors in measuring stream DOs or the inaccuracy of C_S have minimal effects on the computations as can be shown by another example. On September 20, 1979, C_A, C_B, C_{SA}, and C_{SB} were, respectively, 5.53, 6.50, 8.10, and 8.18 mg/l resulting in an r value of 1.52. If, however, both C_{SA} and C_{SB} were actually 0.3 mg/l greater, the r value would come out as 1.45, a minimal difference. Therefore, to make the 10 tandem observations usable with some degree of confidence, the DO concentrations observed below the dam were reduced by 0.3 mg/l (essentially the same as increasing C_S by 0.3 mg/l). This produced good usable positive results for eight of the ten cases as shown by the tabulation presented at the end of Appendix B-3.

The near saturated DO levels also affected the weir box data. Unrealistic a values which resulted are given in table 18 along with more appropriate values estimated by equation 5.

Overall, the Starved Rock gates appear to be the least efficient of any among the four dams that employ Tainter gates as the principal means of discharge control (see tables 15 and 16). However, like the other structures, the discharge is normally unsubmerged, and as a consequence, larger opening widths exhibit significantly reduced aeration capabilities.

Peoria

The Peoria Lock and Dam is one of two along the waterway which does not employ some type of gate as the principal means of releasing flow. The other is the LaGrange Lock and Dam. These structures have designs which are unique in this country. Flow release is controlled by the manipulation of collapsible weirs known as Chanoine wickets. The basic design of the wickets is depicted in Appendix C.

During periods of sustained high flows, the wicket sections are lowered to the river bottom on a hinge, thus allowing unrestricted travel across the structure. An individual wicket is 16.5 feet deep, 4 feet wide, and 1 foot thick; each is separated by a space slightly less than 4 inches wide. During intermediate flows, the major portion of the river flow is allowed to discharge through the spaces between the wickets; a minimal amount of water goes over the top. When very low flows occur, 4-inch by 4-inch wooden 'needles' are inserted in the spaces as needed to create the desired upstream head. Flow at Peoria and LaGrange can also be regulated by opening or closing a number of 6-foot butterfly valves (see table 1) in combination with wicket and needle placement. This type of operation produces great variability in the reaeration coefficient of the dam.

At first glance in the field, the wicket dam appears to be acting as a giant sharp crested weir; water appears to be going over the top of the wickets even in the absence of needle placement. However, in the absence of needles, the river actually flows through the spaces between the wickets which reduces the potential aeration capacity.

The difference in water elevation between the upper and lower flat pools is only 11 feet, so equation 2 can be used with confidence in evaluating the aeration characteristics of this structure.

Table 15 presents a summary of the results of six operating procedures encountered during sampling runs. These results have been summarized and rearranged into four broad classifications as presented in table 16. Of particular note is the fact that when a large proportion of the needles are in place, the weir aeration coefficient closely approximates the theoretical 1.0 value for a sharp crested weir. But when only a small number of needles are in place, the b value is greatly reduced. Only a little aeration is achieved when the butterfly valves are used in conjunction with up wickets without needles. In the areas where a significant number of wickets are down, aeration is essentially nil and no allowance should be made for downstream improvements in the DO in the portion of the flow passing through the down section.

The upstream DOs found at Peoria during all the field sampling dates were somewhat higher than desirable with depth weighted average values ranging from 6 to 9 mg/1. Also, on some dates considerable variation occurred with depth. For example, for one station on July 27, 1979, the DO at 1 foot was 8.4 mg/1 compared to a value of 5.7 mg/1 at 19 feet. Unfortunately, the majority of the low DO water does not have an opportunity to achieve full reaeration potential because it is released near the bottom of the spaces between the wickets.

LaGrange

The LaGrange lock and dam is similar in design to the one at Peoria in that flow release is controlled by use of wickets, needles, and butterfly valves as depicted in Appendix C. The flat pool water elevation difference is only 10 feet. The overall results were essentially the same as obtained at Peoria for similar operating conditions. Some minor differences did occur, however. No evaluation could be made of needle placement because none were in place during any of the sampling dates. In one situation here, the wickets were all up when all the butterfly valves were closed. This appears to produce a slight improvement in the reaeration potential over the situation where the wickets are up but some valves are open, as was the case observed at Peoria. DO pickup through the valves was not significant, though a small but significant increase was noted in areas downstream of down wickets. Values derived for conditions observed at one dam but not at the other can probably be applied to both. For instance, the weir coefficient of 1.0 for needle placement at Peoria is, in all probability, applicable to LaGrange with needle placement between wickets.

The upstream DOs used in making these evaluations were somewhat lower than those at Peoria, although stratification also occurred; at a station on August 22, 1978, the 1-foot DO was 9.6 mg/1 while the 20.5-foot one was 5.8 mg/1. On one occasion (September 21, 1978) very low upstream values of approximately 2.5 mg/1 were found. Unfortunately, at this time all 12 butterfly valves were open and 25 of the 135 wickets were down, thus producing less than a 1 mg/1 increase in DO downstream.

Future Considerations and Applications

Additional Research

An intensive DO-temperature sampling program, under controlled conditions, had been planned but was not implemented because of unfavorable late summer and early fall hydrologic and water quality conditions. This special sampling program will be done at a later date. The principal purpose of the specialized study was to obtain aeration information over a wide range of Tainter gate openings so that an optimal aeration operating procedure could be formulated that would be compatible with navigational interests.

The Starved Rock dam was selected as the best study site. This choice was made primarily by default — the Brandon Road dam gates can be opened a maximum of only 2.25 feet, the Dresden Island dam downstream station access is difficult and somewhat dangerous, and most of the discharge at Marseilles during low flows has to be routed around the dam and through the hydroelectric plant. Taking these facts into consideration, only the Starved Rock dam was an acceptable, relatively safe study site. A significant disadvantage does exist at Starved Rock, however, in that summer and fall daytime DO concentrations persist at or near saturation levels for lengthy periods because of photosynthetic oxygen production. This results from the fact that the Starved Rock pool is wide, relatively shallow, and is 'seeded' with algae cells from the Fox River.

To gain full insight into the reaeration characteristics of an Illinois Waterway Tainter gate, sampling should be carried out during two distinct periods. One should be during summer low flows when the upper and lower water surfaces are at flat pool elevation, thus assuring a free discharge surface. The other should be at higher flows when the downstream pool elevation is such that the discharge through a gate acts as a submerged orifice. The results of this study have clearly shown that for free discharges smaller gate openings produce more aeration. However, because of the random nature of the sampling, reaeration coefficient values could only be generalized by groupings within a rather narrow range of gate opening heights.

More definitive relationships need to be developed relating the dam reaeration coefficient to opening size. No information is available for submerged orifice conditions for Illinois Waterway structures; the possibility exists that for this situation the reaeration coefficient may increase with opening size as was shown to be the case for the Ohio River dams.[10] Reaeration at dams may, at times, be as important during high flows as during low flows. Butts et al.[4] have shown that DO water quality standards are frequently violated in all pools of the upper waterway over a wide range of flow conditions including those which are exceeded over 95 percent of the time.

Corps of Engineers personnel at the Joliet Project office were consulted about a controlled study at Starved Rock. A combination of 8 feet of total gate opening with at least 14 feet of available head was specified as minimal practical conditions under which low flow manipulation of the gates could be achieved. This would allow eight different gate setting combinations. If we assume conditions would warrant an average 8-hour total gate opening of 8 feet, settings per hour could include: 8 gates at 1 ft, 4 at 2 ft, 3 at 3 ft, 2 at 4 ft, 2 at 5 ft, 1 at 6 ft, 1 at 7 ft, and 1 at 8 ft; Some adjustments could be made to accommodate minor changes which may be needed on an hourly basis. For instance, the number of 1-foot gate openings could be reduced to conserve flow since, conceivably, eight 1-foot openings will result in more total discharge than one 8-foot opening. Conversely, if more flow release is needed during an 8-foot gate opening run, it could be handled through a gate remote from the 8-foot open one. This would minimize downstream mixing, thus conserving the integrity of the stream flow from the gate being investigated.

Applications and Implications

The implication of various gate and wicket operating modes is demonstrated here by numerical examples. Simple problems are solved to illustrate the possible consequences of increased diversion on the aeration capacity of a Tainter gate or wicket. The Corps of Engineers has established discharge criteria to be used in assessing the implications of increased diversion. The base flows for the years 1971, 1973, and 1977 were chosen on the rationale that 1971 approximated an average flow year whereas 1973 and 1977 were wet and dry flow years, respectively. To these base flows, excluding existing diversion allotments, total diversion flow of 6600 and 10,000 cfs were added. However, since existing average daily diversion is 3200 cfs and is automatically assumed to be built into daily flows, the actual additional diversions required for the set of conditions are 3400 cfs (6600 - 3200) and 6800 cfs (10,000 – 3200). Under these specifications, flow estimates in the vicinity of the Dresden Island and Marseilles Dams have been generated and are tabulated in table 20.

Stages for the flows in table 20 are presented in table 21. The values were derived by matching the flows in table 20 (within a couple of hundred cfs) with similar ones which occurred during 1971 and 1973 and finding the corresponding stage from a Corps of Engineer computer printout listing 1971, 1973, and 1977 values. The 1977 flow values were not included in the computations because these values appeared to be abnormal. For example, at Marseilles for the 15,143 cfs case, seven 1971 and 1973 matching flows resulted in an above dam average stage of 487.9. Five 1977 matching flows resulted in an average of only 483.0. For smaller flows, the anomaly still existed but on a less exaggerated scale. For example, the above dam average Marseilles value for the 6914 cfs case of 21 matching 1971 and 1973 values was 484.4 versus 483.9 for 18 matching 1977 values. Stages, flows, and gate conditions occurring at the two dams during the field sampling dates are presented in table 22.

The first example will demonstrate the significance of differential gate opening heights on the downstream DOs at Dresden Island under the following conditions: an upstream DO of 5 mg/1, a water quality factor of 1.5, and a water temperature of 20°C for the maximum and minimum flows presented in table 20.

On the basis of calculations using the limited data in table 22, approximately 1375 cfs appears to be released per foot of gate opening at Dresden Island. Consequently, about 4.5 feet and 15 feet of gate opening are needed, respectively, for the minimum flow of 6484 cfs and the maximum flow of 20,349 cfs indicated in table 20. Nine gates are available for flow release; therefore, at minimum conditions four gates could be opened 1 foot and one 0.5 foot while at maximum conditions eight could be opened 1.5 feet and one at 3 feet. These combinations appear to be the most efficient for reaeration. Equations 1 and 2 can be used to solve for the downstream dissolved oxygen concentration (C_B):

Given:

C_A = 5 mg/1
T = 20°C
C_S = 9.02 mg/1
a = 1.5
b =2 (gate openings $\leq$ 1 ft, see table 16)
= 1 (gate openings $\geq$ 2 ft, see table 16)
h = 20.7 ft = 6.31m (min. flow, table 20)
= 16.3 ft = 4.95 m (max. flow, table 20)

Determine C_B for gate openings $\leq$ 1.0 foot, i.e., low flow and no diversion.

From equation 2

$$r = 1+(.38)(1.5)(2)(6.31)[1-(.11)(6.31)][1+(.046)(20)]$$
$$r = 5.22$$

From equation 1

$$C_B = 9.02 - [9.02 - 5)/5.22]$$
$$C_B = 8.25 \text{ mg/1 (predicted downstream DO)}$$

Determine C_B for gate openings > 1.0, i.e., high flow + 6800 cfs diversion.

From equation 2 (using b = 1.5 for 8 gates at 1.5 ft and b = 1 for 1 gate at 3 ft)

1.5 ft gates

$$r = 1+(.38)(1.5)(1.5)(4.95)[1-(.11)(4.95)][1+(.046)(20)]$$
$$r = 4.70$$

3 ft gate

$$r = 1+(.38)(1.5)(1)(4.95)[1-(.11)(4.95)][1+(.046)(20)]$$
$$r = 3.47$$

Table 20. Flow Specifications (cfs) for Water Quality Assessments during Increased Lake Michigan Diversion

Diversion added (cfs)	Dry (1977) Dresden Island	Dry (1977) Marseilles	Average (1971) Dresden Island	Average (1971) Marseilles	Wet (1973) Dresden Island	Wet (1973) Marseilles
0	6,484	6,914(4,900)	7,726	8,343(6,351)	13,549	15,120(12,764)
3400	9,884	10,314(8,234)	11,126	11,743(9,643)	16,949	18,520(15,980)
6800	13,284	13,284(11,446)	14,526	15,143(12,787)	20,349	21,920(19,300)

() Actual flow through dam corrected for raceway diversion to power plant

Tabie 21. Estimated Stages Above and Below Dresden Island and Marseilles Dams For Flows Presented in Table 20

Diversion added (cfs)	Dry (1977) Dresden Island Above	Below	Marseilles Above	Below	Average (1971) Dresden Island Above	Below	Marseilles Above	Below	Wet (1973) Dresden Island Above	Below	Marseilles Above	Below
0	504.9	484.2	484.4	470.7	505.1	484.8	484.8	471.2	505.3	487.2	487.9	472.6
3400	505.3	485.8	486.0	472.0	505.2	485.8	486.2	472.1	505.5	498.5	489.3	473.1
6800	505.2	486.9	487.3	472.4	505.3	487.2	487.9	472.6	505.9	489.6	490.3	473.8

Table 22. Flow and Total Gate Height Open during Field Sampling Dates at Dresden Island and Marseilles Dams

Date	Dresden Island dam Pool elevation Above	Below	Flow (cfs)	Total feet open	Date	Marseilles dam Pool elevation Above	Below	Flow (cfs)	Total feet open
8/25/78	504.6	484.4	6000	4.5	8/24/78	482.9	470.9	7,410	5
9/14/78	504.7	486.9	8900	10	9/19/78	483.1	472.5	16,500	10
8/08/79	504.7	485.9	9000	6	7/06/79	483.2	471.5	11,700	6.5
8/14/79	504.7	484.3	6800	4	9/06/79	483.3	470.7	6,860	3
9/05/79	504.7	483.9	5700	2	9/12/79	483.1	470.7	4,660	3

From equation 1

Below 1.5 ft gates

C_B = 9.02 - [9.02 - 5)/4.70]

C_B = 8.16 mg/1 (predicted downstream DO)

Flow = (8) (1.5) (1375) = 16,500 cfs

Below 3 ft gate

C_B = 9.02 - [9.02 -5V3.47]

C_B = 7.86 mg/1 (predicted downstream DO)

Flow = (1) (3) (1375) = 4,125 cfs

Weighted average net concentration equals:

C_B = [(8.16) (16,500)+ (7.86) (4125)]/ [16,500 + 4125]

C_B = 8.10 mg/1

The primary conclusion which can be reached from this analysis is that increasing diversion will not enhance aeration at the dams, and it may, in fact, have a very slight negative effect. The manipulation of the gates will dictate what this effect will be to some extent. For instance, if the high flow were to be released through only five gates open 3 feet, then the downstream DO would be only 7.86 mg/1. Similarly, if the low flow were to be released through only one gate set at 4.5 feet, the expected downstream DO would also be 7.86 mg/1.

A detailed analysis, similar to that described above, was performed for the Marseilles dam using all the flow conditions presented in tables 20 and 21. The results are presented in table 23. These results are more definitive and accurate because of the availability of flow rating tables for the Marseilles gates. The downstream dissolved oxygen figures listed under the C_B heading represent values expected to occur immediately below the gates. The net overall result is a combination of the gate, power plant turbine, power plant weir, and Nabisco flows. For instance, at the low flow head approximately 2014 cfs is diverted to the raceways and almost all is used for power generation. As a consequence, the net DO below Marseilles with seven

Table 23. Estimated Downstrream DO (C_B)
for Various Flow Conditions at Marseilles Dam

		C_B (mg/l) @ 20°C for			
Flow conditions	*Gate opening combinations*	1.5 5	1.3 5	1.4 5.5	1.5 (a) 6.0 (C_A)
Dry + 0	7 @ 0.5 ft	7.9	7.7		
(4,900) cfs)	3 @ 1 ft, 1 @ 0.5 ft	7.9	7.7		
	2 @ 1.5 ft, 1 @ 0.5 ft	7.9	7.7		
	1 @ 3.5 ft, 1 @ 0.5 ft	7.3	7.2		
	1 @ 4 ft	7.2	7.1		
Dry + 3400 cfs	4 @ 1.5 ft	7.9		8.0	
(8,234 cfs)	3 @ 2.0 ft, 1 @ 0.5 ft	7.9		8.0	
	2 @ 3 ft, 1 @ 0.5 ft	7.3		7.4	
	1 @ 3.5 ft, 1 @ 3 ft	7.2		7.4	
	1 @ 4 ft, 1 @ 2.5 ft	7.3		7.5	
	1 @ 4.5 ft, 1 @ 2 ft	7.4		7.6	
	1 @ 5 ft, 1 @ 1.5 ft	7.4		7.5	
	1 @ 8 ft	7.2		7.4	
Dry + 6800 cfs	5 @ 1.5 ft, 1 @ 1 ft	7.9			8.2
(11,446 cfs)	4 @ 2 ft, 1 @ 0.5 ft	7.9			8.2
	2 @ 3.5 ft, 1 @ 2 ft	7.4			7.8
	1 @ 6 ft, 1 @ 3.5 ft	7.2			7.7
	1 @ 7 ft, 1 @ 2.5 ft	7.3			7.8
	1 @ 7.5 ft, 1 @ 2 ft	7.3			7.8
	1 @ 9 ft, 1 @ 1 ft	7.3			7.7
Average + 0	7 @ 0.5 ft, 1 @ 1 ft	7.9	7.7		
(6,351 cfs)	4 @ 1 ft, 1 @ 0.5 ft	7.9	7.7		
	2 @ 1.5 ft, 3 @ 0.5 ft	7.9	7.7		
	2 @ 2.5 ft	7.6	7.5		
	1 @ 3 ft, 1 @ 2 ft	7.5	7.4		
	1 @ 3.5 ft, 1 @ 1.5 ft	7.4	7.3		
	1 @ 4 ft, 1 @ 1 ft	7.4	7.2		
	1 @ 4.5 ft, 1 @ 0.5 ft	7.3	7.1		
Average + 3400 cfs	3 @ 1.5 ft, 3 @ 1 ft	7.9		8.0	
(9,643 cfs)	3 @ 2.5 ft	7.6		7.7	
	2 @ 3 ft, 1 @ 1.5 ft	7.4		7.5	
	1 @ 3.5 ft, 2 @ 2 ft	7.6		7.7	
	1 @ 4 ft, 1 @ 2 ft, 1 @ 1.5 ft	7.5		7.7	
	1 @ 4 ft, 2 @ 1.5 ft	7.5		7.6	
	1 @ 5 ft, 3 @ 1 ft	7.5		7.6	
Average + 6800 cfs	4 @ 2 ft, 1 @ 1.5 ft, 1 @ 1 ft	7.9			8.2
(12,787 cfs)	4 @ 2.5 ft, 1 @ 0.5 ft	7.6			8.0
	3 @ 3 ft, 1 @ 1 ft	7.3			7.7
	2 @ 3.5 ft, 2 @ 1.5 ft	7.4			7.8
	1 @ 4 ft, 3 @ 2 ft	7.2			7.7
	1 @ 4.5 ft, 2 @ 2 ft, 1 @ 1.5 ft	7.6			7.9
	1 @ 5 ft, 1 @ 4.5 ft, 1 @ 1 ft	7.3			7.7
	1 @ 5.5 ft, 1 @ 5 ft	7.2			7.7
	1 @ 9 ft, 1 @ 2 ft	7.4			7.8
Wet + 0	4 @ 2 ft, 1 @ 1.5 ft, 1 @ 1 ft	7.9		8.0	
(12,764 cfs)	4 @ 2.5 ft, 1 @ 0.5 ft	7.6		7.7	
	3 @ 3 ft, 1 @ 1 ft	7.3		7.4	
	2 @ 3.5 ft, 2 @ 1.5 ft	7.4		7.6	
	1 @ 4 ft, 3 @ 2 ft	7.2		7.4	

Continued on next page

Table 23. Concluded

Flow conditions	Gate opening combinations	C_B (mg/l) @ 20°C for 1.5 / 5	1.3 / 5	1.4 / 5.5	1.5 (a) / 6.0 (C_A)
	1 @ 4.5 ft, 2 @ 2 ft, 1 @ 1.5 ft	7.6		7.7	
	1 @ 5 ft, 1 @ 4.5 ft, 1 @ 1 ft	7.3		7.4	
	1 @ 5.5 ft, 1 @ 5 ft	7.2		7.4	
	1 @ 9 ft, 1 @ 2 ft	7.4		7.5	
Wet + 3400 cfs	5 @ 2.5 ft, 1 @ 1 ft	7.6			8.0
(15,980 cfs)	4 @ 3 ft, 1 @ 0.5 ft	7.2			7.7
	3 @ 3.5 ft, 1 @ 3.5 ft	7.3			7.7
	3 @ 4 ft, 1 @ 1 ft	7.3			7.7
	2 @ 5 ft, 3 @ 1 ft	7.4			7.8
	2 @ 6 ft, 1 @ 1.5 ft	7.3			7.7
	2 @ 6.5 ft, 1 @ 0.5 ft	7.2			7.7
	1 @ 7 ft, 1 @ 6.5 ft	7.2			7.7
Wet + 6800 cfs	6 @ 2.5 ft, 2 @ 1 ft	7.6			8.0
(19,300 cfs)	5 @ 3 ft, 2 @ 1 ft	7.3			7.7
	4 @ 3.5 ft, 3 @ 1 ft	7.6			7.7
	3 @ 4 ft, 2 @ 2 ft	7.4			7.8
	2 @ 4.5 ft, 2 @ 3.5 ft	7.2			7.7
	2 @ 5 ft, 1 @ 3.5 ft, 1 @ 2.5 ft	7.3			7.7
	2 @ 5.5 ft, 1 @ 3 ft, 1 @ 2 ft	7.3			7.7
	2 @ 6.5 ft, 1 @ 2.5 ft, 1 @ 1.5 ft	7.3			7.7
	2 @ 7 ft, 1 @ 2.5 ft	7.3			7.7
	2 @ 7.5 ft, 1 @ 1.5 ft	7.3			7.7
	2 @ 8 ft, 1 @ 1 ft	7.3			7.7
	2 @ 9 ft	7.2			7.7

gates open at 0.5 feet (C_A = 5 @ 20°C) would be only 7.1 mg/l since no aeration can be expected to occur in the turbine discharge.

The gate combinations listed in table 23 represent almost all the possibilities which exist within several hundred cfs of the specified flow values. Computations were performed under constant water quality conditions (CA = 5, a = 1.5, T = 20°C) which assumes lake diversion has no effect on the waterway quality. These results are listed under the first column of the C_B listings and reveal several interesting facts. One is that maximum aeration can be achieved during flows up to at least 13,000 cfs by maintaining the maximum number of gates at minimum openings. At flows in excess of 13,000 cfs, some gates have to be opened by necessity to heights which slightly reduce the overall aeration efficiency. Also, within a given flow (especially at low flows) unnecessarily wide openings can result in significantly lower DOs; a 4900 cfs release through one gate opened at 4 feet would produce 0.7 mg/l less DO downstream than if the same flow were released through seven gates opened 0.5 foot.

The results listed in the other three columns under C_B in table 23 reflect the results of water quality condition changes commensurate with increased natural flows and/or diversion. For example, the actual low flow water quality factors and upstream DOs would likely be lower than those for flows consisting of a greater percentage of high quality Lake Michigan water and/or natural runoff. The principal inference which can be made from these analyses is that, although a slight decrease in aeration efficiency may occur after a certain flow magnitude is reached, it may be more than compensated for by the increased background water quality.

Another possible factor which could influence the aeration efficiency at higher flows at Marseilles is the submergence of the openings by the tailwaters. The gate sill is perched at elevation 470.25 only a short distance above the normal lower pool elevation of 469.0. At the wet weather flow plus 6800 cfs diversion, the lower pool elevation is 473.8 (see table 21). Consequently, for 2.5 feet of opening the bottom of the gate would be at elevation 472.75 resulting in the gate being a foot under water. This small submergence could result in an aeration coefficient significantly different from those listed in table 16.

On September 19, 1978, sampling was done during a high flow period (see table 22). The gates were open 5 feet putting the gate bottom at elevation 475.25; from table 22 the tailwater was at elevation 472.5 leaving a net opening of 2.75 feet. Under these conditions, a relatively high aeration coefficient of 0.8 was calculated. This indicates that for the Marseilles dam a more realistic parameter for use in aeration control could be the net opening. The physical layout at the Dresden Island dam precludes the possibility of gate submergence except under abnormal conditions. At the highest flow listed in table 21, 1.4 feet of freeboard still existed between the gate sill and the lower water surface.

The influence of high flows on the aeration capacities of the wicket dams appears to be much more pronounced than for Tainter gate structures. For example, for the same standard conditions applied during the evaluation of the Dresden Island and Marseilles dams, the downstream DO at low flows with the wickets up and the needles in (b = 1.0) would be 7.8 mg/1. For a higher flow when the wickets are up without the needles (b = 0.2), the predicted downstream DO would be only 6.3 mg/1. This is a highly significant difference indicating that increased diversion could be detrimental to the water quality in the LaGrange and Alton pools. An upstream DO of 7.2 mg/l would be needed during high flows to provide a downstream DO of 7.8 mg/1, the value equivalent to that predicted for low flows.

As a final analysis, the relative aeration efficiency was computed for each dam. The results are given in table 24. At low flows, all the flow release structures at the dams provide excellent aeration except at Lockport, where all the flow is released through submerged sluice gates. The head gates at Brandon Road appear to provide the best aeration, but unfortunately flow is released through them only under special circumstances. The Dresden Island Tainter gates appear to be designed such that they provide the best aeration of any of the structures normally utilized for flow release along the waterway. Included in table 24 for comparison are the results of similar computations made for the two Ohio River and the Mississippi River dams discussed previously.

Table 24. Comparison of Predicted Downstream DO Concentrations (C_A) during Low Flows for a = 1.5, C_A = 5 mg/l, and T = 20°C at Flat Pools

Flow release structure	*Aeration factor, b*	*h (m)*	*C_B (mg/l)*	*Percent increase*
Dresden Island sluice gates	0.3*	11.87	5.2	4
Brandon Road Tainter gates	25*	10.36	8.0	60
Brandon Road head gates	80*	10.36	8.6	72
Dresden Island Tainter gates	2	6.63	8.3	66
Marseilles Tainter gates	1	4.34	7.9	58
Starved Rock Tainter gates	0.8	5.70	7.6	52
Peoria wickets	1	3.35	7.8	56
LaGrange wickets	1	3.05	7.8	56
Meldahl Tainter gates (Ohio R.)	42*	9.14	8.3	66
Markland Tainter gates (Ohio R.)	4*	10.67	6.3	26
Mississippi R. L & D 2 T. gates**	0.14	3.72	6.0	20
Mississippi R. L & D 2 T. gates***	1.2	5.52	8.0	60
Mississippi R. L & D 2 Weirs	0.5	5.52	7.2	44

* *b-values for use in equation 3*
** *Gates submerged*
*** *Gates unsubmerged*

REFERENCES

1 Butts, T. A., V. Kothandaraman, and R. L. Evans. 1973. *Practical considerations for assessing the waste assimilative capacity of Illinois Streams.* Illinois State Water Survey Circular 110.

2 Butts, T. A., R. L. Evans, and J. B. Stall. 1974. *A waste allocation study of selected streams in Illinois.* Prepared by Illinois State Water Survey for the Illinois EPA.

3 Butts, T. A., and R. L. Evans. 1978. *Effects of channel dams on dissolved oxygen concentrations in northeastern Illinois streams.* Illinois State Water Survey Circular 132.

4 Butts, T. A., R. L. Evans, and S. Lin. 1975. *Water quality features of the upper Illinois waterway.* Illinois State Water Survey Report of Investigation 79.

5 Holm, H. W. 1977. *Colonization of nitrifiers.* USEPA Environmental Research Laboratory Quarterly Report Research Highlights, July-September, Athens, Georgia.

6 Gameson, A. L. H. 1957. *Weirs and the aeration of rivers.* Journal of the Institution of Water Engineers (British), v. 6(11):477.

7 Crevensten, D., and A. Stoddard. 1974. *Water quality model of the lower Fox River, Wisconsin.* Proceedings, Seventeenth Conference on Great Lakes Research, International Association for Great Lakes Research, Hamilton, Ontario, Canada.

8 Foree, E. G. 1976. *Reaeration and velocity prediction for small streams.* ASCE Journal of the Environmental Engineering Division v. 102(EE5):937.

9 Susag, R. H., M. L. Robins, and G. J. Schroepfer. 1967. *Improving river aeration at an underflow dam.* ASCE Journal of the Sanitary Engineering Division v. 93(SA6):133.

10 Preul, C. H., and A. G. Holler. 1969. *Reaeration through low dams in the Ohio River.* Proceedings of the 24th Industrial Waste Conference - Part Two, Purdue University, Lafayette, Indiana.

11 Water Research Centre. 1973. *Aeration at weirs. In* Notes on Water Pollution. Elder Way, Stevenage, Herts, England, June, No. 61.

12 Velz, C. J. 1947. *Factors influencing self-purification and their relation to pollution abatement.* Sewage Works Journal v. 7(19):629.

13 Kothandaraman, V. 1971. *Effects of contaminants on reaeration rates in river water.* Journal Water Pollution Control Federation v. 5(43):806.

14 Gameson, A. L. H., K. G. Vandyke, and C. G. Ogden. 1958. *The effect of temperature on aeration at weirs.* Water and Water Engineering (British) v. 753(62):489.

15 Barrett, M. J., A. L. H. Gameson, and C. G. Ogden. 1960. *Aeration studies at four weir systems.* Water and Water Engineering v. 775(64):507, September.

16 Crow, E. L., F. A. Davis, and M. W. Maxfield. 1960. *Statistics Manual.* Dover Publications, Inc. New York, NY.

17 Committee on Sanitary Engineering Research. 1960. *Solubility of atmospheric oxygen in water.* ASCE Journal of the Sanitary Engineering Division, T. A., , 86(SE7):41.

18 U. S. Geological Survey. 1979. *Marseilles lock and dam rating.* Provisional Report, Champaign-Urbana, Illinois (May).

Appendix A-1. Laboratory Weir Box Data, Unreduced

h (ft)	h' (ft)	Flow (l/sec)	Temperature (°C) T_A	Temperature (°C) T_B	DO (mg/l) C_A 1	DO (mg/l) C_A 2	DO (mg/l) C_B 1	DO (mg/l) C_B 2
1.22	.06	.866	15.5	14.6	1.0	1.0	3.0	3.0
0.89	.06	.962	14.0	14.0	2.7	2.9	4.0	4.0
1.22	.06	.866	15.1	14.4	3.8	3.9	5.2	5.15
1.12	.095	.976	14.5	14.5	5.3	5.15	6.1	6.10
1.22	.06	.866	15.3	14.4	7.2	7.3	8.0	8.0
1.21	.06	.724	15.2	14.5	0.9	0.9	2.95	3.0
1.21	.06	.724	15.4	14.4	3.4	3.5	4.8	4.8
1.095	.09	.754	14.5	14.5	5.3	5.3	6.4	6.4
1.21	.06	.724	15.3	14.4	6.7	6.6	7.2	7.2
1.19	.06	.584	15.3	14.4	1.1	1.0	3.0	2.9
1.19	.06	.584	15.4	14.6	2.9	2.8	4.6	4.6
1.08	.085	.610	14.5	14.5	5.3	5.3	6.3	6.3
1.19	.06	.584	15.3	14.5	6.6	6.6	7.2	7.3
1.20	.06	.499	15.4	14.6	1.0	1.1	2.85	2.85
1.20	.06	.499	15.3	14.7	3.2	3.3	4.35	4.4
1.07	.08	.490	14.5	14.5	5.35	5.35	6.5	6.4
1.20	.06	.499	15.3	14.7	5.9	5.9	6.65	6.7
1.11	.10	.858	14.2	14.2	8.4	8.2	8.75	8.5
1.10	.09	.709	14.3	14.3	7.85	7.9	8.25	8.2
1.08	.10	.610	14.3	14.2	8.1	8.3	8.5	8.5
1.085	.10	.519	14.5	14.5	7.8	7.8	8,15	8.0
1.21	.38	.858	15.4	14.5	1.3	1.2	3.6	3.6
1.21	.38	.858	15.1	14.6	2.6	2.6	4 55	4.5
1.21	.38	.858	15.1	14.6	4.75	4.7	6.3	6.3
1.20	.38	.694	15.4	14.5	1.2	1.2	3.65	3.6
1.20	.38	.694	15.2	14.5	3.5	3.5	5.3	5.3
1.20	.38	.694	15.2	14.5	5.1	5.15	6.55	6.5
1.20	.38	.571	15.4	14.7	1.2	1.3	3.6	3.55
0.96	.39	.610	14.0	14.1	2.75	2.6	4.15	4.20
1.20	.38	.571	15.5	14.6	3.9	4.0	5.25	5.20
1.095	.39	.610	14.5	14.5	5.2	5.2	6.4	6.4
1.20	.38	.571	15.4	14.6	6.3	6.5	7.1	7.05
1.18	.38	.490	15.4	14.7	1.2	1.25	3.5	3.5
1.18	.38	.490	15.5	14.6	3.5	3.6	5.2	5.15
1.07	.38	.490	14.5	14.5	5.3	5.3	6.4	6.35
1.18	.38	.490	15.4	14.6	6.15	6.05	6.9	6.9
1.12	.40	.858	14.2	14.2	8.45	8.45	8.8	8.75
1.09	.39	.709	14.3	14.5	7.8	7.9	8.4	8.5
1.10	.39	.610	14.2	14.5	8.15	8.25	8.65	8.7
1.085	.39	.519	14.5	14.5	7.7	7.5	8.0	8.0
1.22	.79	.873	15.4	14.7	1.3	1.3	3.9	3.8
1.22	.79	.873	15.5	14.6	3.6	3.5	5.5	5.5
1.13	.78	.976	14.5	14.5	5.25	5.2	6,4	6.45
1.22	.79	.873	15.4	14.6	4.75	4.8	6.6	6.7
1.22	.79	.714	15.4	14.6	1.25	1.3	3.85	3.9
1.22	.79	.714	15.4	14.6	3.6	3.6	5.4	5.4
1.22	.79	.714	15.5	14.6	5.25	5.2	6.4	6.3
0.96	.77	.610	14.0	14.1	1.45	1.45	3.5	3.55
1.18	.78	.570	15.7	15.0	1.7	1.7	3.95	4.0
0.96	.77	.610	14.0	14.1	2.65	2.7	4.35	4.3

Appendix A-1. (Continued)

h (ft)	h' (ft)	Flow (l/sec)	Temperature (°C) T_A	Temperature (°C) T_B	DO (mg/l) C_A 1	DO (mg/l) C_A 2	DO (mg/l) C_B 1	DO (mg/l) C_B 2
1.18	.78	.570	15.8	14.9	3.8	3.7	5.35	5.3
1.08	.77	.610	14.5	14.5	5.3	5.3	6.5	6.5
1.18	.78	.570	15.7	15.0	6.5	6.5	7.4	7.4
0.93	.77	.490	14.0	14 4	1.4	1.5	3.3	3.55
1.18	.78	.506	15.6	14.9	1.8	1.7	4.2	4.15
1.18	.78	.506	15.8	15.1	3.15	3.1	5.2	5.2
1.08	.77	.490	14.5	14.5	5.4	5.3	6.6	6.6
1.18	.78	.506	15.8	15.1	6.25	6.3	7.0	7.0
1.12	.77	.858	14.2	14.2	8.25	8.4	8.9	8.9
1.10	.76	.709	14.2	14.2	7.9	7.8	8.6	8.6
1.085	.76	.610	14.2	14.2	8.15	8.15	8.6	8.6
1.10	.76	.519	14.2	14.2	7.8	7.7	8.4	8.35
0.99	1.24	.962	14.0	14.1	1.35	1.45	3.5	3.6
1.21	1.23	.830	15.6	14.8	1.8	1.7	4.1	4.1
1.21	1.23	.830	15.4	14.8	3.3	3.35	5.5	5.5
1.13	1.24	.976	14.5	14.5	5.3	5.3	6.5	6.4
1.21	1.23	.830	15.5	14.9	6.0	6.0	6.8	6.8
0.97	1.22	.755	14.0	14.1	1.4	1.5	3.4	3.6
1.21	1.23	.702	15.7	15.1	1.53	1.65	4.0	4.0
1.21	1.23	.702	15.7	15.1	2.95	2.95	4.95	4.9
1.15	1.23	.746	14.5	14.5	4.9	5.0	6.35	6.3
1.21	1.23	.702	15.9	15.1	5.7	5.7	6.9	6.9
0.97	1.22	.623	14.0	14.1	1.45	1.45	3.6	3.6
1.19	1.23	.572	15.9	15.2	2.2	2.1	4.3	4.2
1.19	1.23	.572	15.9	15.2	3.8	3.8	5.65	5.6
1.09	1.22	.610	14.5	14.5	5.0	5.05	6.25	6.3
1.19	1.23	.572	15.9	15.2	6.2	6.2	7.4	7.4
.97	1.22	.490	14.0	14.1	1.35	1.45	3.55	3.35
2.23	.37	.847	15.0	14.4	0.9	0.8	4.6	4.5
2.23	.37	.847	15.4	14.4	2.9	2.9	5.7	5.7
2.23	.37	.847	15.2	14.4	4.7	4.7	6.85	6.7
2.20	.36	.709	15.2	14.4	1.2	1.1	4_7	4.7
2.20	.36	.709	15.2	14.4	3.2	3.1	5.8	5.7
2.20	.36	.709	15.2	14.4	5.15	5.2	7.1	7.1
2.19	.36	.570	15.2	14.6	0.9	1.0	4.4	4.5
1.965	.345	.610	14.5	14.5	3.25	3.35	5.7	5.7
2.19	.36	.570	15.2	14.1	4.4	4.35	6.4	6.5
2.19	.36	.570	15.2	14. 1	5.4	5.4	7.1	7.1
2.20	.365	.502	15.1	14.5	1.15	1.2	4.55	4.0
1.96	.34	.490	14.5	14.5	3.6	3.6	6.0	6.0
2.20	.365	.502	15.2	14.5	4.25	4.3	6.1	6.0
2.20	.365	.502	15.2	14.5	6.5	6.5	7.6	7.6
2.01	.36	.858	14.4	14.4	8.25	8.3	8.8	8.8
1.95	.36	.709	14.4	14.4	7.8	7.9	8.7	8.7
2.00	.36	.610	14.2	14.2	8.15	8.2	9.05	9.1
1.98	.35	.519	14.0	14.2	7.7	7.75	8.6	8.4
1.96	.34	.489	14.5	14.5	2.65	2.6	5.3	5.2
1.965	.34	.623	14.5	14.5	4.1	4.1	6.2	6.2
1.96	.34	.489	14.5	14.5	3.9	3.7	6.1	6.1
1.96	.34	.489	14.5	14.5	2.6	2.55	5.45	5.3

Appendix A-1 (Continued)

h (ft)	h' (ft)	Flow (l/sec)	Temperature (°C) T_A	T_B	DO (mg/l) C_A 1	C_A 2	C_B 1	C_B 2
2.23	.78	.844	15.2	14.4	1.1	1.2	4.9	4.9
2.23	.78	.844	15.4	14.4	3.6	3.6	6.35	6.3
2.015	.78	.962	14.0	14.0	5.25	5.10	7.05	7.2
2.23	.78	.844	15.3	14.4	4.4	4.45	6.65	6.7
1.18	1.23	.494	16.0	15.4	2.75	2.7	4.8	4.70
1.03	1.22	.490	14.5	14.5	3.2	3.2	5.0	4.9
1.18	1.22	.494	16.0	15.4	4.7	4.6	6.5	6.5
1.18	1.23	.494	16.0	15.4	7.4	7.4	7.95	8.0
1.08	1.22	.490	14.5	14.5	3.7	3.7	5.5	5.5
1.115	1.24	.858	14.5	14.5	8.2	8.2	9.0	8.8
1.12	1.23	.709	14.5	14.5	7.5	7.5	8.2	8.2
1.095	1.23	.610	14.5	14.5	7.2	7.2	7.8	7.8
1.10	1.22	.519	14.2	14.2	7.8	7.8	8.3	8.4
1.15	1.23	.623	14.5	14.5	5.7	5.6	6.8	6.7
1.15	1.23	.754	14.5	14.5	5.7	5.7	7.0	7.0
2.24	.05	.810	15.0	14.2	1.1	1.1	3.9	3.85
2.24	.05	.810	14.9	14.1	3.0	2.95	5.2	5.2
2.24	.05	.810	15.0	14.2	4.8	4.9	6.5	6.5
2.22	.05	.714	14.7	14.1	1.2	1.2	3.9	4.0
2.22	.05	.714	14.9	14.2	3.3	3.3	5.7	5.6
2.22	.05	.714	15.0	14.3	4.9	4.85	6.5	6.5
2.20	.05	.590	14.9	14.2	1.2	1.2	4.0	4.0
2.20	.05	.590	15.0	14.2	3.3	3.5	5.65	5.6
2.20	.05	.590	15.0	14.2	5.2	5.25	6.7	6.7
2.19	.05	.510	15.0	14.2	1.2	1.1	3.45	3.35
2.19	.05	.510	15.2	14.4	3.3	3.5	5.4	5.5
1.96	.10	.490	14.5	14.5	5.15	5.2	6.6	6.5
2.19	.05	.510	14.8	14.4	6.5	6.5	7.5	7.5
2.05	.08	.858	14.1	14.1	8.3	8.45	8.75	8.8
2.05	.08	.709	14.0	14.2	8.05	8.05	8.5	8.65
1.95	.08	.610	14.0	14.2	7.9	7.95	8.65	8.55
1.98	.08	.519	14.0	14.2	7.8	7.6	8.25	8.3
2.22	.79	.711	15.1	14.4	0.9	1.0	4.9	4.8
2.22	.79	.711	15.4	14.6	3.1	3.15	6.2	6.3
2.22	.79	.711	15.4	14.6	4.9	4.9	6.9	6.9
2.19	.79	.583	15.3	14.6	1.0	1.0	5.0	4.9
1.97	.735	.610	14.5	14.5	2.8	2.8	6.0	6.0
2.19	.79	.583	15.3	14.6	4.2	4.2	6.7	6.7
2.025	.77	.610	14.0	14.1	5.3	5.3	7.2	7.2
2.19	.79	.583	15.3	14.6	6.8	6.8	8.1	8.1
2.18	.79	.498	15.4	14.7	0.9	0.9	4.85	4.9
1.96	.74	.490	14.5	14.5	3.7	3.8	6.4	6.4
2.18	.79	.498	15.4	14.7	4.2	4.2	6.7	6.6
1 95	.77	.490	14.0	14.1	4.75	4.7	7.0	6.8
2.18	.79	.498	15.5	14.7	6.7	6.55	7.9	8.0
2.02	.77	.858	14.2	14.0	8.3	8.6	9.1	8.95
1.99	.77	.709	14.2	14.2	8.1	7.9	9.0	8.95
1.99	.77	.610	14.2	14.2	8.15	8.2	9.05	9.1
1.965	.76	.519	14.2	14.2	7.8	7.8	8.7	8.8

Appendix A-1. (Continued)

h (ft)	h' (ft)	Flow (l/sec)	Temperature (°C) T_A	Temperature (°C) T_B	DO (mg/l) C_A 1	DO (mg/l) C_A 2	DO (mg/l) C_B 1	DO (mg/l) C_B 2
2.23	1.23	.858	15.4	14.6	0.8	0.9	4.65	4.7
2.23	1.23	.858	15.4	14.6	3.0	3.0	5.95	6.0
2.00	1.25	.976	14.5	14.5	5.35	5.35	7.5	7.35
2.23	1.23	.858	15.5	14.7	6.55	6.3	7.7	7.8
2.21	1.22	.717	15.4	14.5	1.1	1.05	4.9	4.9
2.21	1.22	.717	15.0	14.4	4.5	4.6	6.8	6.9
2.21	1.22	.717	15.2	14.4	3.0	3.0	6.05	6.05
2.20	1.22	.577	15.2	14.5	1.1	1.1	5.0	4.9
2.20	1.22	.577	15.3	14.5	2.5	2.6	5.8	5.8
2.20	1.22	.577	15.3	14.5	4.6	4.5	6.9	6.85
2.18	1.22	.499	15.3	14.5	0.9	1.0	5.0	5.0
2.18	1.22	.499	15 3	14.5	3.3	3.3	6.2	6.2
1.94	1.20	.490	14.5	14.5	5.2	5.2	7.3	7.3
1.94	1.22	.499	15.5	14.6	5.8	5.8	7.6	7.65
2.03	1.23	.858	14.4	14.2	8.4	8.5	9.1	9.2
2.00	1.22	.709	14 2	14.2	7.8	8.0	8.8	8.9
1.98	1.22	.610	14.2	14.2	8.2	8.2	9.1	9.1
1.965	1.22	.519	14.2	14.3	7.8	7.7	8.6	8.7
3.22	.05	.887	15.0	14.8	0.4	0.6	3.9	4.0
3.22	.05	.887	15.0	14.8	0.6	0.6	4.1	4.2
3.22	.05	.889	15.0	14.8	0.65	0.6	4.1	4.1
3.22	.05	.889	15.5	14.4	4.1	4.2	6.3	6.35
3.22	.07	.758	15.5	14.9	0.6	0.6	4.1	4.1
3.22	.07	.758	15.5	14.9	0.6	0.6	4.2	4.1
3.22	.07	.758	15.5	14.9	0.6	0.6	4.15	4.2
3.22	.07	.758	15.5	14.9	4.2	4.3	6.1	4.1
3.19	.06	.581	15.3	15.0	1.05	1.0	4.1	4.1
3.19	.06	.581	15.3	15.0	1.0	1.0	4.1	4.1
3.19	.06	.581	15.5	15.0	1.0	1.0	4.0	4.0
3.19	.06	.581	15.0	14.6	3.6	3.5	5.6	5.6
3.18	.05	.485	15.2	14.8	0.8	0.8	4.0	4.0
3.18	.05	.485	15.2	14.8	0.7	0.7	3.9	3.8
3.18	.05	.485	15.2	14.8	0.7	0.7	3.8	3.8
3.18	.05	.485	15.3	14.7	2.8	2.7	4.95	4.8
3.23	.06	.806	15.5	15.0	1.4	1.4	4.7	4.6
3.23	.06	.806	15.0	14.4	3.1	3.1	5.7	5.7
3.23	.06	.806	15.4	14.4	5.2	5.3	6.9	6.9
3.22	.06	.696	15.0	14.2	1.35	1.4	4.65	4.6
3.22	.06	.696	15.0	14.2	2.95	3.0	5.6	5.6
3.22	.06	.696	15.0	14.2	5.15	5.2	6.95	6.9
3.21	.06	.599	15.0	14.6	1.7	1.7	4.6	4.5
3.21	.06	.599	15.4	14.8	0.8	0.8	4.0	4.0
3.21	.06	.599	15.4	14.8	2.8	2.8	5.35	5.3
3.21	.06	.599	15.4	14.8	4.9	4.9	6.6	6.75
3.19	.06	.506	15.6	14.4	0.7	0.7	3.8	3.8
3.175	.06	.490	14.0	14.0	2.85	2.85	5.6	5.5
3.19	.07	.506	15.5	14.5	2.2	2.1	4.85	4.75
3.19	.06	.506	15.2	14.4	7.2	7.2	7.8	7.8
3.245	.06	.490	14 .6	15.0	5.1	5.1	6.7	6.9
3.19	.11	.506	15.2	14.4	3.85	3.8	6.4	6.4

Appendix A-1. (Continued)

h (ft)	h' (ft)	Flow (l/sec)	Temperature (°C) T_A	T_B	DO (mg/l) C_A 1	C_A 2	C_B 1	C_B 2
3.245	.12	.976	15.5	15.5	7.9	7.9	8.5	8.5
3.215	.11	.746	15.2	15.4	7.1	7.1	8.2	8.2
3.21	.11	.610	15.2	15.5	7.1	7.1	8.1	8.1
3.21	.11	.493	15.2	15.5	7.1	6.9	8.05	8.05
3.23	.39	.855	15.0	14.6	1.0	0.9	5.25	5.2
3.23	.39	.855	15.1	14.6	2.85	2.9	6.2	6.2
3.23	.39	.855	15.0	14.6	4.75	4.7	7.1	7.25
3.225	.37	.721	15.2	14.6	0.85	.9	5.1	5.2
3.225	.37	.721	15.5	14.6	3.0	2.95	6.2	6.2
3.225	.37	.721	15.0	14.2	4.8	4.8	7.2	7.2
3.20	.39	.590	15.4	14.4	0.8	0.85	5.1	5.1
3.20	.39	.590	15.2	14.2	2.5	2.5	5.8	6.0
3.20	.39	.590	15.2	14.2	4.9	4.9	7.3	7.2
3.20	.39	.501	15.2	14.4	0.S	0.8	5.15	5.15
3.20	.39	.501	15.2	14.4	2.6	2.55	6.1	6.1
3.20	.39	.501	15.2	14.4	4.2	4.4	7.1	7.2
3.205	.35	.976	14.0	14.0	7.0	7.0	8.2	8.3
3.205	.35	.755	14.0	14.0	7.4	7.4	8.8	8.8
3.205	.35	.623	14.0	14.0	7.75	7.8	8.8	8.8
3.23	.37	.490	14.0	14.0	7.9	7.9	9.2	9.1
3.245	.37	.976	15.2	15.3	6.0	6.0	7.8	7.8
3.222	.365	.755	15.2	15.2	6.0	6.2	7.75	7.7
3.21	.355	.623	15.5	15.2	6.25	5.85	7.8	7.8
3.21	.35	.489	15.2	15.2	6.2	6.0	7.8	7.9
3.23	.79	.899	15.2	14.4	0.8	0.8	5.4	5.5
3.23	.79	.899	15.2	14.3	2.9	2.95	6.6	6.5
3.23	.79	.899	15.2	14.4	4.7	4.7	7.4	7.35
3.22	.79	.750	15.2	14.4	1.0	1.0	5.8	5.85
3.22	.79	.750	15.2	14.4	3.1	3.1	6.75	6.8
3.22	.79	.750	15.2	14.4	4.8	4.9	7.5	7.4
3.21	.77	.628	14.9	14.2	0.9	0.9	5.65	5.65
3.21	.77	.628	14.8	14.1	2.8	2.8	6.65	6.8
3.21	.77	.628	14.8	14.2	5.1	5.1	7.7	7.6
3.19	.78	.501	14.8	14.1	0.9	0.9	5.7	5.75
3.19	.78	.501	15.2	14.4	2.7	2.65	6.65	6.65
3.19	.78	.501	15.2	14.4	5.2	5.2	7.7	7.9
3.245	.74	.976	15.5	15.5	7.8	7.8	8.7	E.8
3.22	.74	.755	15.5	15.5	7.65	7.65	8.8	8.8
3.22	.74	.623	15.5	15.5	7.4	7.4	8.5	8.5
3.24	.74	.490	14.0	14.0	7.9	7.9	9.2	9.1
3.21	.77	.489	15..5	15.2	6.9	6.9	8.4	8.4
3.24	1.22	.884	15.0	14.2	0.8	0.9	5.5	5.5
3.24	1.22	.884	15.3	14.3	3.0	3.0	6.55	6.55
3.24	1.22	.884	15.0	14.2	4.7	4.7	7.25	7.3
3.21	1.22	.726	15.0	14.2	0.9	0.9	5.55	5.5
3.21	1.22	.726	15.0	14.2	2.95	2.95	6.7	6.6
3.21	1.22	.726	15.2	14.6	5.5	5.6	7.7	7.8

Appendix A-1. (Concluded)

h (ft)	h' (ft)	Flow (l/sec)	Temperature (°C)		DO (mg/l)			
					C_A		C_B	
			T_A	T_B	1	2	1	2
3.21	1.21	.584	15.0	14.4	0.8	0.9	5.8	5.8
3.18	1.22	.623	14.0	14.0	2.8	2.9	6.65	6.7
3.21	1.21	.584	15.0	14.4	3.8	3.8	7.05	7.1
3.20	1.24	.623	14.6	15.0	4.7	4.5	7.2	7.4
3.21	1.21	.584	15.2	14.4	6.4	6.4	8.1	8.2
3.13	1.22	.501	15.2	14.4	0.95	0.95	5.75	5.7
3.175	1.22	.490	14.0	14.0	2.9	2.8	6.75	6.75
3.19	1.22	.501	15.4	14.4	3.5	3.6	6.95	7.1
3.205	1.24	.490	14.6	15.0	5.1	5.0	7.7	7.7
3.19	1.22	.501	15.4	14.4	6.45	6.5	8.1	8.2
3.245	1.245	.976	14.2	14.2	7.4	7.4	8.9	8.85
3.21	1.26	.755	14.0	14.0	7.45	7.45	8.9	8.9
3.23	1.26	.623	14.0	14.0	7.6	7.6	9.0	9.0
3.24	1.27	.490	14.0	14.0	7.S	7.9	9.0	9.0

Appendix A-2. Field Weir Box Data, Unreduced

Dam	Date	h (m)	h' (m)	Temp (°C)	Flow l/sec	DOa (mg/l) 1	DOa (mg/l) 2	DOa (mg/l) 3	DOa (mg/l) 4	DOb (mg/l) 1	DOb (mg/l) 2	DOb (mg/l) 3	DOb (mg/l) 4
Lockport	9/13/78	0.219	0.375	25.0	0.69	1.70	1.60	--	--	2.70	2.80	--	--
		0.602	0.375	25.0	0.69	1.90	1.70	1.60	1.70	5.70	4.10	4.10	3.80
		0.974	0.375	25.0	0.69	1.70	1.60	--	--	4.60	4.60	--	--
	10/13/78	0.238	0.394	21.2	1.18	2.20	2.50	2.50	--	3.30	3.50	3.60	--
		0.619	0.384	21.5	1.18	2.50	2.45	--	--	4.80	4.90	--	--
		0.992	0.393	21.5	1.18	2.35	2.30	--	--	5.30	5.50	--	--
	8/16/79	0.262	0.366	25.5	1.25	2.00	2.00	--	--	3.40	3.35	--	--
		0.644	0.369	25.5	1.25	1.60	1.70	--	--	4.20	4.30	--	--
		1.018	0.369	25.5	1.25	1.40	1.50	--	--	4.70	4.80	--	--
Brandon Road	9/12/78	0.203	0.396	27.3	0.69	4.10	4.20	--	--	4.60	4.70	--	--
		0.579	0.396	27.3	0.69	3.70	3.70	--	--	5.30	5.30	--	--
		0.962	0.380	27.3	0.69	3.70	3.70	--	--	5.40	5.40	--	--
	10/12/78	0.247	0.375	19.8	1.11	3.80	3.70	--	--	4.60	4.60	--	--
		0.632	0.372	19.8	1.11	3.50	3.40	--	--	5.60	5.50	--	--
		1.009	0.378	19.5	1.11	3.50	3.40	--	--	5.80	6.00	--	--
	8/15/79	0.250	0.374	25.0	1.18	0.50	0.60	--	--	2.40	2.10	2.00	2.05
		0.632	0.374	25.0	1.18	0.55	0.65	--	--	3.45	3.50	--	--
		1.010	0.374	25.0	1.18	0.55	0.55	--	--	4.30	4.40	--	--
	8/29/79	0.254	0.369	25.0	1.21	1.90	2.00	--	--	3.20	3.70	3.40	3.20
		0.777	0.374	25.0	1.21	2.20	2.40	2.20	2.20	3.80	4.60	4.50	4.50
		1.014	0.374	25.0	1.21	2.10	2.10	--	--	5.00	5.10	--	--
	9/11/79	0.241	0.378	25.0	1.11	1.90	1.70	1.90	1.80	3.50	3.40	--	--
		0.622	0.378	25.0	1.11	2.20	2.30	--	--	5.00	5.00	--	--
		0.997	0.381	25.0	1.11	2.30	2.20	--	--	5.20	5.10	--	--
Dresden Island	8/25/78	0.227	0.366	27.3	1.33	5.50	5.80	--	--	6.30	6.20	6.70	--
		0.624	0.373	27.8	1.33	6.10	6.30	6.10	--	7.10	7.00	7.10	--
		0.988	0.375	27.6	1.33	6.20	6.40	6.10	--	7.20	7.40	7.20	--
	9/14/78	0.234	0.386	27.0	0.87	4.40	4.40	--	--	4.90	4.70	--	--
		0.610	0.392	27.0	0.87	4.30	4.30	--	--	5.30	5.50	--	--
		0.991	0.390	26.9	0.87	4.60	4.60	--	--	5.80	5.90	--	--
	8/08/79	0.232	0.387	29.5	1.18	4.90	4.80	4.90	--	5.10	5.10	--	--
		0.625	0.390	29.5	1.18	4.90	4.70	4.60	--	5.50	5.90	5.80	--
		0.957	0.390	29.5	1.16	4.60	4.60	4.70	--	5.80	6.00	5.70	--
	8/14/79	0.238	0.378	25.4	1.33	5.40	5.40	--	--	5.70	5.80	--	--
		0.617	0.375	25.4	1.33	4.80	4.80	--	--	6.10	6.10	--	--
		0.997	0.381	25.4	1.33	5.70	5.70	--	--	6.70	6.70	--	--
	9/05/79	0.242	0.381	27.5	1.18	5.80	5.70	--	--	6.10	6.10	--	--
		0.610	0.378	27.5	1.18	5.50	5.50	--	--	6.40	6.40	--	--
		0.975	0.378	27.5	1.18	6.10	6.10	--	--	6.90	6.80	--	--
Marseilles	8/24/78	0.239	0.381	27.0	0.91	6.80	7.35	6.60	--	6.80	7.00	6.60	--
		0.619	0.387	27.0	0.91	6.80	6.50	6.50	--	6.30	6.70	6.70	--
		1.000	0.381	27.0	0.91	6.80	6.40	6.80	--	6.60	6.70	6.70	--
	9/19/78	0.228	0.384	24.0	0.71	4.80	4.90	--	--	5.60	5.60	--	--
		0.610	0.381	23.9	0.71	5.00	4.90	--	--	6.10	5.90	--	--
		0.991	0.381	24.0	0.71	4.90	4.90	--	--	6.20	6.10	--	--
	8/06/79	0.244	0.387	28.9	1.52	4.70	4.60	--	--	5.20	5.10	--	--
		0.629	0.384	28.9	1.52	4.80	4.75	--	--	5.70	5.70	--	--
		1.003	0.387	28.9	1.52	4.70	4.90	4.85	4.80	6.05	6.00	--	--
	9/06/79	0.253	0.384	27.5	1.11	5.60	5.60	--	--	5.90	5.90	--	--
		0.628	0.381	27.5	1.11	5.20	5.20	--	--	6.30	6.30	--	--

Appendix A-2. (Concluded)

Dam	Date	h (m)	h' (m)	Temp (°C)	Flow 1/sec	DOa (mg/1) 1	DOa (mg/1) 2	DOa (mg/1) 3	DOa (mg/1) 4	DOb (mg/1) 1	DOb (mg/1) 2	DOb (mg/1) 3	DOb (mg/1) 4
		1.007	0.384	27.5	1.11	5.20	5.10	--	--	6.60	6.30	6.50	6.50
	9/12/79	0.223	0.381	25.0	1.18	6.70	6.60	--	--	7.00	7.00	--	--
		0.564	0.381	25.0	1.18	6.60	6.50	--	--	7.20	7.10	--	--
		0.978	0.393	25.0	1.18	6.60	6.60	--	--	7.20	7.30	--	--
Starved Rock	8/23/78	0.238	0.378	26.0	0.69	8.00	7.90	--	--	7.50	8.00	8.00	--
		0.622	0.372	26.5	0.69	7.70	7.90	7.8	--	7.50	7.90	8.00	--
		0.997	0.372	26.7	0.69	7.70	--	--	--	7.20	7.70	7.90	--
	9/20/78	0.219	0.390	24.5	0.77	5.65	5.65	--	--	5.90	5.95	--	--
		0.598	0.393	24.5	0.77	5.90	5.70	--	--	6.50	6.40	--	--
		0.978	0.387	24.5	0.77	5.80	5.70	5.65	5.65	6.75	6.70	6.50	6.55
	8/03/79	0.247	0.372	27.5	1.00	6.10	6.10	6.20	6.20	6.70	6.35	6.30	6.40
		0.623	0.372	27.5	1.00	5.90	6.20	6.00	6.00	6.80	6.70	--	--
		1.000	0.375	27.5	1.00	5.70	5.70	--	--	6.80	6.80	--	--
	9/07/79	0.270	0.381	26.0	1.25	7.00	7.10	--	--	7.10	7.00	--	--
		0.661	0.381	26.0	1.25	8.00	7.90	--	--	7.90	7.90	--	--
		1.017	0.375	26.0	1.25	7.70	7.70	--	--	7.70	7.70	--	--
	9/14/79	0.248	0.381	23.0	1.11	6.80	6.80	--	--	7.30	7.40	--	--
		0.636	0.378	23.0	1.11	7.00	7.10	--	--	7.80	7.70	--	--
		1.010	0.381	23.0	1.11	6.90	6.90	--	--	7.90	7.80	--	--
Peoria	8/12/78	0.209	0.392	25.7	1.00	6.40	--	--	--	6.80	--	--	--
		0.590	0.386	25.7	1.00	6.60	--	--	--	7.00	--	--	--
		0.969	0.386	26.3	1.00	6.60	--	--	--	7.00	--	--	--
	10/02/78	0.244	0.372	24.3	1.11	6.60	7.00	--	--	7.60	7.80	--	--
		0.628	0.369	24.3	1.11	6.70	7.10	7.00	6.90	7.70	7.80	7.70	7.60
		1.003	0.375	24.3	1.11	6.90	6.90	--	--	7.80	7.80	--	--
	7/27/79	0.223	0.374	28.1	1.26	5.90	6.70	6.20	6.10	6.40	6.50	6.40	6.40
		0.332	0.381	28.1	1.26	6.00	6.10	6.70	6.80	6.90	6.70	7.10	7.20
		0.936	0.372	28.0	1.26	6.00	5.90	6.60	--	6.90	6.80	6.80	7.30
	8/01/79	0.216	0.378	27.0	1.09	6.00	6.00	--	--	6.20	6.50	6.40	6.40
		0.558	0.381	27.0	1.09	6.40	6.20	6.30	6.30	6.70	6.70	--	--
		0.951	0.381	27.0	1.09	6.00	6.00	--	--	6.70	6.70	--	--
	10/10/79	0.203	0.387	14.1	1.14	9.00	9.20	--	--	9.10	9.10	--	--
		0.591	0.381	14.1	1.14	9.40	9.10	9.10	9.00	9.40	9.40	--	--
		0.969	0.387	14.1	1.14	8.90	9.20	9.30	9.30	9.60	9.70	--	--
LaGrange	8/22/78	0.296	0.378	26.4	0.95	6.30	--	--	--	6.40	--	--	--
		0.555	0.378	26.6	0.95	6.90	--	--	--	7.00	--	--	--
		0.936	0.372	26.5	0.95	6.50	--	--	--	6.90	--	--	--
	9/21/78	0.249	0.366	25.0	0.87	3.10	3.10	--	--	4.10	4.15	--	--
		0.629	0.369	25.0	0.87	3.05	3.20	--	--	5.30	5.25	--	--
		[illegible]	0.369	25.0	0.87	3.05	3.10	--	--	5.55	5.60	--	--
	8/07/79	0.264	0.378	29.1	1.11	4.80	4.85	--	--	5.40	5.50	--	--
		0.669	0.354	29.1	1.11	4.70	4.80	--	--	5.85	5.90	--	--
		1.049	0.351	29.1	1.11	4.95	5.00	--	--	6.05	6.15	--	--
	9/18/79	0.229	0.381	22.4	1.05	5.90	5.80	--	--	5.40	6.00	6.00	6.00
		0.605	0.381	22.4	1.05	6.30	6.20	--	--	7.10	7.00	--	--
		0.988	0.374	22.5	1.05	6.00	6.40	6.10	6.10	7.40	7.30	--	--
	9/26/79	0.241	0.378	21.3	1.11	6.80	6.80	--	--	7.20	7.30	--	--
		0.619	0.375	21.0	1.11	6.50	6.60	--	--	7.60	7.70	--	--
		0.998	0.378	21.0	1.11	6.70	6.60	--	--	7.60	7.60	--	--

Appendix A-3. Instream DO-Temperature Data, Unreduced

Dam	Date	Upstream				Downstream			
		Station	Depth (ft)	Temp (°C)	DO (mg/l)	Station	Depth (ft)	Temp (°C)	DO (mg/l)
Lockport	9/13/78	Penstock	1	27.2	1.8	Turbine	1	26.0	2.5
		Intake	3	27.2	1.8	Discharge	3	26.0	2.1
			15	27.2	1.8		9	26.0	2.1
			30	27.2	1.8		18	26.0	2.4
	10/13/78	Penstock	1	20.2	2.5	Turbine	1	19.8	2.5
		Intake	3	20.2	2.5	Discharge	3	19.8	2.5
			13	20.4	2.4		8	19.8	2.4
			27	20.3	2.55		16	19.8	2.5
	8/16/79	Penstock	1	26.0	1.6	Turbine	1	26.5	0.9
		Intake	3	26.0	0.7	Discharge	3	26.5	1.0
			15	26.0	1.5		8	26.0	1.0
			18	26.0	1.1		16	25.5	1.0
			30	26.0	0.7	Centerline	1	26.0	1.05
		Penstock	1	26.0	0.8	Stream	3	25.5	1.0
		Intake	3	26.0	0.4		8	25.5	0.9
			30	26.0	0.7		16	25.5	1.0
Brandon Road	9/12/78	CL Gate 1	1	27.5	3.1	In Rapids	1	27.5	6.6
			3	27.5	3.1	Near Dam	1	27.5	6.5
			4.5	--	--		1	27.5	6.6
		CL Gate 2	1	27.5	3.2	Channel	1	27.7	6.5
			3	27.2	3.1	at Bridge	1	27.7	6.9
			4.5	--	--		1	27.7	6.9
		CL Gate 4	1	27.5	3.2		1	27.7	6.9
			3	27.2	3.1				
			5.6	--	--				
		CL Gate 6	1	27.5	3.2				
			3	27.0	3.4				
			6	--	--				
	10/12/78	CL Pier of	1	19.8	3.4	Left Bank	1	18.9	7.4
		Gates 3 & 4	3	19.5	3.4		3	18.9	7.4
			6.5	--	--		4.5	--	--
		CL Gate 9	1	19.5	3.4	CL Bridge	1	19.3	7.4
		for 8, 9, 10	3	19.5	3.4		3	19.3	7.4
			7.1	--	--		3.3	--	--
						Right Bank	1	19.4	7.4
							3	19.4	7.4
							6	--	--
	8/15/79	CL Headgates	1	24.5	0.7	Right Bank	1	24.0	7.0
			6	24.5	0.7		3	24.0	7.1
		CL Dam	1	25.0	0.6	CL Bridge	1	24.0	7.0
			5	25.0	0.5		3	24.0	7.1
		CL Gate 14	1	25.0	0.6	Left Bank	1	24.0	7.1
			5	25.0	0.5		3	24.0	7.2
	8/29/79	CL Headgates	1	26.2	2.0	Right Bank	1	25.0	6.8
			5	26.0	1.7		3	25.0	6.75
		CL Gate 16	1	25.5	1.8	CL Bridge	1	25.0	6.5
			5	25.5	1.1		3	25.0	6.55
		CL Gate 18	1	25.3	1.6	Left Bank	1	25.0	6.5
			5	25.3	1.4		3	25.0	6.5
	9/11/79	CL Headgates	1	26.0	1.9	Right Bank	1	26.1	7.7

Appendix A-3. (Continued)

Dam	Date	Upstream Station	Depth (ft)	Temp (°C)	DO (mg/1)	Downstream Station	Depth (ft)	Temp (°C)	DO (mg/1)
			3	26.0	1.85		3	26.1	7.6
			8	26.0	1.9	CL Bridge	1	26.1	7.5
		CL Gate 11	1	26.0	1.8		3	26.1	7.65
			6	26.0	1.1	Left Bank	1	26.1	6.6
		CL Gate 18	1	26.0	1.7		3	26.1	6.75
			4	26.0	1.3				
Dresden Island	8/25/78	CL Gate 4	1	27.3	6.3	LB Channel	1	27.3	7.1
			3	26.9	5.7		3.5	27.3	7.5
			9	26.2	5.5	Center	1	27.3	7.1
			18	25.2	5.6		6	27.3	6.9
		CL Pier of Gates 5, 6, 7, 8	1	27.1	5.8	RB Channel	1	27.3	7.3
			3	27.0	5.6		2.5	27.3	7.4
			11	25.8	5.6	RR Bridge (Composite)	1	27.4	6.85
			22	25.5	5.6		6	27.4	6.8
							13.5	27.4	6.9
	9/14/76	CL Pier of Gates 2, 3	1	26.2	4.5	LB Channel	1	27.0	6.9
			3	26.2	4.5		2	27.0	6.8
			14	26.2	4.5		3	27.0	6.8
		CL Gate 5 for 4, 5, 6	1	26.2	4.8	Center	1	27.0	6.6
			3	26.2	4.5		2	27.0	6.6
			21	26.2	4.5		3	27.0	6.5
		CL Pier of Gates 7, 8	1	26.8	4.6	RB Channel	1	27.2	6.0
			3	26.6	4.6		2	27.2	6.6
			21	26.1	4.5		3	27.2	6.8
	8/08/79	CL Gate 5	1	32.0	6.4	LB Channel	1	30.5	6.8
			3	31.5	6.1		3	30.5	6.7
			9	30.5	5.7	Center	1	31.0	6.6
			19	30.0	4.3		3	30.5	6.6
		CL Gate 7	1	31.5	6.3	RB Channel	1	30.0	6.7
			3	31.0	5.4		3	30.5	--
			10.5	30.0	4.9				
			21	30.0	4.3				
		CL Gate 9	1	31.5	6.3				
			3	31.0	5.5				
			8	30.0	4.9				
			16.5	30.0	4.9				
	8/14/79	CL Gate 3	1	25.5	5.9	LB Channel	1	24.8	7.8
			3	25.5	5.9		3	24.8	7.75
			7	25.0	5.6	Center	1	24.8	7.6
			14	25.0	5.45		3	24.8	7.6
		CL Gate 5	1	25.5	5.75	RB Channel	1	24.8	7.9
			3	25.0	6.1		3	24.8	7.9
			11	25.0	5.7				
			21.5	25.0	5.1				
		CL Gate 7	1	25.5	6.0				
			3	25.0	6.1				
			12	24.5	5.3				
			23.5	24.5	5.1				
		CL Gate 9	1	25.5	6.0				
			3	25.3	6.0				
			11.5	25.0	5.6				
			23.0	24.5	5.1				

Appendix A-3. (Continued)

Dam	Date	Upstream Station	Upstream Depth (ft)	Upstream Temp (°C)	Upstream DO (mg/l)	Downstream Station	Downstream Depth (ft)	Downstream Temp (°C)	Downstream DO (mg/l)
	9/05/79	CL Closed Gates 1-6	1	28.6	6.1	LB Channel	1	28.0	9.0
			3	28.6	5.9		3	27.9	7.1
			6	28.0	5.7	Center	1	29.0	7.1
			12	28.0	5.5		3	29.0	7.1
		CL Gate 7	1	29.0	6.5	RB Channel	1	29.0	7.1
			3	28.4	6.0		3	29.0	7.1
			11	27.6	5.8				
			22	27.5	5.55				
		CL Gate 9	1	29.0	7.0				
			3	28.6	6.5				
			11	27.4	5.0				
			22	27.[illegible]	4.9				
Marseilles	8/24/78	CL Closed Gates 1-4	1	26.0	6.5	CL Gate 7	1	27.4	7.0
			5.5	28.0	6.6		3	27.6	7.3
			11	28.0	6.6				
		CL Gate 7	1	27.8	6.7				
			5.5	28.0	6.7				
			11	28.2	6.3				
	9/19/78	CL Pier of Gates 1, 2	1	25.9	5.1	CL Pier of Gates 1,2	1	25.0	6.6
			3	25.1	4.8		3	25.0	6.4
			9	25.0	4.6	CL Closed Gates 3-8	1	25.0	6.4
			18	24.6	4.5		3	25.0	6.5
		CL Closed Gates 3-8	1	25.0	4.9				
			3	24.9	4.6				
			12	24.2	4.5				
	8/06/79	CL Gate 4	1	29.0	4.75	CL Gate 4	1	29.5	6.1
			3	29.0	4.8		3	29.5	6.2
			7	29.0	4.9	CL Gate 6	1	29.5	6.1
			14.5	28.5	4.3		3	29.5	6.2
		CL Gate 6	1	29.0	4.9	CL Gate 8	1	29.0	6.25
			3	28.5	4.8		3	29.0	6.20
			6	29.0	4.9				
			12	29.0	4.6				
		CL Gate 8	1	29.5	5.2				
			3	29.0	5.1				
			6	29.0	4.95				
			12	29.0	4.85				
Marseilles	9/06/79	CL Pier of Closed Gates 2, 3	1	28.5	5.4	CL Pier of Closed Gates 2,3	1	27.9	7.05
			3	--	5.6		3	27.9	7.05
			7	--	5.5				
			14	26.5	5.5	CL Gate 5	1	27.9	7.2
		CL Gate 5	1	--	5.7		3	27.9	7.2
			3	--	5.5	CL Gate 7	1	27.8	6.8
			6	--	5.4		3	27.8	6.8
			12.5	--	5.4				
		CL Gate 7	1	--	5.6				
			3	--	5.6				
			7	--	5.4				
			14	--	5.4				

Appendix A-3. (Continued)

Dam	Date	Upstream Station	Depth (ft)	Temp (°C)	DO (mg/l)	Downstream Station	Depth (ft)	Temp (°C)	DO (mg/l)
	9/12/79	CL Pier of	1	25.5	6.4	CL Pier of	1	25.5	7.7
		Closed Gates	3	25.5	6.5	Closed Gates	3	25.5	7.7
		2, 3	7	25.5	6.2	2, 3			
			13	25.5	6.35	CL Gate 5	1	25.4	7.5
		CL Gate 5	1	25.5	6.6		3	25.4	7.4
			3	25.5	6.3	CL Gate 7	1	25.3	7.6
			7	25.2	6.4		3	25.4	7.5
			13	25.2	6.2				
		CL Gate 7	1	25.5	6.9				
			3	25.5	6.6				
			7	25.2	6.4				
			13	25.0	6.5				
Starved Rock	8/23/78	CL Pier of	1	25.8	7.5	CL Pier of	1	27.2	7.9
		Gates 1, 2	3	25.8	6.8	Gates 1,2	5.5	27.2	7.9
			9	25.8	7.0	CL Gate 5	1	27.2	7.8
			18	25.8	7.0	for 4, 5, 6			
		CL Gate 5	1	27.5	8.1	CL Pier of	2	27.2	8.0
		for 4, 5, 6	3	27.0	8.0	Gates 7, 8			
			9.5	26.4	7.0	CL Gate 9	2	27.2	7.9
			19	25.9	6.5				
		CL Pier of	1	28.0	9.7				
		Gates 7, 8	3	27.7	9.6				
			10	26.2	7.9				
			20	25.1	5.9				
		CL Gate 9	1	27.3	9.0				
			3	27.0	8.7				
			8.5	25.5	6.4				
			17	25.1	6.1				
	9/20/78	CL Gate 1	1	25.0	5.55	CL Gate 1	1	25.0	6.9
			3	24.8	5.75		3	25.0	7.0
			9	24.8	6.05	CL Gate 3	1	25.0	6.5
			18	24.7	5.95	for 2, 3, 4	3	25.0	6.5
		CL Gate 3	1	25.5	5.5				
		for 2, 3, 4	3	25.7	5.6				
			10	25.3	5.45				
	8/03/79	CL Pier of	1	29.5	8.0	CL Pier of	1	28.2	6.8
		Gates 4, 5	3	29.5	8.0	Gates 4, 5	3	28.2	6.6
			6.5	29.0	7.0	CL Gate 6	1	27.0	6.9
			13	28.0	5.3		3	27.0	6.95
		CL Gate 6	1	29.0	8.4	CL Gate 7	1	27.2	6.9
			3	29.0	7.8		3	27.2	7.0
			6	28.5	5.8				
			12	27.5	5.1				
		CL Gate 7	1	29.5	8.2				
			3	29.0	6.5				
			7.5	28.0	5.9				
			15	27.0	5.3				
	9/07/79	CL Gate 4	1	26.0	7.7	CL Gate 4	1	25.5	7.9
			3	26.0	7.7		3	25.5	8.0
			4	26.0	8.0	CL Gate 6	1	25.1	8.1
			8	26.0	8.7		3	25.1	8.0

Appendix A-3. (Continued)

Dam	Date	Upstream Station	Depth (ft)	Temp (°C)	DO (mg/1)	Downstream Station	Depth (ft)	Temp (°C)	DO (mg/1)
		CL Gate 6	1	25.2	8.3	CL Pier of	1	25.0	8.1
			3	25.0	8.0	Gates 8, 9	3	25.0	8.1
			10	25.0	7.0				
			20	25.0	6.3				
		CL Pier of	1	25.5	8.2				
		Gates 8, 9	3	25.5	8.0				
			10	25.0	7.4				
			20	24.8	6.7				
	9/14/79	CL Pier of	1	23.5	7.4	CL Pier of	1	23.0	8.7
		Closed Gates	3	23.5	7.2	Closed Gates	3	23.0	8.7
		2, 3	6	23.1	7.3	2, 3			
		CL Gate 6	1	23.2	8.1	CL Gate 6	1	22.5	8.8
		for 5, 6, 7	3	22.5	8.1	for 5, 6, 7	3	22.5	8.7
			8	22.5	8.2	CL Closed	1	22.5	8.65
		CL Closed	1	22.7	8.3	Gate 8	3	22.5	8.7
		Gate 8	3	22.5	8.3				
			10	22.5	8.1				
			19	22.5	7.6				
Peoria	8/12/78	22 Wickets	1	25.9	7.0	22 Wickets	1	26.5	6.5
		from RB	3	25.1	6.2	From RB	22	26.2	6.6
			7	25.1	6.1		44	26.0	6.5
			14.5	25.1	6.1	44 Wickets	1	26.2	6.6
		44 Wickets	1	25.5	7.2	from RB	17.5	26.2	6.8
		from RB	3	25.3	6.55		35	26.2	6.4
			7	25.1	6.8	67 Wickets	1	26.2	6.6
			14.5	25.1	6.8	from RB	7.5	26.0	6.6
		67 Wickets	1	25.5	8.2		15	26.0	6.7
		from RB	3	25.3	6.5	90 Wickets	1	26.2	6.6
			8	25.1	6.1	from RB	5	26.2	6.8
			16.5	25.1	6.2		10	26.2	6.8
		90 Wickets	1	25.8	7.5	113 Wickets	1	26.2	6.8
		from RB	3	25.5	7.0	from RB	4	26.2	6.8
			8	25.1	6.45		8	26.2	6.45
			16.5	25.0	6.1				
		113 Wickets	1	25.3	7.0				
		from RB	3	25.1	6.5				
			8.5	25.0	6.4				
			17	25.0	6.3				
	10/02/78	22 Wickets	1	23.2	7.1	22 Wickets	1	18.9	7.4
		from RB	3	21.8	7.1	from RB	3	18.9	7.5
			8	20.5	6.8		15	18.9	7.4
			17	19.8	7.0		32	18.9	7.4
		44 Wickets	1	19.7	7.2	44 Wickets	1	18.9	7.3
		from RB	3	19.6	7.15	from RB	3	18.9	7.5
			9	19.2	7.1		15	18.9	7.4
			18	19.2	7.0		32	18.9	7.4
		67 Wickets	1	19.5	7.3	67 Wickets	1	18.9	7.4
		from RB	3	19.2	7.1	from RB	5	18.9	7.4
			9	19.1	7.0		10	18.9	7.4
			18	19.1	7.0	90 Wickets	1	18.9	7.5

Appendix A-3. (Continued)

Dam	Date	Upstream Station	Upstream Depth (ft)	Upstream Temp (°C)	Upstream DO (mg/l)	Downstream Station	Downstream Depth (ft)	Downstream Temp (°C)	Downstream DO (mg/l)
		90 Wickets	1	19.4	7.4	from RB	5	18.9	7.3
		From RB	3	19.4	7.45		10	18.9	7.4
			10	19.2	7.3	113 Wickets	1	18.9	7.5
			20.5	19.0	7.0	from RB	4	18.9	7.4
		113 Wickets	1	19.5	7.3		8	18.9	7.4
		from RB	3	19.2	7.1				
			10.5	19.1	7.05				
			21	19.1	7.1				
	7/27/79	33 Wickets	1	31.0	7.0	33 Wickets	1	28.0	6.7
		from RB	3	30.8	6.1	from RB	3	28.0	6.2
			7	29.1	5.8		24	28.0	6.2
			14	29.0	5.7		48	28.5	6.5
		67 Wickets	1	30.9	8.4	67 Wickets	1	28.2	6.3
		from RB	3	29.5	6.1	from RB	3	29.0	6.3
			8	29.3	5.8		15	28.2	6.3
			16	29.0	5.7		31	28.0	5.8
		101 Wickets	1	29.0	6.4	101 Wickets	1	28.5	6.5
		from RB	3	29.1	6.4	from RB	3	28.2	6.4
			9	29.2	6.3		7.5	28.2	6.5
			18	28.9	6.2		15	28.2	6.3
	8/01/79	33 Wickets	1	26.2	6.2	33 Wickets	1	26.2	6.4
		from RB	3	26.2	6.2	from RB	3	26.2	6.6
			8	26.7	6.0		23	26.5	6.3
			17	26.9	5.8		46	26.8	6.6
		67 Wickets	1	26.0	6.2	67 Wickets	1	26.6	6.7
		from RB	3	26.5	6.1	from RB	3	26.6	6.7
			8	26.9	6.0		7	26.6	6.65
			17	26.8	5.9		14	25.5	6.55
		130 Wickets	1	26.6	6.2	130 Wickets	1	26.5	6.7
		from RB, CL	3	26.6	6.3	from RB, CL	2	26.5	6.7
		10 Down Wickets	10	27.0	6.2	Down Wickets			
			20	26.9	6.1	(10 down)			
	10/10/79	33 Wickets	1	15.0	9.1	33 Wickets	1	14.5	9.5
		from RB	3	15.0	9.2	from RB	3	14.5	9.7
			8	14.3	9.0		14.5	14.2	9.5
			16	14.0	9.0		29	14.0	9.75
		67 Wickets	1	14.5	9.1	67 Wickets	1	14.0	9.7
		from RB	3	14.5	8.9	from RB	3	14.0	9.8
		(needles up)	8.5	14.5	8.9		12	14.0	9.7
			17	14.5	9.0		24	14.0	9.75
		101 Wickets	1	14.5	9.0	101 Wickets	1	14.2	9.85
		from RB	3	14.5	8.9	from RB	3	14.4	9.8
			9	14.4	9.1		20	14.1	9.8
			18	14.5	9.1		40	13.9	9.6
LaGrange	8/22/78	27 Wickets	1	26.0	8.0	27 Wickets	1	26.1	6.6
		from RB	3	26.0	6.5	from RB	11	26.3	6.6
			11	25.4	6.4		22	26.2	6.8
			22.5	25.1	5.3	54 Wickets	1	27.0	6.7
		54 Wickets	1	26.2	9.6	from RB	13	27.0	6.7
		from RB	3	26.0	6.6		26	26.5	6.7
			10	25.2	6.1	81 Wickets	1	26.3	6.8
			20.5	25.2	5.8	from RB	15	26.9	6.7

Appendix A-3. (Continued)

Dam	Date	Upstream Station	Depth (ft)	Temp (°C)	DO (mg/l)	Downstream Station	Depth (ft)	Temp (°C)	DO (mg/l)
LaGrange		81 Wickets	1	26.5	8.9		30	26.8	6.8
		from RB	3	25.3	6.4	108 Wickets	1	26.3	6.5
			8.5	25.2	6.4	from RB	13	26.8	6.6
			17	25.2	5.8		26	26.4	6.8
		108 Wickets	1	26.4	8.8	Butterfly	1	26.1	6.4
		from RB	3	25.2	6.0	Valves	10	26.6	6.4
			7	25.1	6.0		20	26.8	6.5
			14	25.1	6.3				
		Butterfly	1	26.4	8.5				
		Valves	3	25.2	6.2				
			7.5	25.1	6.0				
			15.5	25.1	6.2				
	9/21/78	33 Wickets	1	24.5	2.7	33 Wickets	1	24.0	3.75
		from RB	3	23.6	2.6	from RB	3	24.0	3.0
			9	24.2	2.6		20	24.0	3.2
			18	24.1	2.7		39	24.0	3.1
		67 Wickets	1	24.1	2.65	67 Wickets	1	24.0	3.3
		from RB	3	23.6	2.5	from RB	3	24.0	3.1
			9	24.2	2.5		20	24.0	3.15
			18	24.1	2.5		40	24.0	2.9
		123 Wickets	1	24.1	2.7	123 Wickets	1	24.0	3.5
		from RB,CL 25	3	23.6	2.6	from RB,CL 25	2	24.0	3.1
		Down Wickets	10	24.2	2.6	Down Wickets	5	24.0	2.8
	8/07/79	33 Wickets	1	30.5	5.15	33 Wickets	1	40.0	5.1
		from RB	3	30.1	5.3	from RB	3	40.0	5.1
			10.5	30.0	5.0		8	40.0	5.3
			21	30.0	4.9		13	40.0	5.3
		67 Wickets	1	30.5	5.2	67 Wickets	1	29.5	5.5
		from RB	3	30.0	5.0	from RB	3	30.0	5.6
			10.5	29.8	4.8		15	30.0	5.8
			21	29.7	4.7		30	30.0	5.7
		125 Wickets	1	30.0	4.9	125 Wickets	1	29.5	5.1
		from RB,CL 20	3	29.8	4.75	from RB,CL 20	3	29.5	5.1
		Down Wickets	10.5	29.5	4.75	Down Wickets	9	29.5	5.1
			21	29.4	4.55				
	9/18/79	33 Wickets	1	24.1	6.5	33 Wickets	1	23.8	7.4
		from RB	3	24.1	6.1	from RB	3	23.9	7.45
			11	23.2	6.0		5.5	24.0	7.45
			22	23.5	5.9		11	23.5	7.5
		67 Wickets	1	24.0	6.5	67 Wickets	1	23.8	7.5
		from RB	3	24.0	6.5	from RB	3	23.5	7.55
			8.5	23.2	5.9		7.5	23.0	7.5
			17	23.5	5.9		15	23.0	7.5
		102 Wickets	1	23.5	6.0	102 Wickets	1	23.5	7.4
		from RB	3	23.6	5.9	from RB	3	23.0	7.4
			7	23.1	5.9		20.5	23.0	7.4
			14	23.6	6.3		41	23.0	7.4
	9/26/79	33 Wickets	1	23.5	6.4	33 Wickets	1	22.5	8.5
		from RB	3	23.1	6.3	from RB	3	22.5	7.9

Appendix A-3. (Concluded)

Dam	Date	Upstream Station	Upstream Depth (ft)	Upstream Temp (°C)	Upstream DO (mg/l)	Downstream Station	Downstream Depth (ft)	Downstream Temp (°C)	Downstream DO (mg/l)
LaGrange	9/26/79		11.5	22.0	6.0		9	22.0	8.0
			23	23.4	6.3	67 Wickets	1	21.5	7.5
		67 Wickets	1	22.0	7.0	from RB	3	22.0	7.5
		from RB	3	22.0	6.5		8.5	22.0	7.8
			8.5	22.0	6.5		17	21.5	7.5
			17	23.0	6.6	102 Wickets	1	21.0	7.4
		102 Wickets	1	22.0	6.6	from RB	3	21.5	7.4
		from RB	3	21.9	6.2		21.5	21.5	7.5
			7	22.0	6.2		43	21.5	7.5
			14	22.0	6.0	Below Butterfly Valve	5	23.0	6.1

Appendix B-1. Laboratory Weir Box Data, Reduced

h (meters)	h' (meters)	DO . (mg/1)	Q (liter/sec)	r	ab	h	h'	DO	Q	r	ab
0.371	0.018	1.00	0.866	1.2526	1.10	0.369	0.116	1.25	0.858	1.3282	1.45
0.271	0.018	2.80	0.962	1.1916	1.17	0.367	0.116	2.60	0.858	1.3238	1.43
0.371	0.018	3.85	0.866	1.2337	1.03	0.369	0,116	4.725	0.858	1.3825	1.69
0.341	0.029	5.225	0.976	1.2162	1.04	0.366	0.116	1.20	0.694	1.3410	1.51
0.371	0.018	7.25	0.866	1.2526	1.11	0.366	0.116	3.50	0.694	1.3390	1.51
0.369	0.018	0.90	0.724	1.2674	1,18	0,366	0.116	5.125	0.694	1.3432	1.53
0.369	0.018	3.45	0.724	1.2897	0.93	0.366	0.116	1.25	0.571	1.3324	1.47
0.334	0.027	5.30	0.754	1.2936	1.44	0.293	0.119	2.675	0.610	1.2512	1.42
0.369	0.018	6.65	0.724	1.1172	0.52	0.366	0.116	3.95	0.571	1.2194	0.97
0.363	0.018	1.04	0.584	1.2352	1.06	0.334	0.119	5.20	0.610	1.3203	1.57
0.363	0.018	2.85	0.584	1.2845	1.27	0.366	0.116	6.30	0.571	1.1957	0.87
0.329	0.026	5.30	0.610	1.2600	1.29	0.360	0.116	1,225	0.490	1.3210	1.45
0.363	0.018	6.60	0.584	1.1676	0.73	0.360	0.116	3.55	0.490	1.2879	1.30
0.366	0.018	1.05	0.439	1.2229	0.99	0,326	0.116	5.30	0.490	1.285C	1.43
0.366	0.018	3.25	0.499	1.1731	0.77	0.360	0.116	6.10	0.490	1.1928	0.87
0.326	0.024	5.35	0.490	1.2976	1.49	0.341	0.122	8.45	0.858	1.2256	1.09
0.366	0.018	5.90	0.499	1.1871	0.83	0.332	0.119	7.85	0.709	1.3805	1.88
0.338	0.030	8.30	0.858	1.2043	0.99	0,335	0.119	8.20	0.610	1.3694	1.81
0.335	0.027	7.875	0.709	1.1779	0.87	0.331	0,119	7.60	0.519	1.1863	0.92
0.329	0.030	8.20	0.610	1.1615	0.81						
0.331	0.030	7.80	0.519	1.1902	0.94						

Appendix B-1. (Continued)

h (meters)	h' (meters)	DO (mg/1)	Q (liter/sec)	r	ab	h	h'	DO	Q	r	ab
0.372	0.241	1.30	0.873	1.3830	1.67	0.306	0.378	1.40	0.962	1.3249	1.78
0.372	0.241	3.55	0.873	1.3831	1.67	0.369	0.374	1.75	0.830	1.3634	1.59
0.344	0.238	5.225	0.976	1.3224	1.54	0,369	0.374	3.325	0.830	1.4459	1.96
0.372	0.241	4.775	0.873	1.4884	2.13	0.344	0.378	5.30	0.976	1.3111	1.48
0.372	0.241	1.275	0.714	1.3875	1.69	0.369	0.374	6.00	0.830	1.2049	0.90
0.372	0.241	3.60	0.714	1.3433	1.50	0.296	0.372	1.45	0.755	1.3077	1.72
0.372	0.241	5.225	0.714	1.2450	1.07	0.369	0.374	1.60	0.706	1.3773	1.64
0.293	0.235	1.45	0.610	1.3125	1.76	0.369	0.374	2.95	0.702	1.3624	1.58
0.360	0.238	1.70	0.570	1.3501	1.56	0.351	0.374	4.95	0.746	1.3598	1.69
0.293	0.235	2.675	0.610	1.2829	1.60	0.369	0.374	5.70	0.702	1.3294	1.43
0.360	0.238	3.75	0.570	1.2910	1.30	0.296	0.372	1.45	0.623	1.3274	1.83
0.329	0.235	5.30	0.610	1.3291	1.64	0.363	0.381	2.15	0.572	1.3393	1.49
0.360	0.238	6.50	0.570	1.2832	1.26	0.363	0.381	3.80	0.572	1.3831	1.69
0.382	0.235	1.45	0.490	1.2933	1.71	0.332	0.372	5.025	0.610	1.3228	1.59
0.360	0.238	1.75	0.506	1.3860	1.73	0.363	0.381	6.20	0.572	1.4044	1.78
0.360	0.238	3.125	0.506	1.3994	1.78	0.296	0.372	1.40	0.490	1.3054	1.71
0.329	0.235	5.35	0.490	1.3524	1.75	0.360	0.374	2.725	0.494	1.3713	1.64
0.360	0.238	6.275	0.506	1.1898	0.85	0.329	0.372	3.20	0.490	1.3367	1.68
0.341	0.235	8.325	0.858	1.4371	2.12	0.360	0.374	4.65	0.494	1.4991	2,21
0.335	0.232	7.85	0.709	1.4643	2.29	0.360	0.374	7.40	0.494	1.3874	1.93
0.331	0.232	8.15	0.610	1.2786	1.39	0.329	0.372	3.70	0.490	1.2258	1.00
0.331	0.232	7.75	0.519	1.3396	1.67	0.340	0.378	8.20	0.858	1.5614	2.71
						0.341	0.374	7.50	0.709	1.5596	1.73
						0.334	0.374	7.20	0.610	1.2557	1.26
						0.335	0.372	7.80	0.519	1.2948	1.45
						0.351	0.374	5.65	0.623	1.3353	1.57
						0.351	0.374	5.70	0.754	1.4127	1.93

Appendix B-1. (Continued)

h (meters)	h' (meters)	DO (mg/1)	Q (liter/sec)	r	ab	h	h'	DO	Q	r	ab
0.683	0.015	1.10	0.810	1.4091	1.02	0.680	0.112	0.85	0.847	1.6343	1.58
0.683	0.015	2.975	0.810	1.4055	1.01	0.680	0.112	2.90	0.847	0.5764	1.43
0.683	0.015	4.85	0.810	1.3953	0.99	0.680	0.112	4.70	0.847	1.5583	1.39
0.677	0.015	1.20	0.714	1.4155	1.05	0.671	0.110	1.15	0.709	1.6162	1.55
0.677	0.015	3.30	0.714	1.4799	1.21	0.671	0.110	4.15	0.709	1.5476	1.38
0.677	0.015	4.875	0.714	1.3972	1.00	0.671	0.110	5.175	0.709	1.5685	1.43
0.671	0.015	1.20	0.590	1.4249	1.08	0.668	0.110	0.95	0.570	1.5932	1.50
0.671	0.015	3.40	0.590	1.4452	1.13	0.599	0.105	3.30	0.610	1.5397	1.52
0.671	0.015	5.225	0.590	1.3680	0.93	0.668	0.110	4.375	0.570	1.4820	1.23
0.668	0.015	1.15	0.510	1.3035	0.77	0.668	0.110	5.40	0.570	1.4624	1.18
0.668	0.015	3.40	0.510	1.3963	1.00	0.671	0.111	1.175	0.502	1.5580	1.41
0.597	0.030	5.175	0.490	1.3823	1.08	0.597	0.104	3.60	0.490	1.5788	1.64
0.668	0.015	6.50	0.510	1.3406	0.87	0.671	0.111	4.275	0.502	1.4298	1.08
0.624	0.024	8.375	0.858	1.2891	0.79	0.671	0.111	6.50	0.502	1.3702	0.93
0.624	0.024	8.05	0.709	1.3482	0.96	0.613	0.110	8.275	0.858	1.3833	1.06
0.594	0.024	7.925	0.610	1.4465	1.28	0.594	0.110	7.85	0.709	1.5784	1.65
0.604	0.024	7.70	0.519	1.3202	0.91	0.610	0.110	7.60	0.610	1.4195	1.17
						0.604	0.110	7.725	0.519	1.1505	0.67
						0.597	0.104	2.625	0.489	1.5259	1.49
						0.597	0.104	4.10	0.623	1.5321	1.50
						0.597	0.104	3.80	0.489	1.5683	1.61
						0.597	0.104	2.575	0.489	1.5868	1.66

Appendix B-1 (Continued)

h (meters)	h' (meters)	DO (mg/1)	Q (liter/sec)	r	ab	h	h'	DO	Q	r	ab
0.680	0.238	1.15	0.844	1.6775	1.69	0.680	0.375	0.85	0.858	1.6692	1.66
0.680	0.238	3.60	0.844	1.6505	1.62	0.680	C.375	3.00	0.858	1.6689	L67
0.614	0.238	5.175	0.962	1.6217	1.74	0.610	0.381	5.35	0.976	1.7624	2.12
0.680	0.238	4.425	0.844	1.5861	1.46	0.680	0.375	6.425	0.858	1.4879	1.20
0.677	0.241	0.95	0.712	1.7035	1.76	0.674	0.372	1.075	0.717	1.6845	1.71
0.677	0.241	3.125	0.711	1.7606	1.89	0.674	0.372	4.55	0.717	1.6867	1.75
0.677	0.241	4.85	0.711	1.5805	1.44	0.674	0.372	3.00	0.717	1.6521	1.64
0.668	0.241	1.00	0.583	1.7332	1.65	0.671	0.372	1.10	0.577	1.7106	1.79
0.600	0.224	2.80	0.610	1.7717	2.17	0.671	0.372	2.55	0.577	1.7065	1.78
0.668	0.241	4.20	0.583	1.6844	1.73	0.671	0.372	4.55	0.577	1.6559	1.65
0.617	0.234	5.30	0.610	1.6329	1.76	0.664	0.372	0.95	0.499	1.7521	1.91
0.668	0.241	6.80	0.583	1.5650	1.42	0.664	0.372	3.30	0.499	1.6894	1.75
0.664	0.241	0.90	0.498	1.7307	1.85	0.591	0.366	5.20	0.490	1.7377	2.11
0.597	0.226	3.75	0.490	1.7073	2.00	0.664	0.372	5.80	0.499	1.6501	1.64
0.664	0.241	4.20	0.498	1.6647	1.68	0.619	0.379	8.45	0.858	1.6139	1.69
0.594	0.235	4.725	0.490	1.6584	1.89	0.610	0.372	7.90	0.709	1.6957	1.95
0.664	0.241	6.625	0.498	1.5333	1.34	0.604	0.372	8.20	0.610	1.8068	2.28
0.616	0.235	8.45	0.858	1.4275	1.19	0.599	0.372	7.75	0.519	1.5984	1.70
0.607	0.235	8.00	0.709	1.7860	2.21						
0.607	0.235	8.175	0.610	1.8297	2.34						
0.599	0.232	7.80	0.519	1.6482	1.84						

Appendix B-1 (Continued)

h (meters)	h' (meters)	DO (mg/l)	Q (liter/sec)	r	ab	h	h'	DO	Q	r	ab
0.981	0.015	0.50	0.887	1.5556	O.S'9	0.984	0.119	0.95	0.855	1.8543	1.53
0.981	0.013	0.60	0.887	1.5912	1.05	0.984	0.119	2.875	0.855	1.8.87	1.46
0.S8.L	0.015	0.625	0.889	1.5737	1.02	0.984	0.119	4.725	0.855	1.8003	1.43
0.981	0.015	0.415	0.889	1.5018	0.89	0.983	0.113	0.875	0.721	1.8324	1.48
0.981	0.021	0.60	0.758	0.5653	1.00	0.983	0.113	2.975	0.721	1.7708	1.37
0.981	0.021	0.60	0.758	1.5786	1.02	0.983	0.113	4.80	0.721	1.7358	1.32
0.981	0.021	0.60	0.758	1.5853	1.04	0.975	0.119	0.825	0.590	1.7991	1.43
0.981	0.021	4.25	0.758	1.4340	0.77	0.975	0.119	2.50	0.590	1.7356	1.33
0.972	0.018	1.025	0.581	1.5070	0.91	0.975	0.119	4.90	C.590	1.7163	1.29
0.972	0.018	1.00	0.581	1.5112	0.91	0.975	0.119	0.85	0.501	1 8208	1.48
0.972	0.018	1.00	0.581	1.4789	0.85	0.975	0.119	2.575	0.501	1.8220	1.48
0.972	0.018	3.55	0.581	1.4333	0.78	0.975	0.119	4.30	0.501	1.884??	1.59
0.969	0.015	0.80	0.485	1.5117	0.92	0.977	0.107	7.00	0.976	1.6214	1.14
0.969	0.015	0.70	C.485	1.4914	0.88	0.977	0.107	7.40	0.755	1.9578	1.76
0.969	0.015	0.70	0.485	1.479??	0.86	0.977	0.107	7.775	0.623	1.7012	1.29
0.969	0.015	2.75	0.485	1.3810	0.69	0.985	0.113	7.40	0.490	1.9143	1.65
0.985	0.018	1.40	0.806	1.5831	1.03	0.989	0.113	6.00	0.976	1.8046	1.47
0.985	0.018	3.10	0.806	1.5514	0.99	0.982	0.111	6.10	0.755	1.7175	1.27
0.985	0.018	5.25	0.806	14J62	0.78	0.978	0.108	6.05	0.623	1.7919	1.40
0.981	0.018	1.375	0.696	1.5489	0.99	0.978	0.107	6.10	C.485	1.8178	1.45
0.981	0.018	2.975	0.696	1.5295	0.95						
0.981	0.018	5.175	0.696	1.4767	0.86						
0.978	0.018	1.70	0.599	1.4952	0.89						
0.978	0.018	0.80	0.599	1.5045	0.90						
0.978	0.C18	2.80	0.599	1.5031	0.89						
0.978	0.018	4.90	0.599	1.4823	0.86						
0.972	0.018	0.70	0.506	1.4447	0.80						
0.968	0.021	2.85	0.490	1.5730	1.06						
C.972	0.018	2.15	0.506	1.4539	0.81						
0.972	0.018	7.20	0.506	1.5534	0.98						
0.989	0.034	5.10	0.490	1.1773	0.32						
0.972	0.018	3.825	0.506	1.6354	1.15						
0.989	0.037	7.90	0.976	1.4214	C.73						
0.980	0.034	7.10	0.74o	1.6554	1.16						
0.978	0.034	7.10	0.610	1.5845	1.03						
0.978	0.034	7 00	0.493	1.5956	1.05						

Appendix B-1 (Concluded)

h (meters)	h' (meters)	DO (mg/l)	Q (liter/sec)	r	ab	h	h'	DO	Q	r	ab
0.984	0.241	0.80	0.899	1.9471	1.69	0.988	0.372	0.85	0.884	1.9477	1.69
0.984	0.241	2.925	0.899	1.9395	1.68	0.988	0.372	3.00	0.884	1.9129	1.62
0.S84	0.241	4.70	0.899	1.8928	1.59	0.988	0.372	4.70	0.884	1.8140	1.46
0.981	0.241	1.00	0.750	2.0692	1.91	0.978	0.372	0.90	0.726	1.9474	1.71
0.981	0.241	3.10	0.750	2.0296	1.84	0.978	0.372	2.95	0.726	1.9869	1.78
0.981	0.241	4.85	0.750	1.8899	1.59	0.978	0.372	5.55	0.726	1.8701	1.56
0.978	0.234	0.90	0.628	2.0056	1.82	0.978	0.369	0.85	0.584	2.1018	1.98
0.978	0.234	2.80	0.628	2.0717	1.94	0.969	0.372	2.85	0.623	2.0664	1.97
0.978	0.234	5.10	0.628	1.9407	1.70	0.978	0.369	3.80	0.584	2.0145	1.82
0.972	0.238	0.90	0.501	2.0336	1.88	0.975	0,378	4.60	0.623	2.0204	1.83
0.972	0.238	2.675	0.501	2.0783	1.94	0.978	0.369	6.40	0.584	1.7775	1.39
0.972	0.238	5.20	0.501	2.0213	1.84	0.972	0.372	0.95	0.501	2.0339	1.86
0.989	0.226	7.80	0.976	1.8094	1.41	0.968	0.372	2.85	0.490	2.1106	2.06
0.981	0.226	7.65	0.755	2.0234	1.80	0.972	0.372	3.55	0.501	2.0339	1.86
0.978	0.226	7.40	0.623	1.7726	1.36	0.977	0.378	5.05	0.490	2.1738	2.11
0.988	0.226	7.90	0.490	2.1244	2.04	0.972	0.372	6.475	0.501	1.7185	1.29
0.978	0.234	6.90	0.489	1.9020	1.59	0.989	0.379	7.40	0.976	2.1003	1.99
						0.978	0.384	7.45	0.755	2.0648	1.95
						0.984	0.384	7.60	0.623	2.1095	2.02
						0.988	0.387	7.90	0.490	1.8718	1.59

Appendix B-2. Field Weir Box Data and Instream Water Quality Data, Reduced

Dam	Date	0.2 - 0.3m a	0.2 - 0.3m DOa (% Sat)	0.6 - 0.8m a	0.6 - 0.8m DOa (% Sat)	1.0m a	1.0m DOa (% Sat)	Avg. a	Avg. DOa (% Sat)	Algae (no/ml)	SS (mg/l)	COD (mg/l)	MBAS (mg/l as LAS)
Lockport	9/13/78	1.16	20.2	1.27	21.1	1.16	20.2	1.20	20.5	113	30	19.0	0.06
	10/13/78	1.04	27.3	1.39	28.3	1.37	26.6	1.27	27.4	193	26	20.4	0.15
	8/16/79	1.38	24.7	1.37	20.4	1.32	17.9	1.36	21.0	694	14	16.8	0.09
Brandon Road	9/12/78	0.92	53.0	1.36	47.3	0.95	47.3	1.08	49.2	147	17	19.3	0.08
	10/12/78	1.09	41.4	1.34	38.1	1.18	37.9	1.21	39.1	500	22	19.0	0.15
	8/15/79	1.23	0.7	1.27	0.7	1.35	0.7	1.29	0.7	673	11	17.2	0.10
	8/29/79	1.24	23.9	1.08	26.9	1.28	25.7	1.20	25.4	1288	24	18.3	0.10
	9/11/79	1.79	22.3	1.83	27.5	1.32	27.5	1.65	25.8	853	6	17.3	0.12
Dresden Island	8/25/78	2.01	72.2	2.65	79.4	2.64	80.1	2.43	77.2	674	13	17.2	0.05
	9/14/78	0.67	55.9	0.92	54.6	0.82	58.3	0.80	56.3	796	28	18.6	0.05
	9/08/79	0.48	64.8	1.08	63.0	0.93	61.7	0.83	63.2	1458	18	15.3	0.08
	8/14/79	0.75	66.6	1.36	59.2	0.97	70.3	1.02	65.3	843	33	18.1	0.06
	9/05/79	1.02	73.7	1.31	70.5	1.06	78.2	1.13	74.2	1256	20	17.2	0.08
Marseilles	8/24/78	0.47	85.1	0.35	82.6	0.11	83.9	0.31	83.9	668	18	18.2	0.06
	9/19/78	1.54	58.2	0.95	59.3	0.81	58.8	1.10	58.8	95	176	31.1	0.14
	8/06/79	0.97	61.2	0.94	62.9	0.98	63.4	0.96	62.5	885	27	15.1	0.09
	9/06/79	0.75	71.8	1.46	66.7	1.30	66.1	1.17	68.2	705	35	22.2	0.08
	9/12/79	1.67	81.3	1.35	80.1	0.94	80.7	1.34	80.7	795	14	17.3	0.06
Starved Rock	8/23/78	12.16	99.1	-45.50	98.2	17.19	97.3	-5.38	98.2	1197	47	32.0	0.04
	9/20/78	0.68	68.4	0.80	70.3	0.80	69.1	0.76	69.3	809	118	28.9	0.07
	8/03/79	0.67	78.9	1.43	77.0	1.44	73.1	1.18	76.3	631	20	15.4	0.07
	9/07/79	0.00	87.9	-0.81	99.1	0.00	96.0	-0.27	94.3	1352	34	26.3	0.08
	9/14/79	2.54	80.0	2.02	83.0	2.09	81.2	2.22	81.4	694	29	23.7	0.07
Peoria	8/12/78	1.86	79.3	0.82	81.8	0.56	82.8	1.34	81.3	771	45	23.9	0.06
	10/01/78	8.03	82.1	2.81	83.6	2.58	83.3	4.71	83.0	920	55	24.2	0.09
	7/27/79	1.47	78.7	2.81	83.0	1.02	80.0	1.25	80.6	1251	89	20.6	0.05
	8/01/79	1.39	76.2	0.77	80.0	0.82	76.2	0.99	77.5	864	67	18.1	0.06
	10/10/79	0.00	88.9	1.15	88.6	1.20	90.5	1.18	89.3	922	42	22.1	0.05
LaGrange	8/22/78	0.27	79.1	0.24	87.0	0.54	81.8	0.35	82.6	582	39	23.6	0.03
	9/21/78	1.28	37.9	1.55	38.2	1.31	37.6	1.38	37.9	550	77	22.7	0.08
	8/07/79	1.30	63.8	1.21	62.8	0.89	65.8	1.13	64.1	742	86	17.8	0.03
	9/18/79	0.33	68.0	1.18	72.7	1.53	70.7	1.36	70.4	1399	39	23.5	0.06
	9/26/79	1.66	77.4	2.14	74.1	1.15	75.2	1.41	75.6	1627	55	27.8	0.05
Tap Water used in Laboratory Experiment									10.0	0	0	3.2	0.06

Appendix B-3. Instream DO-Temperature Data, Reduced

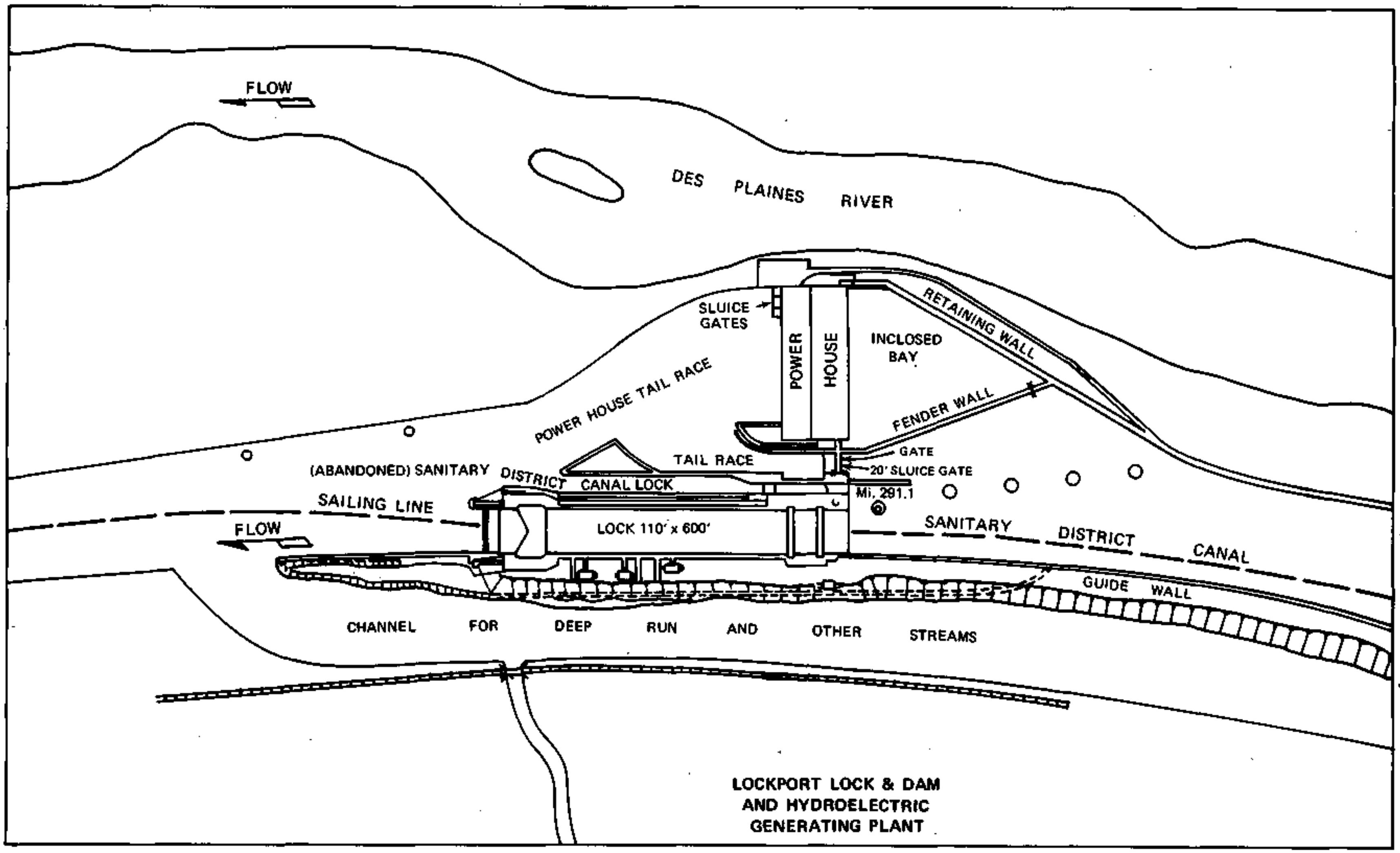
Dam	Date	Station	a	Temperature (°C) Above	Temperature (°C) Below	DO (mg/l) Above	DO (mg/l) Below	Pool Elev (MSL) Above	Pool Elev (MSL) Below	b	Gate/Wicket setting
Lockport	9/13/78	Sluice Gates 1 & 2	1.16	27.20	26.00	1.80	2.22	574.7	539.0	0.39	?
	10/13/78	Sluice Gates 1	1.37	20.31	19.80	2.47	2.46	575.7	538.7	-0.14	?
	8/16/79	Sluice Gates 1 & 2	1.32	26.00	25.81	0.81	0.98	575.2	537.85	0.16	?
Brandon Road	9/12/78	Gates 1, 2, 4, 6	0.95	27.32	27.50	3.18	6.57	538.5	505.2	33.62	2'
	10/12/78	Gates 3, 4, 8, 9,10	1.18	19.55	19.00	3.40	7.15	538.5	505.0	20.50	2'
	8/15/79	CL Headgates	1.35	24.50	23.80	0.70	6.78	538.45	505.2	34.27	8'+4'
		CL Dam	1.35	25.00	23.80	0.56	6.78	538.45	505.2	34.43	leakage
		CL Gate 14	1.35	25.00	23.80	0.56	6.88	538.45	505.2	37.36	leakage
	8/29/79	CL Headgates	1.28	26.12	24.80	1.88	6.53	538.20	506.36	25.87	8'
		Gates 16 & 18	1.28	25.40	24.80	1.52	6.28	538.20	506.36	23.81	2'
	9/11/79	CL Headgates	1.32	26.00	25.90	1.88	7.42	538.27	504.83	79.90	6'
		CL Gate 11	1.32	26.00	25.90	1.51	7.30	538.27	504.83	69.91	leakage
		CL Gate 18	1.32	26.00	25.90	1.55	6.40	538.27	504.83	26.34	2'
Dresden Island	8/25/78	CL Gate 4	1.03	26.23	27.30	5.66	7.24	504.6	484.4	1.71	0.5'
		CL Gates 5,6,7,8	1.03	26.12	27.30	5.62	7.33	504.6	484.4	2.19	1'
	9/14/78	CL Gates 2 & 3	0.82	26.20	27.00	4.50	6.85	504.7	486.9	1.60	1'
		CL Gates 4, 5, 6	0.82	26.20	27.00	4.53	6.58	504.7	486.9	1.11	2'
		CL Gates 7 & 8	0.82	26.40	27.20	4.56	6.78	504.7	486.0	1.45	1'
	8/08/79	CL Gate 5	0.93	30.74	30.05	5.49	6.77	504.6	485.9	0.99	2'
		CL Gate 7	0.93	30.37	30.83	5.00	6.60	504.6	485.9	1.28	2'
		CL Gate 9	0.93	30.39	30.17	5.20	6.70	504.7	485.9	1.15	2'
	8/14/79	CL Gate 3	0.97	25.18	24.80	5.67	7.78	504.7	484.3	3.08	1'
		CL Gate 5	0.97	25.04	24.80	5.65	7.60	504.7	484.3	2.03	1'
		Gates 7 & 9	0.97	24.85	24.80	5.55	7.90	504.8	484.3	4.95	1'
	9/05/79	CL Closed Gates 1-6	1.06	28.22	27.97	5.76	7.10	504.6	483.9	1.16	leakage
		CL Gates 7 & 9	1.06	27.85	29.00	5.68	7.10	504.7	483.9	1.86	1'
Marseilles	8/24/78	CL Gate 7	1.04	28.00	27.47	6.60	7.10	482.9	470.9	0.31	4'
	9/19/78	CL Gates 1 & 2	0.81	25.02	25.00	4.68	6.53	483.2	472.5	0.81	5'
		CL Closed Gates 3-8	0.81	24.65	25.00	4.61	6.43	483.1	472.5	0.78	leakage
	8/06/79	CL Gate 4	0.98	28.87	29.50	4.70	6.13	483.1	471.45	0.58	0.5'
		CL Gate 6	0.98	28.90	29.50	4.80	6.13	483.2	471.45	0.45	3'
		CL Gate 8	0.98	29.08	29.00	5.00	6.23	483.2	471.45	0.48	3'
	9/06/79	CL Closed Gates 2&3	1.30	27.50	27.90	5.51	7.05	483.3	470.7	0.93	leakage
		CL Gate 5	1.30	27.50	27.90	5.47	7.20	483.3	470.7	1.33	1'
		CL Gate 7	1.30	27.50	27.80	5.47	6.80	483.2	470.7	0.58	2'
	9/12/79	CL Closed Gates 2&3	0.94	25.50	25.50	6.33	7.70	483.2	470.7	2.00	leakage
		CL Gate 5	0.94	25.30	25.40	6.36	7.47	483.1	470.7	1.02	1'
		CL Gate 7	0.94	25.37	25.33	6.54	7.57	483.1	470.7	1.08	2'

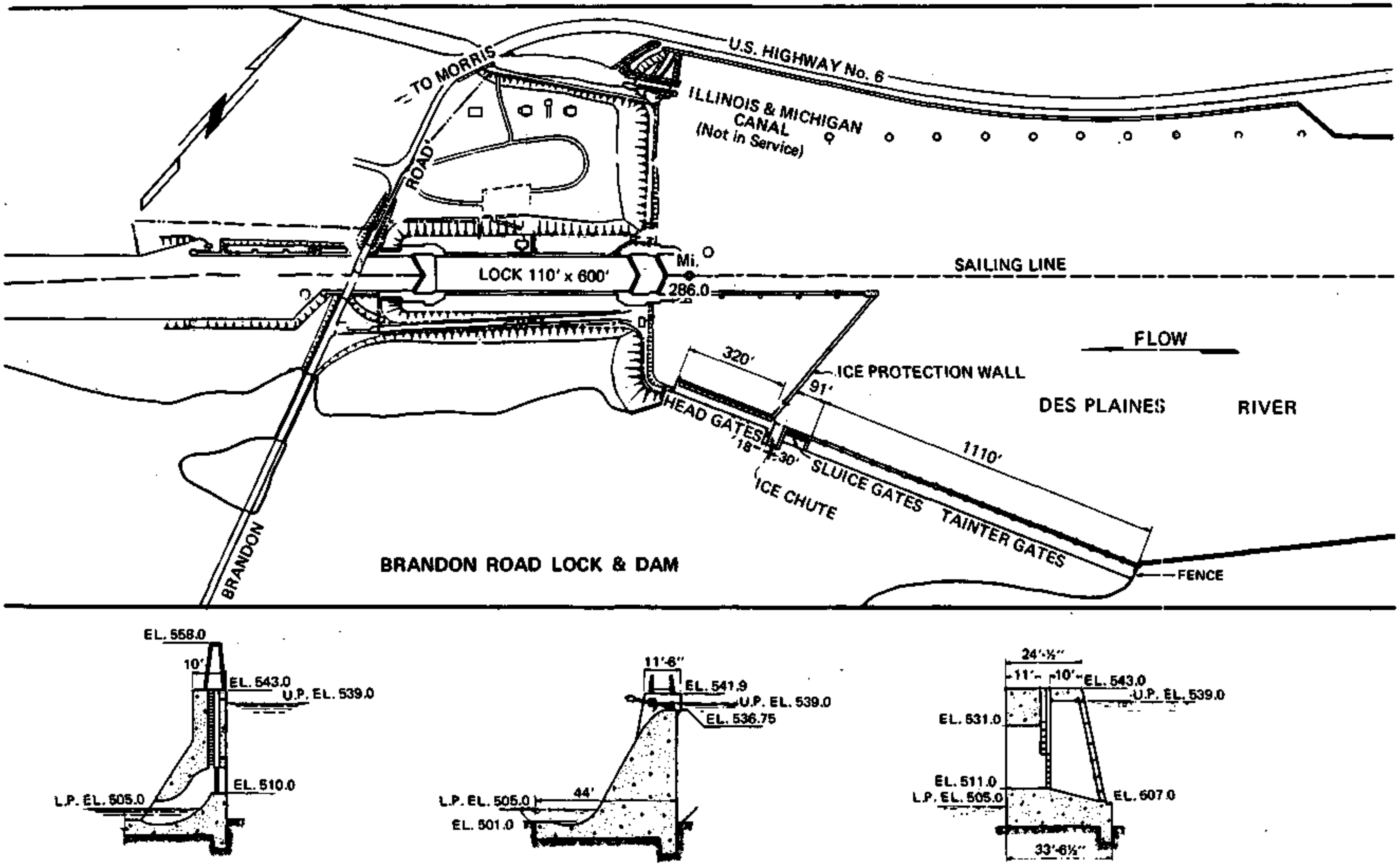
Appendix B-3. (Continued)

Dam	Date	Station	a	Temp. (°C) Above	Temp. (°C) Below	DO (mg/l) Above	DO (mg/l) Below	Pool Elev (MSL) Above	Pool Elev (MSL) Below	b	Gate/Wicket Setting
Starved Rock	8/23/78	CL Gates 1 & 2	1.43	25.80	27.20	7.01	7.90	458.5	442.8	-6.83	0.5'
		CL Gates 4, 5, 6	1.43	26.52	27.20	7.21	7.80	458.5	442.8	6.13	0.5'
		CL Gates 7 & 8	1.43	26.44	27.20	7.96	8.00	458.4	442.9	-0.35	1'
		CL Gate 9	1.43	25.94	27.20	7.14	7.90	458.4	442.9	-5.87	1.5'
	9/20/78	CL Gate 1	0.80	24.80	25.00	5.90	6.93	458.5	447.3	0.61	4'
		CL Gates 2, 3, 4	0.80	25.52	25.00	5.53	6.50	458.5	447.2	0.38	3'
	8/03/79	CL Gates 4 & 5	1.44	28.93	28.20	6.94	6.73	458.8	443.0	-0.11	2'
		CL Gate 6	1.44	28.44	27.00	6.47	6.92	458.7	443.0	0.09	4'
		CL Gate 7	1.44	28.17	27.20	6.19	6.93	458.7	443.0	0.23	3'
	9/07/79	CL Gate 4	1.32	26.00	25.50	8.04	7.93	458.8	442.4	-0.45	2'
		CL Gate 6	1.32	25.02	25.10	7.18	8.07	458.8	442.5	4.12	1'
		CL Gates 8 & 9	1.32	25.11	25.00	7.44	8.10	458.8	442.5	3.49	leakage
	9/14/79	CL Closed Gates 2&3	1.22	23.40	23.10	7.29	8.70	458.9	440.5	-3.02	leakage
		CL Gates 5, 6, 7	1.22	22.68	22.50	8.13	8.77	458.9	440.5	-1.59	1'
		CL Closed Gate 8	1.22	22.52	22.50	8.05	8.67	458.9	440.5	-3.44	leakage
Peoria	8/12/78	22 Wickets from RB	1.15	25.21	26.23	6.24	6.55	440.2	433.1	0.21	wickets up
		44 Wickets from RB	1.15	25.2	26.20	6.80	6.55	440.2	433.1	-0.04	wickets up
		67 Wickets from RB	1.15	25.19	26.05	6.47	6.62	440.2	433.1	0.13	wickets up
		90 Wickets from RB	1.15	25.24	26.20	6.60	6.74	440.2	433.1	0.15	wickets up
		113 Wickets from RB	1.15	25.66	26.20	6.47	6.71	440.2	433.1	0.16	wickets up
	10/02/78	22 Wickets from RB	1.16	20.09	18.90	6.95	7.42	440.1	433.6	0.11	wickets up
		44 Wickets from RB	1.16	19.34	18.90	7.10	7.42	440.1	433.6	0.11	wickets up
		67 Wickets from RB	1.16	19.17	18.90	7.06	7.40	440.1	433.6	0.12	wickets up
		90 Wickets from RB	1.16	19.21	18.90	7.27	7.39	440.1	433.6	0.03	wickets up
		113 Wickets from RB	1.16	19.16	18.90	7.10	7.43	440.1	433.6	0.12	wickets up
	7/27/79	33 Wickets from RB	1.02	29.71	28.12	6.01	6.30	440.4	433.5	0.03	wickets up
		67 Wickets from RB	1.02	29.47	28.32	6.17	6.17	440.4	433.5	-0.07	wickets up
		101 Wickets from RB	1.02	29.08	28.24	6.31	6.43	440.4	433.5	0.00	wickets up
	8/01/79	33 Wickets from RB	0.82	26.59	26.49	6.43	6.45	440.8	435.6	0.00	10 down
		67 Wickets from RB	0.82	26.69	26.32	6.02	6.64	440.8	435.6	0.47	wickets up
		130 Wickets from RB	0.82	26.85	26.50	6.20	6.70	440.8	435.6	0.40	wickets up
	10/10/79	33 Wickets from RB	1.20	14.47	14.20	9.06	9.61	439.9	431.7	0.59	wickets up
		67 Wickets from RB	1.20	14.50	14.00	8.95	9.74	439.9	431.7	0.95	wickets up
		101 Wickets from RB	1.20	14.46	14.13	9.04	9.75	439.8	431.7	0.97	wickets up
LaGrange	8/22/79	27 Wickets from RB	1.12	25.51	26.22	6.28	6.65	428.9	423.0	0.27	wickets up
		54 Wickets from RB	1.12	25.47	26.87	6.47	6.70	428.9	423.0	0.27	wickets up
		81 Wickets from RB	1.12	25.37	26.71	6.54	6.75	428.9	423.0	0.26	wickets up
		108 Wickets from RB	1.12	25.30	26.57	6.47	6.62	428.9	423.0	0.19	wickets up
		Butterfly valves	1.12	25.29	26.51	6.42	6.45	428.9	423.0	0.11	3 down

Appendix B-3. (Concluded)

Dam	Date	Station	a	Temp. (°C) Above	Temp. (°C) Below	DO (mg/l) Above	DO (mg/l) Below	Pool Elev (MSL) Above	Pool Elev (MSL) Below	b	Gate/Wicket Setting
LaGrange	9/21/78	33 Wickets from RB	1.31	24.07	24.00	2.64	3.16	429.1	425.8	0.11	wickets up
		67 Wickets from RB	1.31	24.03	24.00	2.52	3.08	429.1	425.8	0.11	wickets up
		123 Wickets from RB	1.31	23.91	24.00	2.62	3.13	429.1	425.8	0.11	25 down
	8/07/79	33 Wickets from RB	0.89	30.07	30.00	5.06	5.22	429.6	425.8	0.08	wickets up
		67 Wickets from RB	0.89	29.89	30.00	4.86	5.71	429.6	425.8	0.62	wickets up
		125 Wickets from RB	0.89	29.59	29.50	4.71	5.10	429.6	425.8	0.19	20 down
	9/18/79	33 Wickets from RB	1.53	23.56	23.82	6.04	7.45	429.2	420.9	0.72	wickets up
		67 Wickets from RB	1.53	23.54	23.21	6.10	7.51	429.2	420.9	0.65	wickets up
		102 Wickets from RB	1.53	23.39	23.02	6.01	7.40	429.2	420.9	0.55	wickets up
	9/26/79	33 Wickets from RB	1.15	22.73	22.34	6.18	8.08	429.3	421.0	2.14	wickets up
		67 Wickets from RB	1.15	22.25	21.82	6.58	7.62	429.3	421.0	0.56	wickets up
		102 Wickets from RB	1.15	21.98	21.48	6.21	7.47	429.2	421.2	0.58	wickets up
		Butterfly Valves	1.15	21.98	23.00	6.21	6.10	429.2	421.2	0.02	wickets up
Starved Rock Adjusted Values: 0.3 mg/l subtracted from C_B											
	8/23/78	CL Gates 1 & 2	1.43	25.80	27.20	7.01	7.60	458.5	442.8	1.22	0.5'
		CL Gates 4, 5, 6	1.43	26.52	27.20	7.21	7.50	458.5	442.8	0.42	0.5'
		CL Gates 7 & 8	1.43	26.44	27.20	7.96	7.70	458.4	442.9	-0.38	1'
		CL Gate 9	1.43	25.94	27.20	7.14	7.60	458.4	442.9	0.98	1.5'
	9/07/79	CL Gate 4	1.32	26.00	25.50	8.04	7.63	458.8	442.4	-0.42	2'
		CL Gate 6	1.32	25.02	25.10	7.18	7.77	458.8	442.5	0.63	1'
		CL Gates 8 & 9	1.32	25.11	25.00	7.44	7.80	458.8	442.5	0.38	leakage
	9/14/79	CL Closed Gates 2&3	1.22	23.40	23.10	7.29	8.40	458.9	440.5	0.32	leakage
		CL Gates 5, 6, 7	1.22	22.68	22.50	8.13	8.47	458.9	440.5	1.37	1'
		CL Closed Gate 8	1.22	22.52	22.50	8.05	8.37	458.9	440.5	0.74	leakage

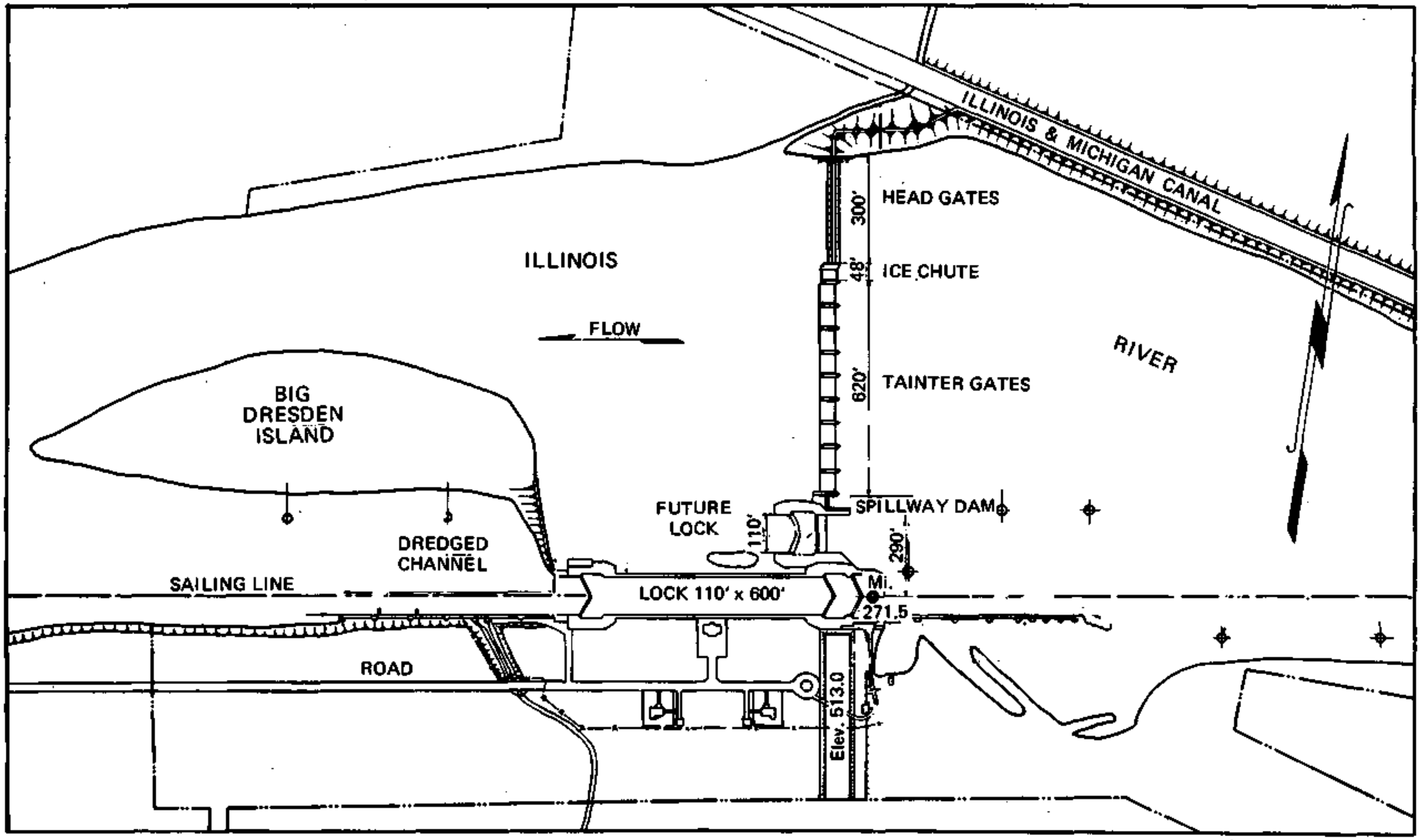

FLOW
DES PLAINES RIVER
SLUICE GATES
POWER HOUSE
INCLOSED BAY
RETAINING WALL
POWER HOUSE TAIL RACE
FENDER WALL
TAIL RACE
GATE
20' SLUICE GATE
(ABANDONED) SANITARY DISTRICT CANAL LOCK
Mi. 291.1
SAILING LINE
FLOW
LOCK 110' x 600'
SANITARY DISTRICT CANAL
GUIDE WALL
CHANNEL FOR DEEP RUN AND OTHER STREAMS
LOCKPORT LOCK & DAM
AND HYDROELECTRIC
GENERATING PLANT

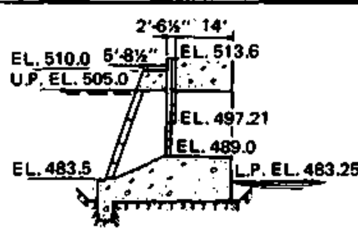


CROSS SECTION OF SLUICE GATE

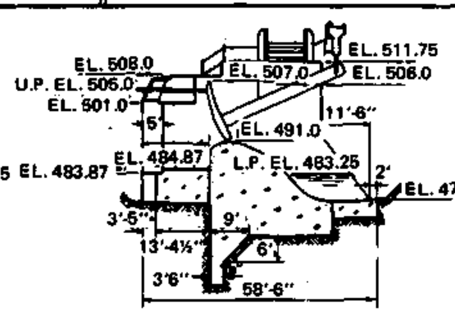
CROSS SECTION OF TAINTER GATE

CROSS SECTION OF HEAD GATES





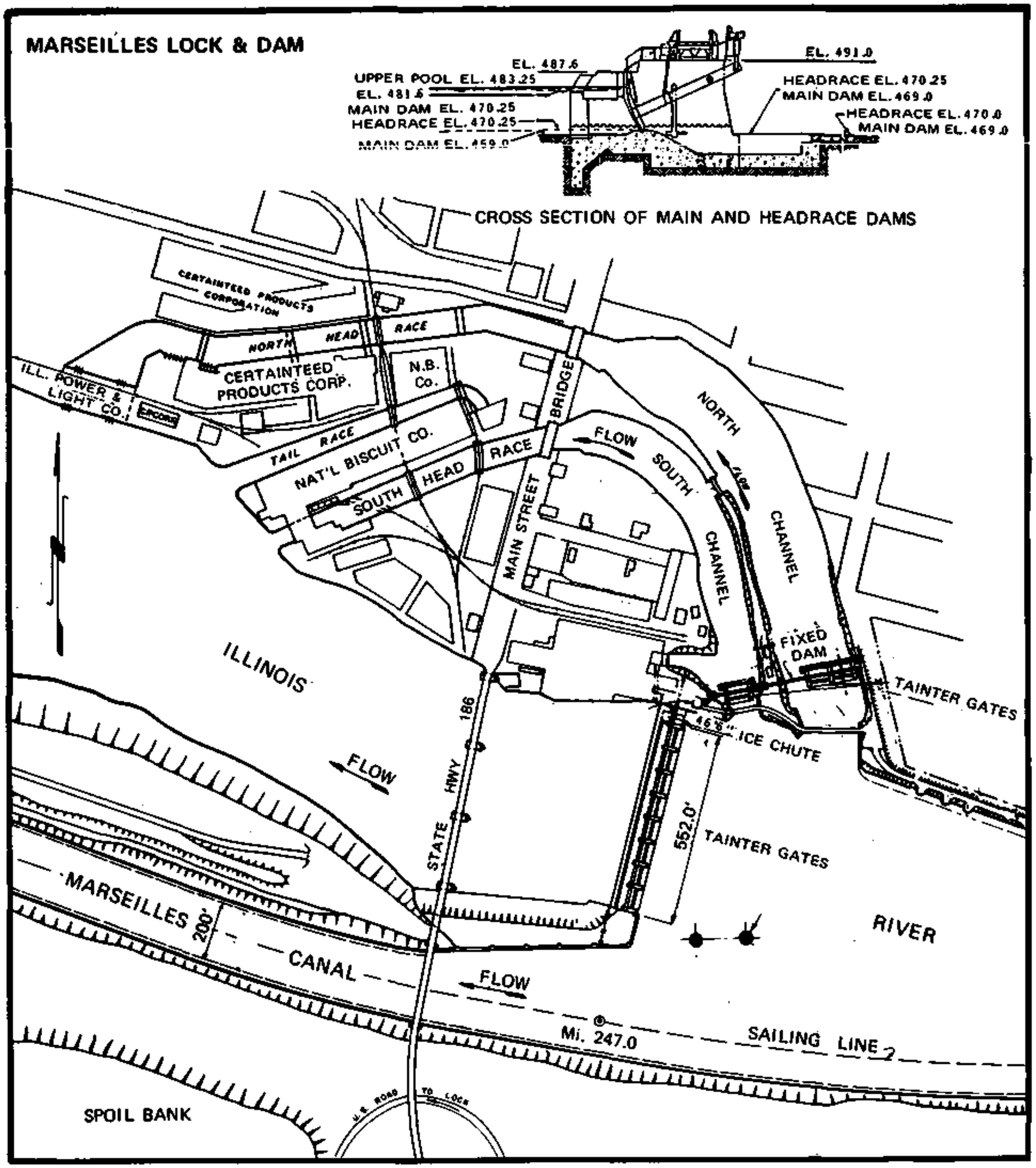
CROSS SECTION OF
HEAD GATES

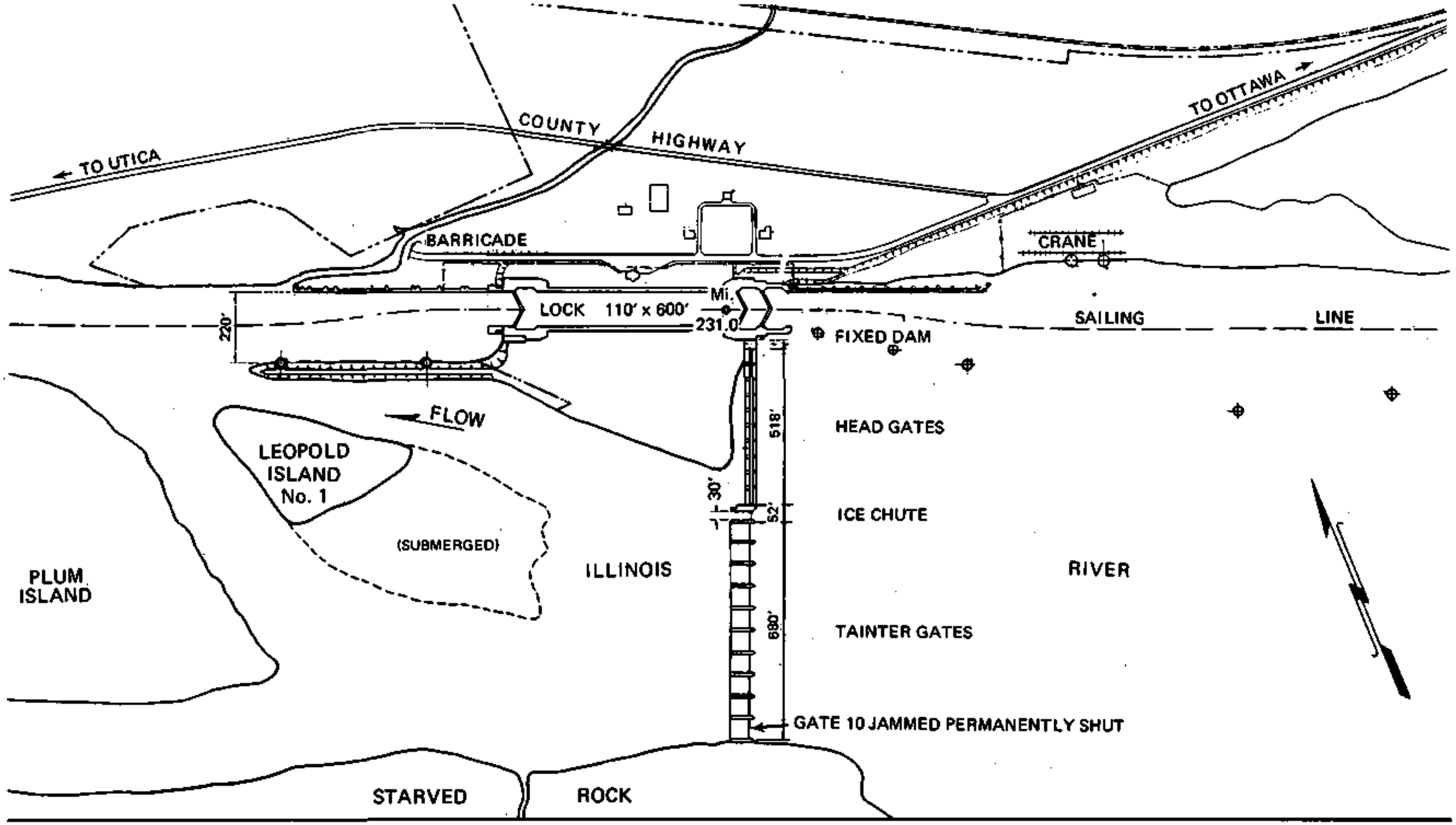


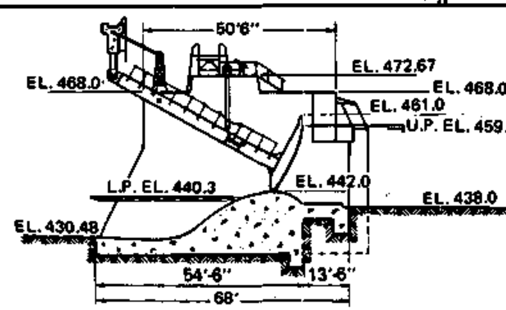
CROSS SECTION OF
T AINTER GATES

DRESDEN ISLAND
LOCK & DAM

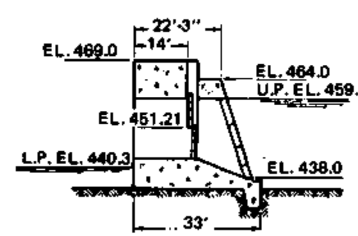
Appendix C. (Continued)







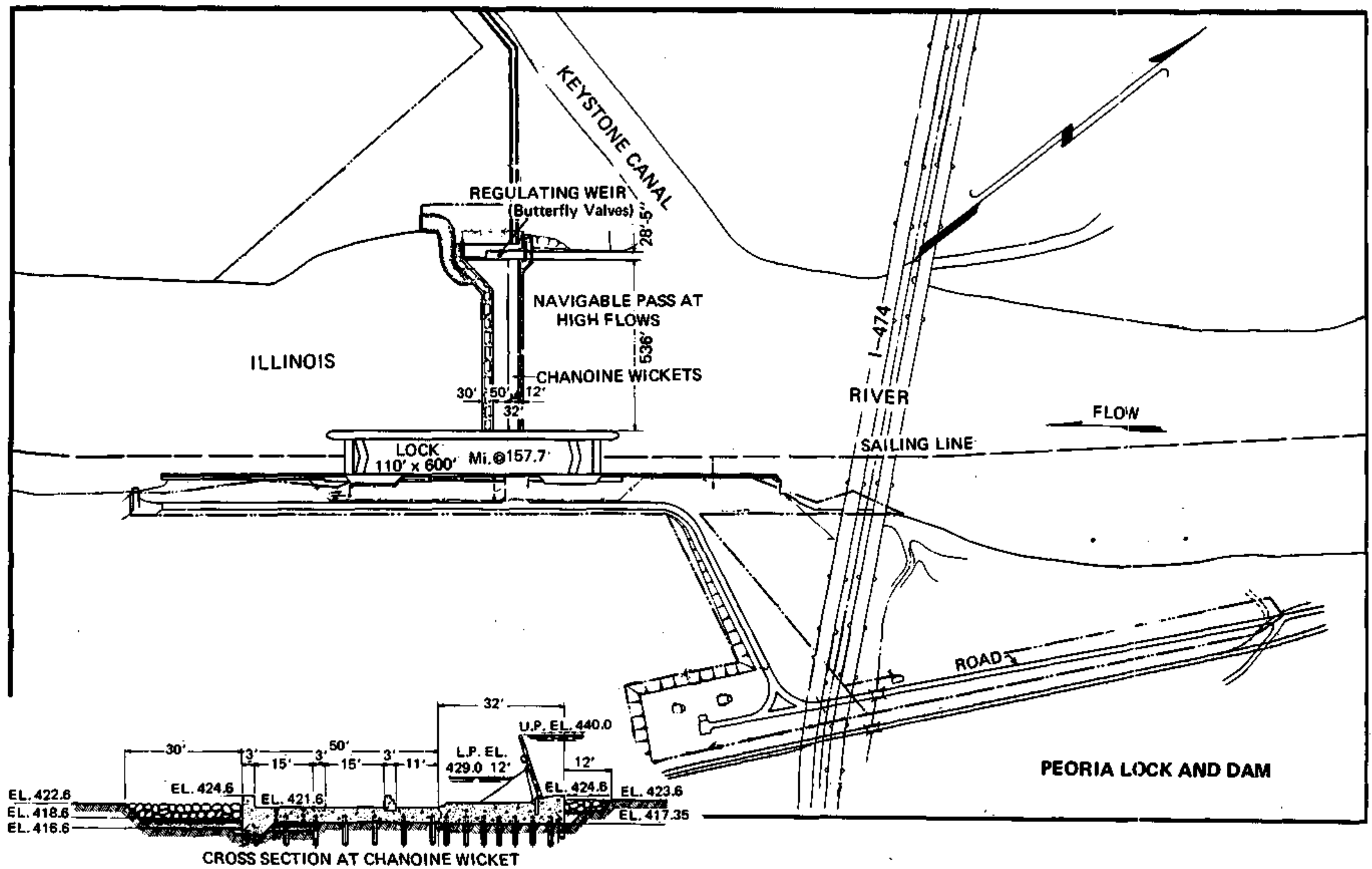
CROSS SECTION OF TAINTER GATES



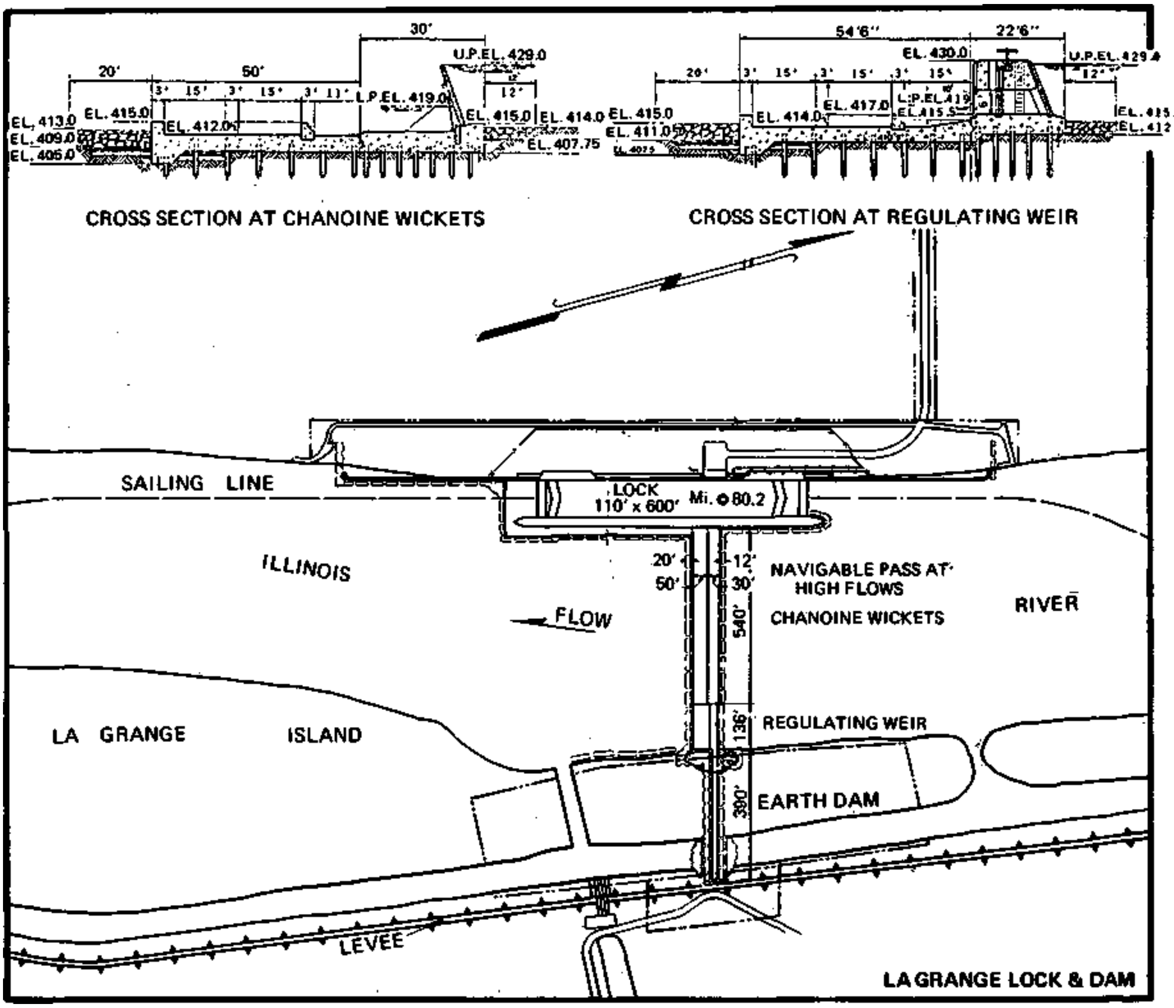
CROSS SECTION OF HEAD GATES

STARVED ROCK
LOCK & DAM

Appendix C. (Continued)



PEORIA LOCK AND DAM


CROSS SECTION AT CHANOINE WICKETS
CROSS SECTION AT REGULATING WEIR
SAILING LINE
LOCK 110' x 600'
Mi. 80.2
ILLINOIS
RIVER
FLOW
NAVIGABLE PASS AT HIGH FLOWS
CHANOINE WICKETS
REGULATING WEIR
EARTH DAM
LA GRANGE ISLAND
LEVEE
LA GRANGE LOCK & DAM