PART I

OF RICHELIEU RIVER
POLLUTION SURVEY

OXYGEN BALANCE
Richelieu River P.Q.

By
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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for a degree of Master of Engineering.

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and Applied Mechanics
McGill University
Montreal. March 1967.

FOREWARD

In 1964 the Department of Civil Engineering and Applied Mechanics, McGill University, received a research grant from the Department of National Health and Welfare to conduct a pollution survey of the Richelieu River, P.Q.

A comprehensive three-part survey was designed to adequately evaluate the degree of pollution of the River in terms of dissolved oxygen concentration, chemical pollution and bacterial contamination.

This report deals with the first part of the River survey, the dissolved oxygen concentrations in the River. The pollutional loads causing the oxygen deficiency were investigated, and the capacity of the River for restoration of the dissolved oxygen utilized in biochemical oxidation of these pollutional loads was studied. The sum of the two components, deoxygenation and reaeration, represents the net dissolved oxygen concentrations observed in the River. The magnitude and interaction of these components were determined to describe the biochemical regime of the River.

ACKNOWLEDGEMENTS

This investigation was supported by a research grant No. 607-7-528 of the National Department of Health and Welfare.

The technical assistance of the staff in the following organizations is deeply appreciated.

Mr. A.G. Murphy, Controller and General Manager of the Water Purification Board; for letters of reference sent to each town and municipality along the Richelieu River.

Mr. S. Huberman, Regional Engineer of the Department of Northern Affairs and National Resources - Water Resources Branch; who supplied River flow data, men and equipment during the Hydrologic Regime studies.

The Consulting Engineer firms of; Delaney, Love and Associates; Beauchemin, Beaton, Lapointe; Alary, Tanquay and Associates; Lalonde, Girourd, Letendre; who supplied data and sewer layout maps of the major towns along the Richelieu River.

The Honeywell Corporation, Electronic Data Processing Center; for the use of a Honeywell H-200 Computer and instruction in series 200 Operating System - Mod. 1, Fortran Compiler D.

The guidance and helpful suggestions of Mr. D.K. Mackay, instructor, and Mr. H.O. Weber, programmer, Honeywell Education Department; in writing, compiling and executing of the computer programs used in this study are sincerely appreciated.

The assistance of Mr. F.M. Kuo and Mr. B.P. Neelakantiah, graduate students, in the laboratory analysis of collected samples is gratefully acknowledged.

The writer wishes to express his gratitude and sincere appreciation to Dr. A. Pakalnins, Department of Civil Engineering, for advice, direction and encouragement during all phases of the River studies.

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CHAPTER I

INTRODUCTION

The continuous concentration of population in urban areas and the growth of industrial complexes have resulted in a sharp increase in the demand and use of the natural resource - water. Consequently, the planning of a rational multipurpose use of water has become imperative. The surface waters in the form of streams and lakes serve a dual purpose. They are the sources of public and industrial water supply, and are also used for the disposal of wastes by dilution.

The quantity of surface waters available for such a double use has remained substantially unchanged, while the amount of wastes disposed has increased. This has led to a considerable impairment of the quality of water available for subsequent uses, and has caused a general concern.

Every natural body of water has a definite and limited capacity for disposal of wastes which can be assessed by conducting a river survey. This thesis deals with the evaluation of the present and future pollutional conditions of the Richelieu River, P.Q.

The aims of the planned field survey, the laboratory and the analytical work may be listed as follows.

1. To establish the parameters of the hydrologic

regime of the River, and to derive the drought flow frequency.

2. To evaluate the magnitude and characteristics of the pollutional loads, present and future.
3. To determine the degree of pollution at present.
4. To formulate a mathematical model that best describes the dissolved oxygen sag curve.
5. To assess the dissolved oxygen distribution on the cross sections of the River, and determine the statistical reliability of the sampling procedure.
6. To forecast the dissolved oxygen saturation levels in the River for varying drought flow frequencies and at different degrees of waste treatment provided at some future time.

CHAPTER II

PRELIMINARY SURVEY

The first step in any river pollution study is the preliminary survey which is required in order to collect data and to establish or derive the following.

1. Visual inspection of the river to determine the extent of physical pollution.
2. Preliminary dissolved oxygen readings to establish the extent of the pollutional survey required.
3. Establish the survey stations within the region of pollution.
4. Study the hydrologic regime of the river within the survey region.
5. Establish the procedure of sample collection.

The preliminary survey was conducted during the Summer and Fall of 1964. The relationships or derivations resulting from the preliminary survey were designed to accommodate the 1965, 1966, River conditions, the period during which intensive sampling was done.

1. Visual Inspection of the River

Visual inspection for pollution is defined by R. Bonin (3) as evidence of scum, slime, floating solids, discoloured water and odour. The visual inspection of the

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(3) See References in the Appendix

Richelieu River consisted of noting any evidence of physical pollution that might be objectionable to the general public. Since survey stations were not yet established, only general areas of pollution were recorded. The degree of pollution was determined by the body senses of touch, smell and sight. The stretch of the River inspected was from the Canada - United States border at the outlet of Lake Champlain to St. Charles, a town twenty-five miles upstream from Sorel.

Lake Champlain water was very clear with no evidence of physical pollution. Further downstream investigation of the River revealed that near the Town of St. Jean, specifically, the waste outlet of the David Lord Cannery, the River was polluted by a high concentration of organic waste undergoing both aerobic and anerobic decomposition, and a sludge bank existed on the bottom of the River. The evidence that led to the suspicion of local pollution was green, bubbling water and an offensive odour.

Further downstream there were reports of a fish kill in the St. Jean area. Some dead fish were found above and below St. Jean as well as at Beloeil, but the quantity found was only a small fraction of that reported.

No extensive physical pollution was observed in the region from Fryers Island Dam to Chambly Basin.

At Chambly Basin traces of oil slicks and floating scum were observed.

From Chambly Basin to McMasterville no evidence of physical pollution was found.

At McMasterville, The Canadian Industries Limited plant discharged waste water through four major outlets. The two upstream ones ran clear and had a small volume discharge. The third discharged a milky white waste water carrying a high percentage of settleable material as was evidenced by a delta being formed in the River along the bank. The downstream outlet discharged highly coloured wastes.

At St. Hilaire the Beet Sugar Plant and Refinery discharged a milky white waste water at certain times of the year. In October this white water discharge can be traced several thousand feet downstream.

From St. Hilaire to St. Charles no further evidence of physical pollution was observed.

Throughout the whole River stretch there was a distinct odour of detergents, especially noticeable at the River banks.

From the visual inspection of the River, it was decided that the region from St. Jean to St. Charles, a distance of about thirty-three miles, showed sufficient evidence of physical pollution to be further investigated with a portable dissolved oxygen meter before station locations were finalized.

2. Preliminary Dissolved Oxygen Readings

Preliminary dissolved oxygen readings were taken between St. Jean and St. Charles to verify that within this region the dissolved oxygen level in the River did in fact reach a sag point or a minimum value, and a recovery zone. The preliminary dissolved oxygen survey gave the following general results.

TABLE 1

Sample Location	Dissolved Oxygen in Percent Saturation
C.N.R. Bridge above St. Jean	85
Highway No. 9 bridge below St. Jean	75
Highway bridge between Richelieu and Chambly	85
100 yards upstream from C.I.L.	82
Highway bridge at Beloeil	77
Isle aux Cerfs, six miles below Beloeil	75
St. Charles, twelve miles below Beloeil	80

There are no major towns or industries either above St. Jean or below St. Charles. Within the region between St. Jean and St. Charles the dissolved oxygen readings indicated two sag areas and two recovery zones in the river. These two towns were then chosen as defining the limits of the River stretch where permanent survey stations should be established.

3. Establishing the Stations

Gannon and Downs (9) have done a dissolved oxygen analysis of the Willamette River in Oregon, a river comparable to the Richelieu River in size and discharge. The Willamette River has a discharge of three to four thousand cubic feet per second, and a depth between ten and thirty feet. The Richelieu River has a summer discharge of three to four thousand cubic feet per second and a depth of five to twenty feet. In establishing the stations on the Willamette River, Gannon and Downs state that; "This need not be done with a high degree of surveying accuracy, but rather emphasis should be placed on more frequent sounding wherever possible. Physically it can be accomplished by means of a sounding rod or weighted line, together with a good map of the river stretch in question for location and orientation in the field."

In the Richelieu River survey a series of twenty-five stations were chosen and marked off on a hydrographic map of the River. The stations were located above and below the major sources of pollution as determined by the preliminary dissolved oxygen readings. Distances from the stations to recognizable land marks were scaled on the map and the corresponding distances chained along the shore line. Initially a triangulation network was set out along the River to establish exact distances between stations but it was found that locating stations from scaled distances on the hydrographic map gave sufficiently accurate results. The difference between scaled distances and triangulated distances was ± 25 feet per mile surveyed. The accuracy of the map was thus established and all other stations were located from the map.

At each station two markers, five feet long and six inches wide, were placed on the east shore on the perpendicular line to the River channel. These were painted red and white for easy identification at a later date. The marker location was then recorded with reference to some immovable object should the spring floods dislodge them in the following years.

A drawing of the station locations can be found in Appendix D.

4. Hydrologic Regime

The basic river parameters required for the subsequent calculation of the dissolved oxygen sag curve may be derived from the following relations.

a) Cross sectional area of the River at each station
b) Stage-to-discharge relationships
c) Change in flow between stations
d) Flow time between stations
e) Return period of critical minimum flow

4(a) Cross Sectional Area

The cross sectional area at each station was determined by the use of three pieces of surveying equipment;

a transit and stadia rod to measure distance, a portable Raytheon Fathometer to measure depth, and a boat for transportation.

The Fathometer was checked against a sounding lead at one of the stations and gave readings that agreed with the lead weight sounding to ± 0.1 feet per each ten feet of depth. This instrument was then used to obtain all other cross sections.

The Fathometer operates on a twelve-volt car battery and is equipped with a 'marker' switch to manually identify any sounding on the continuous graph which the instrument produces. The plot points for each cross section were determined as follows.

A stadia rod was mounted in the boat with the zero mark at water surface elevation. The recording Fathometer was set up so that the 'transceiver' was just submerged in the water. A transit was set up beside the shore marker closest to the water, and the height of instrument determined using the bottom of the marker as datum elevation. The boat operator navigated the boat from the west shore to the east shore of the River keeping the course of the boat in line with the two station markers. This ensured that the cross section was taken perpendicular to the River channel. The transit operator signaled the fathometer operator at each fifty foot change in stadia distance. At each signal the fathometer operator identified the location of the sounding with the marker switch. As the boat approached the transit the last stadia distance was noted and the water surface elevation with respect to the marker datum elevation was determined. The distance from the marker to the near shore and far shore was measured by stadia. This completed all the physical measurements of the River width, depth, distances from shore, and water surface elevations that were needed to plot the cross section at each station. The continuous graph indicated the changes in the River bottom elevations, their locations were plotted to the scale established by the confining fifty foot stadia intervals. The cross sections were plotted on 18" x 24" sheets and the area determined from polar planimeter readings.(22)

4(b) Stage-to-Discharge Relationships

The purpose of establishing river stage-to-discharge relationships for each station was to be able to calculate the cross sectional area of the River under different flow conditions. Gannon and Downs (9) realized the difficulty in gauging each and every station and have solved the problem by making the following assumption. "Since river cross section work may extend over several days, with the possibility of varying runoff during the period, it frequently is necessary to adjust river stage to a common runoff regime. Here a rating curve is necessary, and ideally should be available for every cross section. Unfortunately this is rarely the case in most instances and reliance must be placed on some nearby gauge assuming characteristics at the gauge are representative of the river stretch in question."

Originally, an attempt was made to establish the datum elevation of each station marker, and from the information obtained while surveying the cross sections of the River, the water surface elevation at each station could be calculated. In the Chambly to St. Charles stretch of the River, two facts precluded the continuance of this effort. First, that at any given flow between two and four thousand cubic feet per second, the change in water surface elevation between stations was less than 0.10 feet. Secondly, there was no surveying method by which the contour of the river bottom could be held to this accuracy. A Price current meter was used to determine the River flow velocities at four locations between Chambly and St. Charles to assess whether there were any changes in velocity thus indicating a change in River bed configuration. All metered stations revealed an average velocity between 0.50 and 0.60 ft./sec. The cross sections that were determined previously were checked for changes in cross sectional area. Corrected cross sectional areas for any given flow between Chambly and St. Charles, agreed to ± 5 percent.(22) From the above considerations, the River flow and channel characteristics were assumed to be uniform and according to Gannon and Downs (9) this assumption was justified. From the government gauging station data (22) at Chambly and St. Ours, 28.7 miles downstream, stage-to-discharge curves were plotted. (Figure 1). The water surface elevations for these gauging stations were corrected to Geodetic survey of Canada bench marks. Under normal summer flow conditions, the slope of the River surface between Chambly and St. Ours, a distance of 28.7 miles is 0.60 feet. A graph of water surface slope-to-discharge (Figure 2) was constructed. The slope of the River surface under normal summer flow conditions varied from 3.75 to 6.00 x 10^{-6} feet per foot. This was beyond the accuracy of normal surveying technique and the change in water surface elevation at the survey stations, for a given flow, was calculated as being proportional to the distance from the gauge. The stage-to-discharge relationships for each station between Chambly and St. Charles were thus established. From Chambly upstream to St. Jean there was one permanent gauging station at Fryers Island, the stage-to-discharge relationship (Figure 3) was determined. Between Chambly and St. Jean the survey station cross sections were adjusted for each sample date by noting the rise or fall in water surface elevation from a fixed datum point established on the day the cross section was taken. The River flow for the corresponding sample date was obtained from the continuous recorder at Fryers Island. From these two items of information,

FIGURE 1

STAGE TO DISCHARGE - STAFF GAUGE AT : ST OURS
ST CHARLES
BELOEIL
CHAMBLY

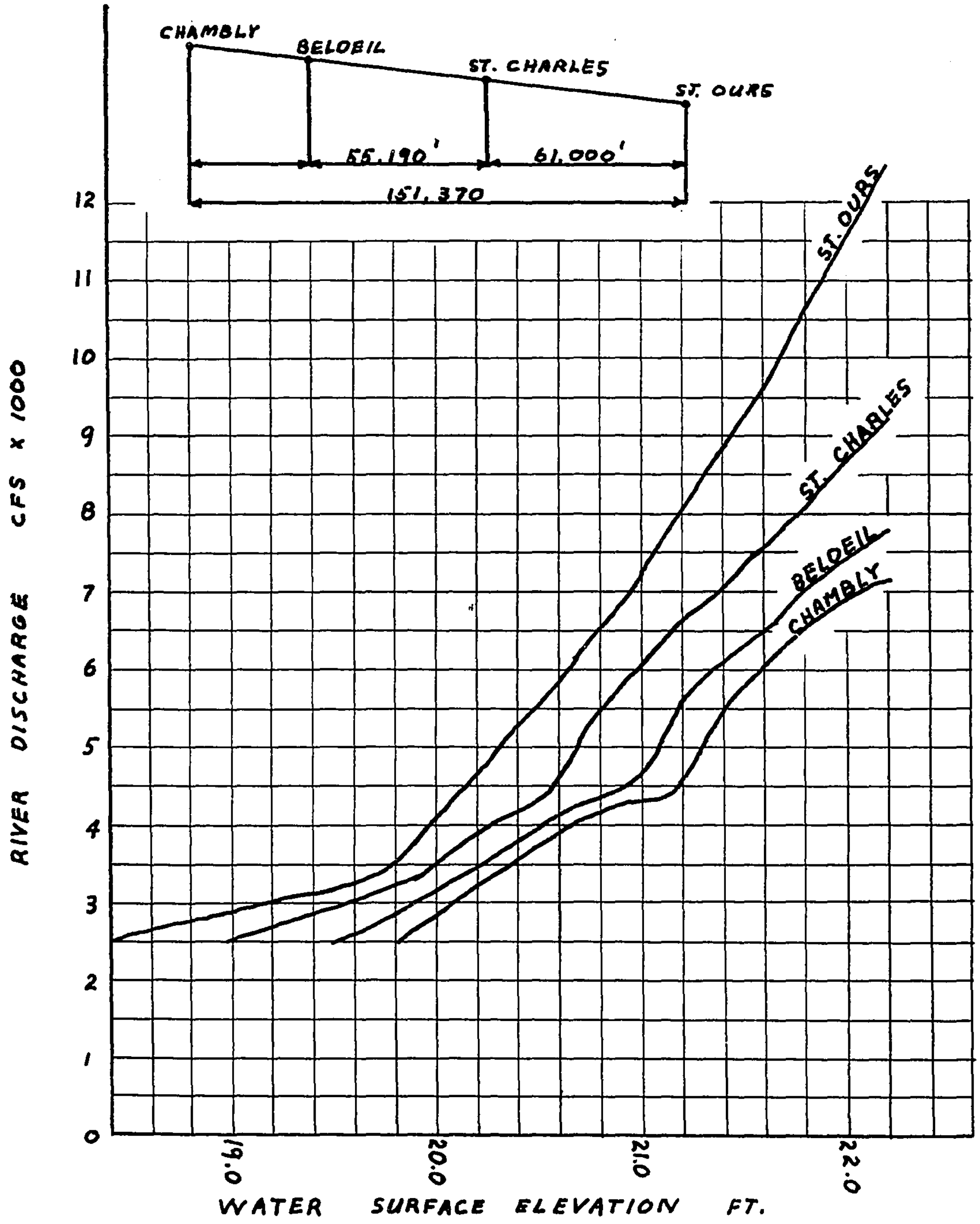


FIGURE 2

SLOPE TO DISCHARGE
CHAMBLY TO ST CHARLES

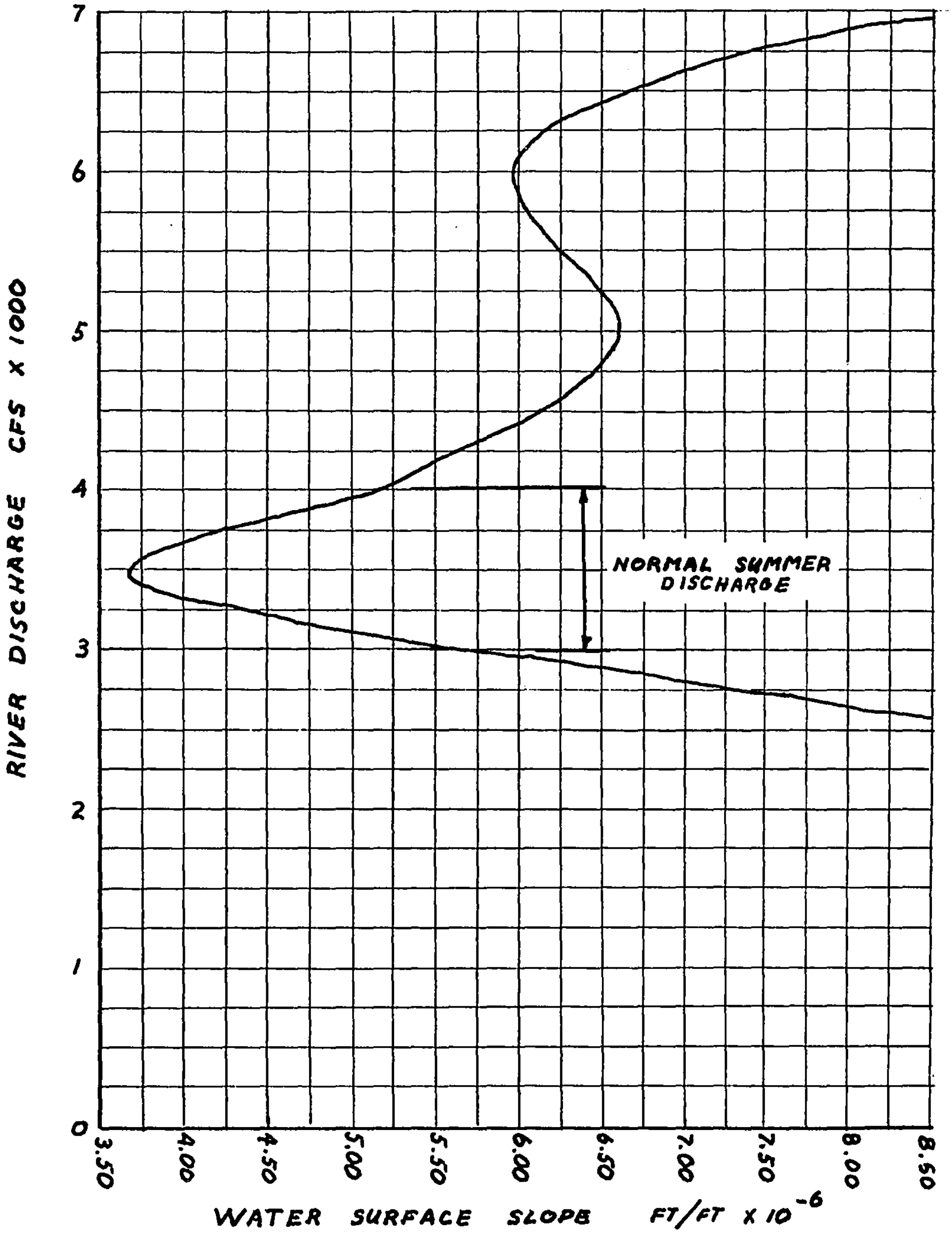
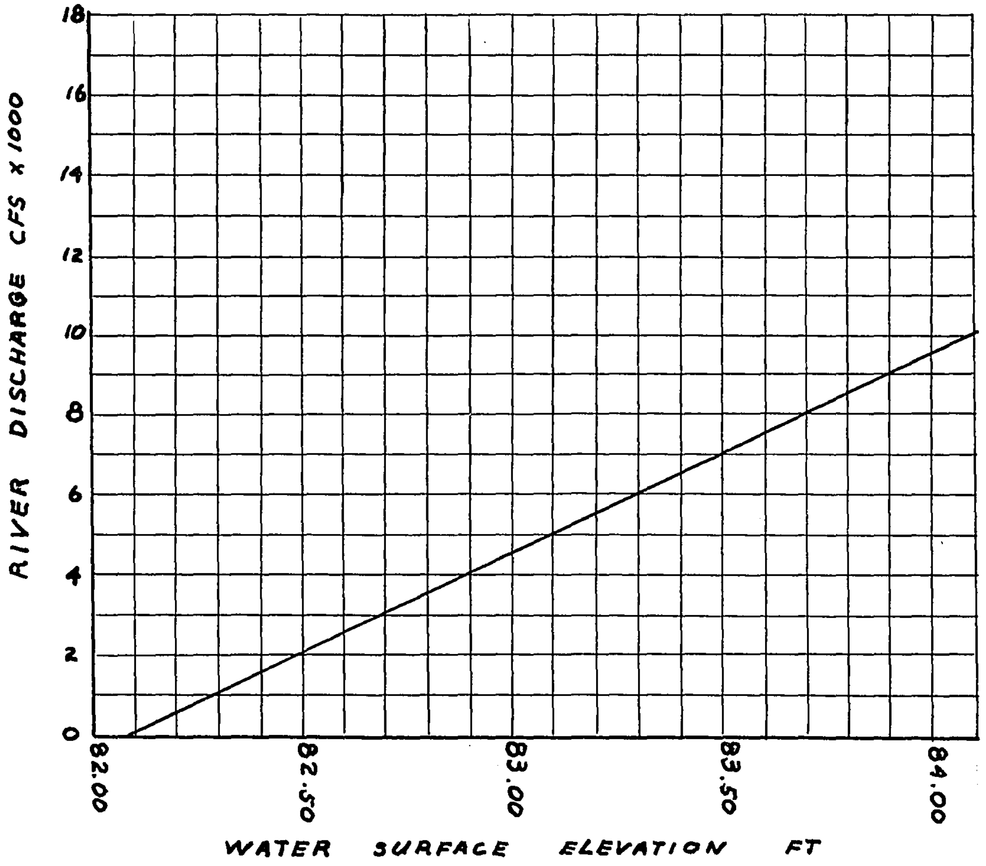


FIGURE 3

STAGE TO DISCHARGE - STAFF GAUGE AT FRYERS ISLAND DAM



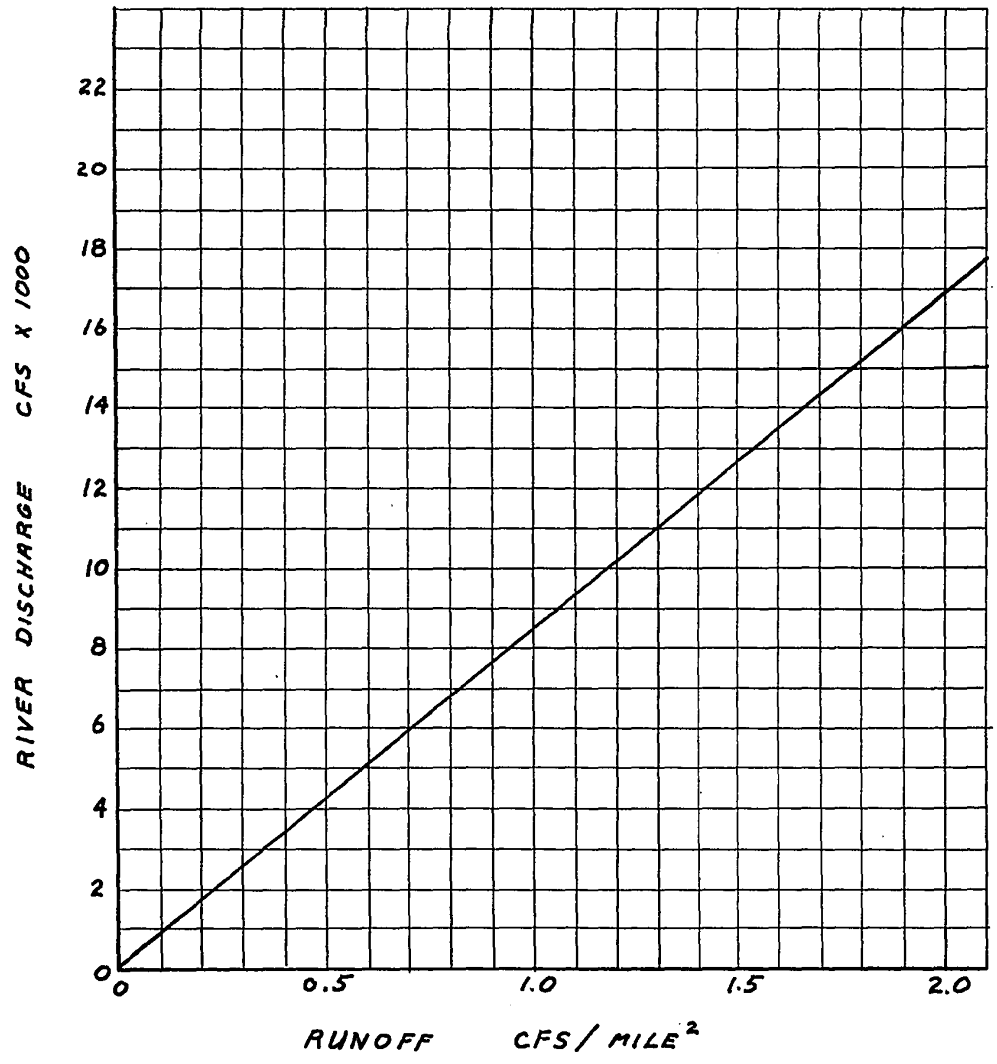
the stage-to-discharge relationships were calculated for survey stations between Chambly and St. Jean. (22).

4(c) Change in Flow Between Stations

The stretch surveyed in the Richelieu River was 32.7 miles. In this length of River, tributaries, drainage and surface runoff account for measureable flow changes between stations. The contributing drainage basin at each station was determined from a topographic map. The areas were measured by a polar planimeter and converted to square miles as the scale of the map indicated. This map is included in Appendix D. The Water Resources Branch (22) supplied a table of runoff coefficients at different flow quantities and a graph of runoff, in cubic feet per second per square mile, versus River discharge in cubic feet per second was plotted as shown in Figure 4. The contributing flow at each station was then calculated and the cumulative flow at each successive downstream station for various conditions of River discharge calculated. At Fryers Island a continuous recording of flow was taken and this was used as the reference point for all River flow calculations. The increment of flow was subtracted from upstream stations and added to downstream stations. The method of calculating the change in flow between stations from drainage basin area and runoff coefficients was found to be satisfactory. The calculated increase in flow for the River stretch was 6¼%

FIGURE 4

PLOT OF DISCHARGE VERSUS RUNOFF



while the actual metered flow increase for the River stretch was 6%. (22).

4(d) Flow Time Between Stations

From the River channel characteristics, as determined by cross sectional areas for various conditions of flow, the flow time between stations was calculated. The average cross sectional area of two consecutive stations multiplied by the distance between stations was considered to be the volume of water between those two stations. The volume divided by the flow gave the time of flow between stations. The volume of Chambly Basin was calculated from a plot of depth contours and the detention time determined for various conditions of flow. A graph of flow versus detention time is given in (Figure 5).

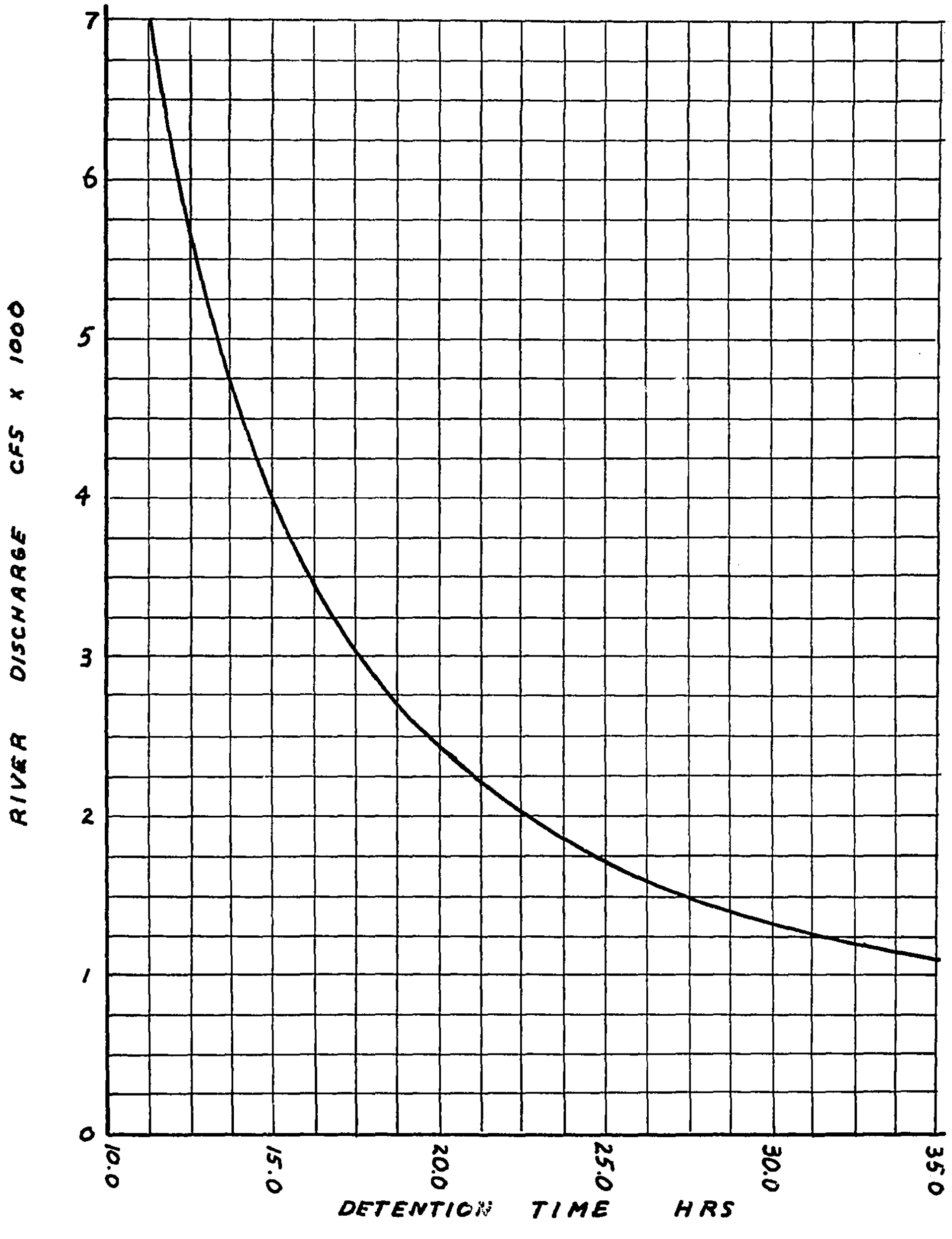
The flow time from St. Jean to St. Charles for any River discharge was then determined by summing the appropriate times between stations and the detention time in Chambly Basin. A plot of cumulative flow time versus distance downstream for various conditions of flow is given in (Figure 6).

4(e) Return Period of the Critical Minimum Flow

R.W. Purdy (16) has evaluated the critical minimum return flow of rivers as follows. "We make a detailed study of existing runoff records to determine the probability of drought flows in accordance with Professor E.J. Gumbel's

FIGURE 5

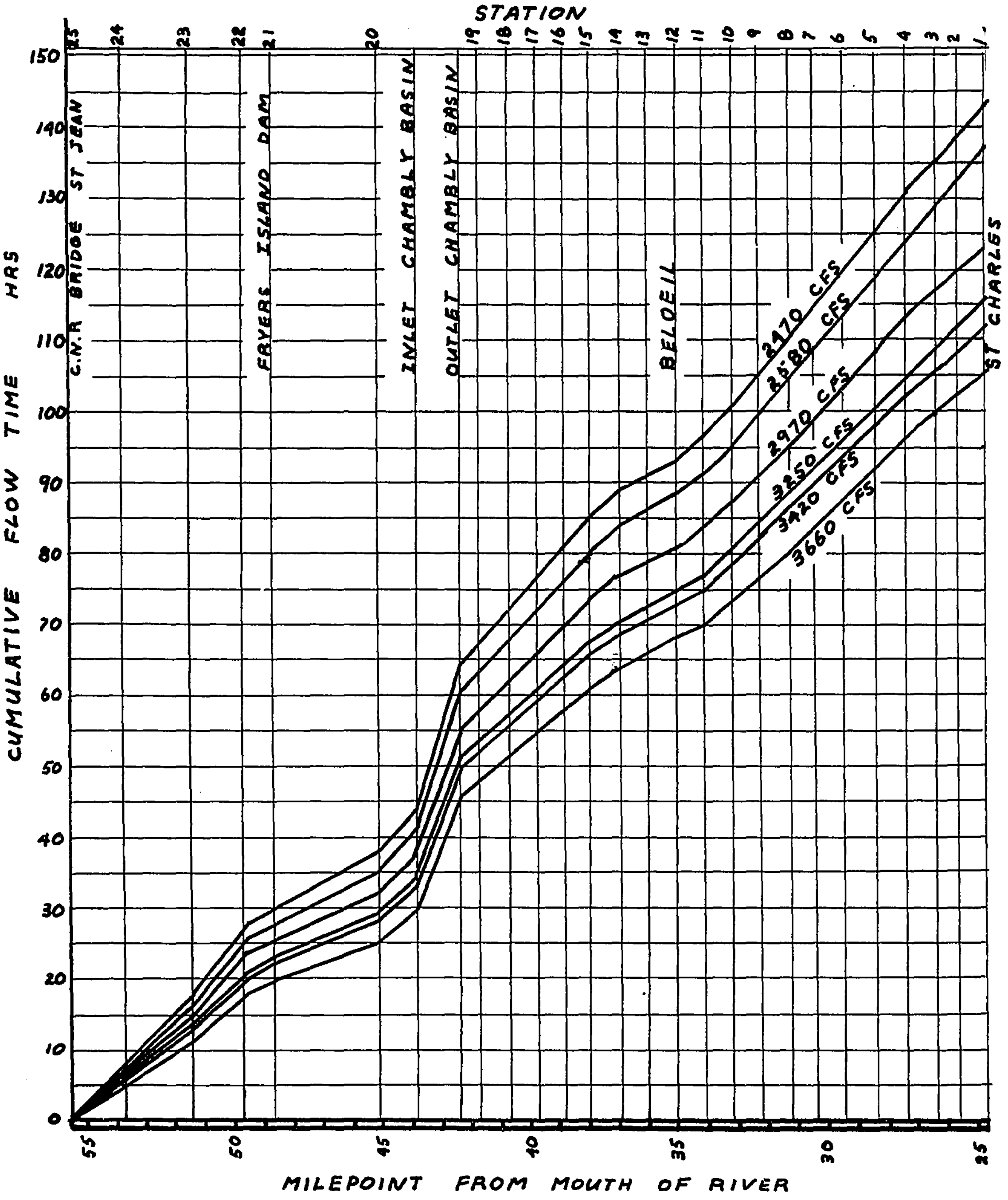
DETENTION TIME OF CHAMBLY BASIN



10x

FIGURE 6

TIME OF PASSAGE OF FLOW



statistical basis for analysing the distribution of extreme values applicable to droughts. From this we can obtain the expected drought severity for any frequency of occurrences, within the limits of the data available."

The Water Resources Branch had thirty-six years runoff records for the Richelieu River. Since the critical condition of biochemical activity in the River occurred during the low flow periods during the summer months, these data were analysed for the lowest one month, two month, and three month duration between July and October. The occurrences of these durations were plotted on extreme value paper, as proposed by E.J. Gumbel. The graphs are given in (Figures 7, 8, 9). From these graphs the expected return period for five, ten, and twenty years of the drought for one, two, or three month duration was determined. A graph of drought flow versus the drought duration was then constructed for the three return periods of five, ten and twenty years. (Figure 10). The critical minimum flow for one month duration was determined as:

2400 cfs	once in 20 years
3000 cfs	once in 10 years
3500 cfs	once in 5 years

FIGURE 7

RETURN PERIOD OF CRITICAL ONE MONTH DROUGHT JULY TO OCTOBER

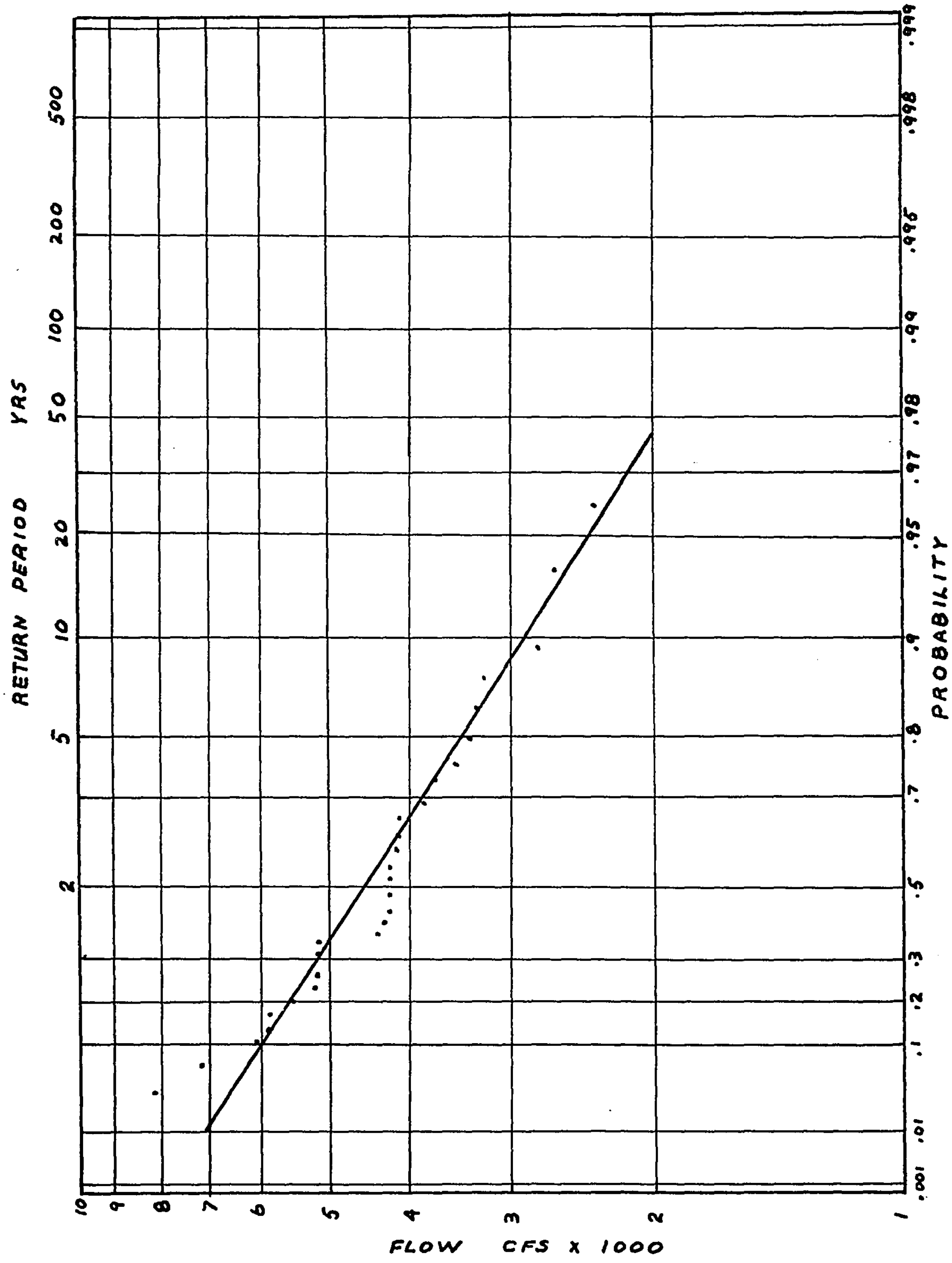


FIGURE 8

RETURN PERIOD OF CRITICAL TWO MONTH DROUGHT JULY TO OCTOBER

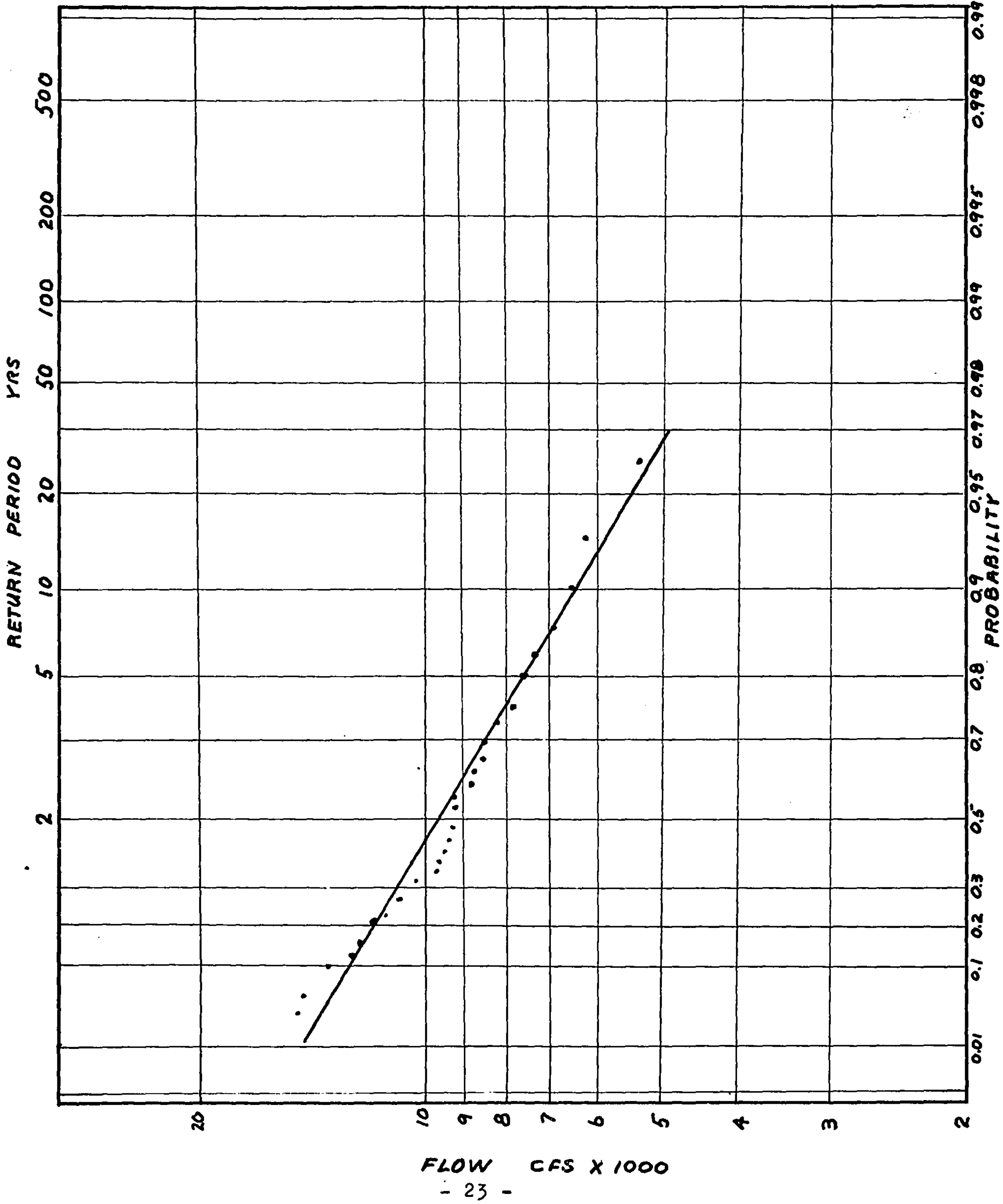


FIGURE 9

RETURN PERIOD OF CRITICAL THREE MONTH DROUGHT JULY TO OCTOBER

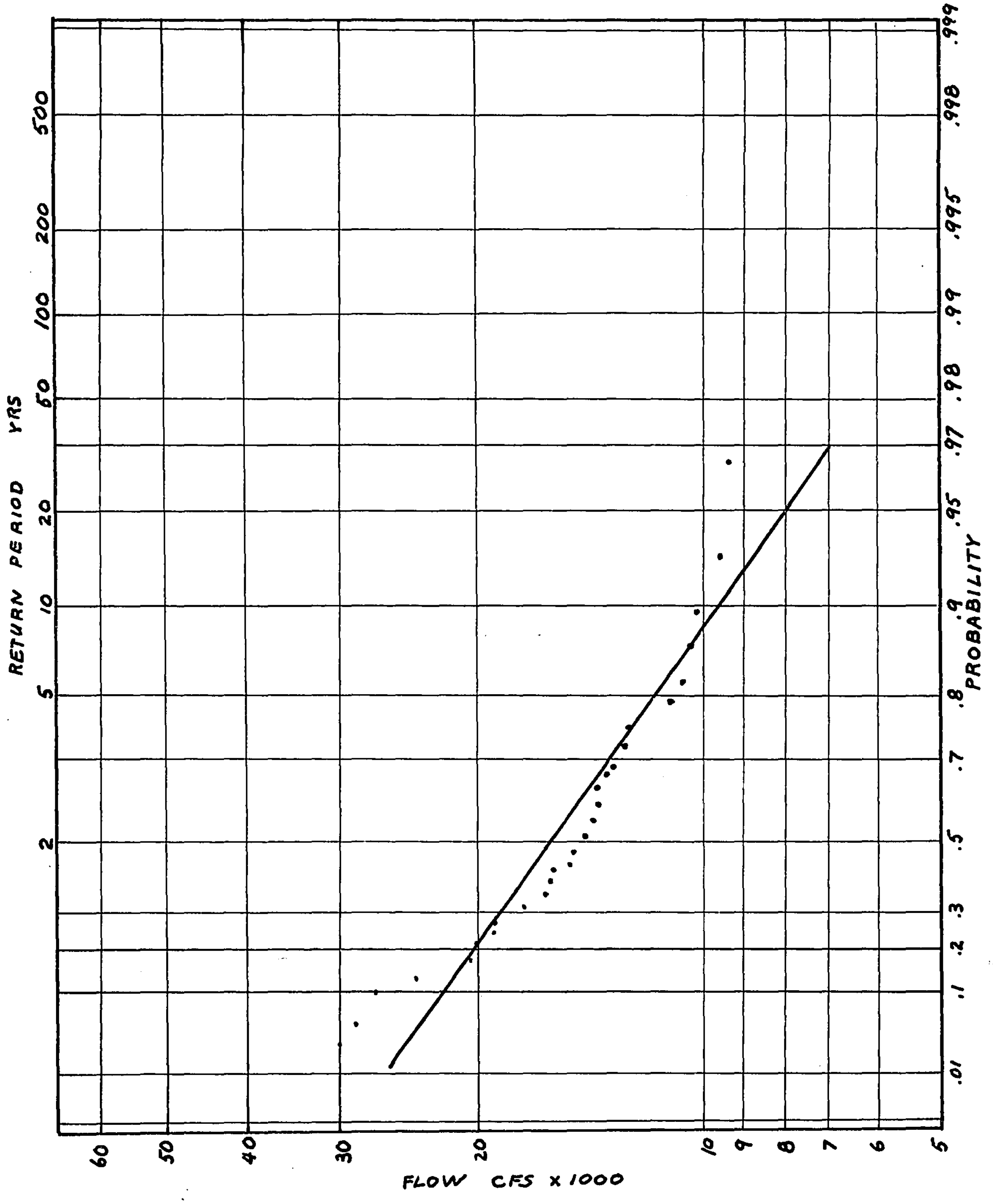
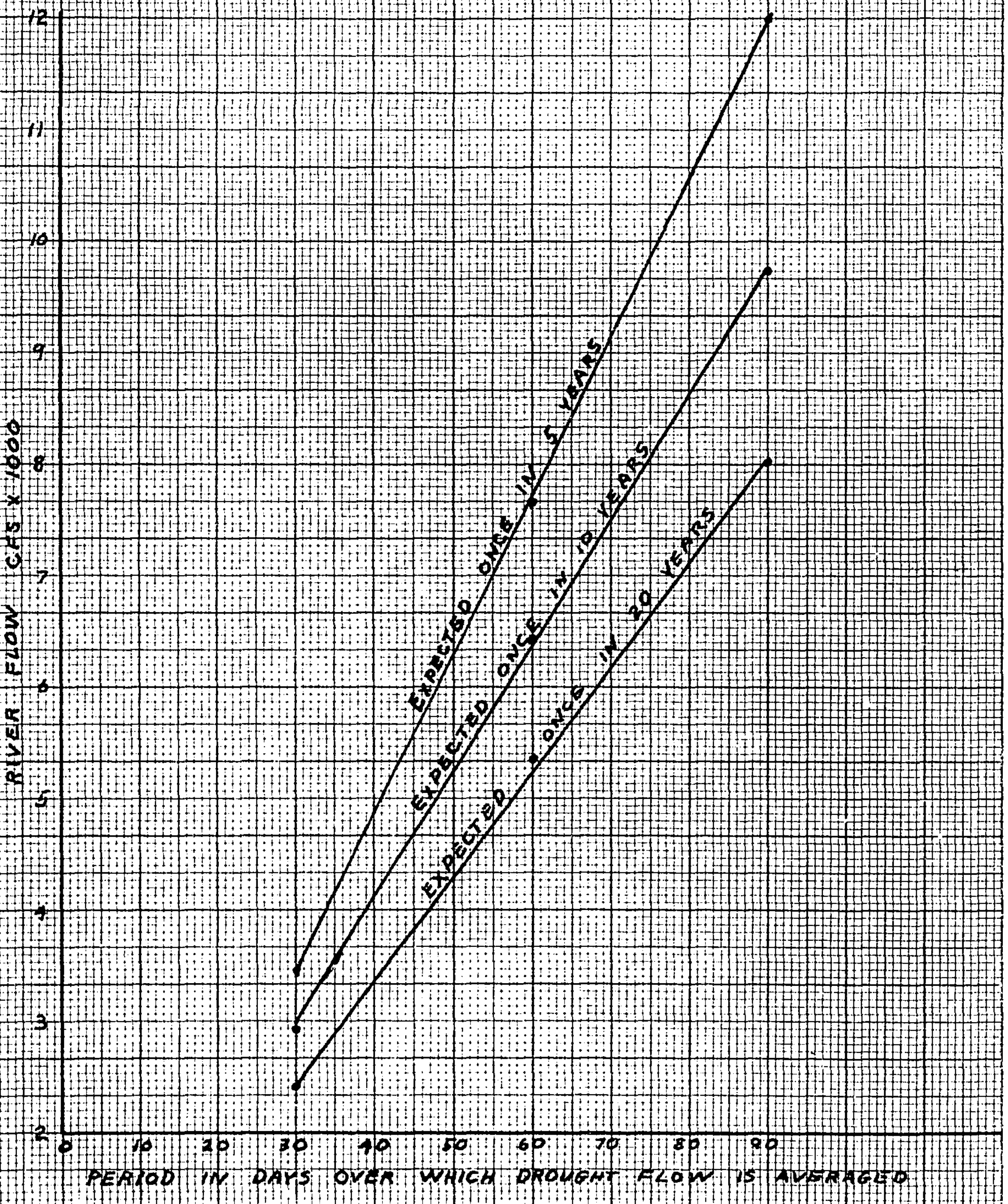


FIGURE 10

RETURN PERIOD AND DROUGHT DURATION



5. Establishing the Procedure of Sample Collection

The sampling procedure in the Richelieu River study was designed to make the maximum use of the information gathered in the preliminary survey. The preliminary dissolved oxygen readings indicated two sag areas and two recovery zones in the River stretch from St. Jean to St. Charles. Since the location of maximum and minimum dissolved oxygen concentrations was of particular interest in calculating the oxygen sag curve of the River, stations at these points were sampled more intensively under various conditions of flow than were the remainder of the stations. There were six stations which required intensive sampling.

TABLE 2

Location	Reason for sampling	Station No.	Total No. of samples taken
C.N.R. bridge above St. Jean	First upstream station	25	44
Fryers Island	Beginning of first recovery zone below St. Jean	21	48
Richelieu-Chambly bridge above Chambly Basin	High dissolved oxygen concentration	20	42

TABLE 2 (continued)

Location	Reason for sampling	Station No.	Total No. of samples taken
Outlet of Chambly Basin	To study the effect of Chambly Basin on Reaeration	19	48
Beloeil	Low dissolved oxygen concentration; just below C.I.L.	12	96
St. Charles	Last downstream station	1	52

Eight samples were taken from each of the remaining 19 stations as check values for the subsequent calculation of the dissolved oxygen sag curve.

The configuration of the cross sectional areas of the River revealed both deep and shallow zones within the same cross section. To properly determine the effect on the dissolved oxygen concentrations of this irregular configuration, samples were taken at specific locations within each zone. On each sample date, samples were taken from these locations in the cross section.

From the analysis of the return period of critical minimum flow three River discharge values were of particular interest; 3500, 3000, and 2400 cubic feet per second. Rather than calculate what the dissolved oxygen level would be at these discharge values, it was decided to wait for low flow conditions and measure the dissolved oxygen directly. By keeping a close surveillance on the River water level, some sampling dates were closely representative of the critical flow conditions.

TABLE 3

Sample Date 1965	Flow on Sample Date cfs	Calculated Critical Minimum flows cfs
August 24	3420	3500
July 12	3660	
July 26	2930	
August 12	2970	3000
July 21	3250	
August 4	2470	2400
August 6	2580	

The purpose of planning the sampling phase of the River study were as follows.

1) Reduce to a minimum the factors which might cause variations in dissolved oxygen and biochemical oxygen demand measurements.

2) Achieve a sampling program that was representative

of the River conditions.

3) Obtain enough samples for statistically reliable results but maintain an economy in the expenditure of time and money in the collection of these samples.

CHAPTER III

OXYGEN BALANCE

The process of biodegradation of organic wastes discharged into a stream has been defined by the two basic laws.

The biochemical oxygen demand B.O.D. law has been mathematically formulated by the well-known monomolecular reaction

$$-\frac{\partial L}{\partial t} = K_1 L$$

The above equation states that the time rate of biochemical oxidation of an organic substance is proportional to the concentration of unoxidized substance, or

$$L_t = L_o \cdot e^{-K_1 t}$$

Expressing the B.O.D. law in terms of dissolved oxygen (D.O.) saturation deficiency D,

$$\frac{\partial D}{\partial t} = K_1 (L_a - Y)$$

where L_a = concentration of organic substance at the time $t=o$,

Y = concentration of organic matter oxidized in time = t

K_1 = time rate constant

The second basic law governing the D.O. relations in a stream has been defined as follows,

$$-\frac{\partial D}{\partial t} = K_2 D \qquad D_t = D_o e^{-K_2 t}$$

These equations state that the time rate of decrease of D.O. saturation deficit in absence of B.O.D. is proportional to the saturation deficit.

The net time rate of change in D.O. saturation deficit in a stream has been formulated as the sum of the above basic processes

$$\frac{\partial D}{\partial t} = K_1 (L_a - Y) - K_2 D \ ,$$

and

$$D_t = \frac{K_1 L_a}{K_2 - K_1} \left(e^{-K_1 t} - e^{-K_2 t} \right) + D_a \, e^{-K_2 t} \qquad (3\text{-}1)$$

where D_a = D.O. saturation deficit at time $t=o$

D_t = D.O. saturation deficit at time t

L_a = concentration of organic matter at time $t=o$

K_1 and K_2 = time rate constants

This formulation defines D.O. saturation deficit at any time t downstream from the waste discharge point, and is the D.O. sag curve equation.

The critical values of D_t and flow time t are reached at the sag point of the curve, where;

$$D_c = L_a \frac{K_1}{K_2} \, e^{-K_1 t_c}$$

and

$$t_c = \frac{1}{K_2 - K_1} \ln \left\{ \frac{K_2}{K_1} \left[1 - \frac{(K_2 - K_1) D_a}{K_1 L_a} \right] \right\} \qquad (3\text{-}2)$$

The equations (3-1) and (3-2) are called the Streeter-Phelps formulations (18). This equation also indicates that

a) when L_a approaches infinity, t_c approaches its maximum value of t_m

b) t_c approaches the maximum value of t_n irrespective of D_a when L_a approaches infinity, and

c) t_c reaches the maximum value t_n when $D_a = o$.

$$t_m = \frac{\ln K_2 - \ln K_1}{K_2 - K_1} \qquad L_a \rightarrow \infty$$

The well-known equations outlined on the previous pages may be applied to the D.O. balance calculation of a stream. While the concentration of organic substance and the D.O. deficiency at any section of the river may be easily determined, the time rate constants K_1 and K_2 may cause certain difficulties in assessing the degree of pollution.

Constant of Biochemical Oxidation

The time rate constant of biochemical oxidation can be readily determined by incubating a river water sample at 20°C. for a time of 10 or more days. The daily measurements of D.O. remaining in the B.O.D. bottle would provide the necessary data for K_1 calculation.

Actually, such incubation represents static conditions of the oxidation process, where all environmental factors are rigidly controlled. The river environment is dynamic, and a very considerable difference in the actual and laboratory-derived constants K_1 have been repeatedly observed. This difference in observations has lead to the introduction of a biochemical time rate of oxidation constant of the river, where

$$K_{\text{river}} \leq K_{\text{laboratory}}$$

According to Eckenfelder (7) the observed differences between the two constants may be due to changes in oxidation caused by the following factors.

a) Turbulence in the river, providing a much greater contact opportunity between the microorganisms and organic substance,

b) Biological growth in the river in the form of plankton, algae, and bacterial growth on stones and rocky river bottom,

c) Nutrients - the change in nutrient content due to turbulence and nutrient surplus or deficiency may greatly influence the oxidation rate,

d) Lag of oxidation due to absence or small number of bacteria present, and

e) Immediate oxygen demand and the distribution of the compounds with such a demand.

The observed difference between the two constants may be due also to the changes in the removal rate of organics due to

a) Sedimentation and flocculation, resulting in formation of sludge banks,

b) Scour or resuspension of organic sludge deposits by changes in atmospheric pressure and river stage, and

c) Volatilization of deposited organics, with endproducts of CO_2 and CH_4, not requiring oxidation.

Thus, the river water sample analysis and the analysis of the waste waters discharged into the river do not provide complete data for the evaluation of dynamic relations actually existing in the stream. Accordingly, Liebman and Loucks (12) have proposed to modify the D.O. sag curve introducing the following assumptions.

1) The removal of organic substances L with a definite B.O.D. by adsorption and sedimentation is proportional to the amount of the substance present, or the removal is formulated by $K_3 x L$,

2) The rate of addition of B.O.D. from benthal sludge layer, and the overland runoff is constant for a given stream flow, P=const.

3) The rates of removal of oxygen by benthal demand and plant respiration, and the rates of addition of oxygen by photosynthesis processes of algae are constant for a given stream flow, A=const.

The previous basic equations can now be rewritten as follows

$$\frac{\partial D}{\partial t} = K_r L - K_2 D - A$$

and

$$\frac{\partial L}{\partial t} = -(K_1 + K_3) L + P$$

where K_3 = sedimentation-adsorption rate constant

A = either oxygen production or reduction, mg/L/day.

P = B.O.D. addition rate due to runoff and scour, mg/L/day.

The modified D.O. sag curve expression can be given as follows.

$$D_t = \frac{K_r}{K_2 - (K_r + K_3)} \left(L_a - \frac{P}{K_r + K_3} \right) \left(e^{-(K_r + K_3)t} - e^{-K_2 t} \right) + \frac{K_1}{K_2} \left(\frac{P}{K_r + K_3} - \frac{A}{K_r} \right) \left(1 - e^{-K_2 t} \right) + D_a e^{-K_2 t}$$

It should be noted that due to experimental difficulties the rate factor K_3 has been determined in a very few cases only, and using approximations to relate the static and dynamic conditions. The same considerations apply also to the factors A and P.

In an actual river survey, the river time rate factor can be calculated when the amounts of oxidatizable substances are measured at two survey stations. When these amounts are L_a = upstream station, and L_b = downstream station, and the flow time between the stations is t

$$K_r = \frac{1}{t} \ln \frac{L_A}{L_B} \ / \ day$$

Reaeration Constant K_2

The theoretical derivations of the reaeration coefficient K_2 are based on Henry's Law concerning solubility of gases, and Fick's Law of hydrodiffusion.

Introducing the two-film concept,

$$\frac{\partial m}{\partial t} = -K_L' \, A D$$

The above expression states that the time rate of mass transfer by diffusion is directly proportional to the liquid film coefficient K_L^1, the area A through which the diffusion takes place, and the saturation deficit D in the film.

In the terms of oxygen transfer

$$\frac{\partial D}{\partial t} = K_L D$$

where K_L = time rate of oxygen transfer, and

D = D.O. saturation deficiency

The previous equation is directly applicable to the conditions of an absolutely quiescent body of surface waters. It necessarily follows that the effects of turbulence and mixing of the saturated surface film must be considered.

A mathematical relation of such mixing and turbulence was first formulated by Phelps (15) and later put into a graphical form by Velz (20) (21). The corresponding reaeration equation is given below.

$$D = 100 - \left[\left(1 - \frac{D_a}{100}\right) \times 81.06 \left(e^{-k} + \frac{e^{-9k}}{9} + \frac{e^{-25k}}{25} + \cdots \right) \right]$$

where D = final D.O. content as % of saturation per mix,

D_a = initial average D.O. content as % of saturation,

$$k = \frac{\pi^2 a t}{4 L^2}$$

where t = time of exposure, hours,

L = depth of water in centimeters

a = diffusion coefficient determined experimentally, and a function of water temperature.

In 1958, O'Connor and Dobbins (14) formulated the rate of surface renewal, r, as follows

$$r = \frac{\bar{v}}{l}$$

where $\bar{v}$ = velocity gradient
U = average stream flow velocity, and
l = mixing length
H = average depth of stream, feet,
S = average slope of river channel, ft./ft.

$$U = B \sqrt{H \cdot S}$$

and when the Chesy coefficient B is larger than 17, isotropic flow conditions exist, while for B less than 17, non-isotropic, turbulent flow governs. Accordingly, for isotropic turbulence of a stream with no shear stresses and negligible velocity gradient

$$K_2 = \frac{480\ D_L^{0.5}\ S^{0.25}}{H^{1.25}}$$

and for non-isotropic, turbulent flow conditions,

When the necessary data is collected in a river survey, a direct reaeration coefficient K_2 calculation can be made.

Assume that observations have been made at:

Stations	A	B
B.O.D. of oxidizable organics	L_a	L_b
Average	$L = \frac{L_A + L_B}{2}$	
D.O. deficit, % of saturation	D_a	D_b
Average	$D = \frac{D_A + D_B}{2}$	
Difference of saturation deficit,	$\Delta D = D_A - D_B$	

Using a Streeter-Phelps formulation, $K_2 = k_r \frac{L}{D} - \frac{\Delta D}{2.3\,\Delta t D}$

Calculations of D.O. Sag.

When a river pollution survey is conducted, the planning of sampling program depends on the method chosen for further data processing. The length of a river surveyed and the number of survey stations established may produce a very large amount of data, requiring tedious and time-consuming calculations so that computers are frequently resorted to in order to facilitate the required calculations. In this connection, it should be noted that computer programs must be written and while a number of programs already exist, they are not readily available for all the methods promulgated for sag calculations.

The basic methods successfully applied may be discussed as follows:

a) Streeter-Phelps method

This method is the oldest of sag curve formulations available, and it has been described on the previous pages. It is used by several Water Resources Commissions for evaluating the existing and permissible degrees of pollution, and Purdy (16) describes the application of Streeter-Phelps formulation by the Water Resources Commission of Michigan.

The time rate constants K_r and K_2 are calculated for each river stretch between two stations, and employed to estimate the D.O. deficit levels at any flow and loading conditions, present and future. The use of the sag curve equation is connected with trial-and-error calculations, and repeated corrections, so that computers are usually employed.

b) Fair's formulation

Fair (8) in his derivations introduced a rate of self-purification f, where $f = \frac{k_2}{k_r}$

The pollutional load L_a is formulated by the biochemical oxidation rate constant K_r, self-purification constant f, the critical D.O. saturation deficit D_c, and the initial D.O. saturation deficit D_a.

A set of generalized f values is provided, and using the nomograph constructed the allowable loading of a stream may be easily derived. Similarly, the critical deficit and critical flow time for any pollutional load may be assessed by the use of this nomograph.

This method may be considered as very helpful in preliminary assessment of pollution with a minimum of fieldwork required.

c) Thomas method

Thomas (19) recognized that the use of Streeter-Phelps formulation for practical applications requires tedious trial-and-error procedures. He developed a simplification of the above formulation, and devised a nomograph for a direct derivation of the deficit D at any downstream distance.

From the field survey data obtained at the stations, the value of K_r, K_2, L_a and D_a must be calculated, as indicated in previous discussions, using the Streeter-Phelps formulation. Deriving the values D_a/L_a, K_2/K_r, and K_2t the nomograph is entered and D/L_a read, so that deficit D can be immediately calculated. Nemerow (13) states that the Thomas nomograph has provided convenient, accurate, and time-saving method in many practical applications. The Thomas nomograph is shown in (Figure 11).

d) Churchill method

Churchill (5) made a detailed analysis of the Streeter-Phelps formulation and found that the D.O. sag occurring in a stream depends primarily on the following 3 factors: B.O.D., river water temperature, and river flow.

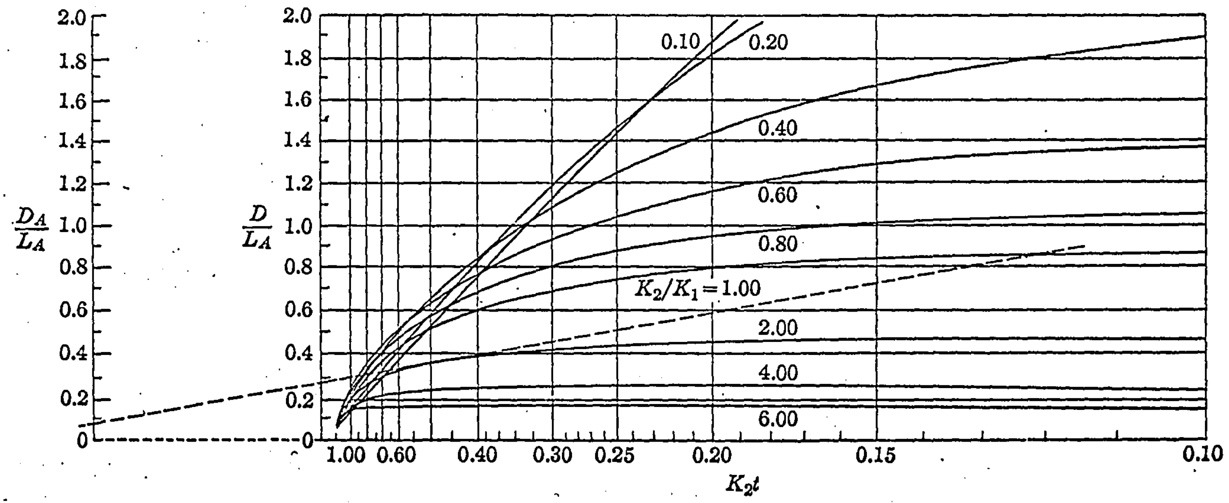
The application of the least square method (6) led to the formulation of line of regression, and the D.O. sag could be predicted for any B.O.D. load applied.

Using this formulation, there is no need to calculate the flow time t between stations, and the calculation of the time rate constants has been eliminated as well.

Further investigations by Simmons (17) showed that a good correlation of the above variables will be obtained if the stream samples are collected when one of the variables has reached a minimum or maximum condition. Thus, samples can be conveniently obtained at low stream discharges, or at high water temperatures.

FIGURE 11

THE THOMAS NOMOGRAPH



Another advantage of this purely statistical approach to the sag curve equation is the relatively limited number of samples to be obtained.

Field surveys were conducted by Simmons (17) to evaluate the number of observations required to obtain accurate results. The data are given in Table No. 4 below.

TABLE 4

OBSERVED AND CALCULATED D.O. DROP

Observed D.O. Drop mg/l	Deviations Three Samples	Observed Four Samples	Calculated Five Samples
2.3	0.73	0.36	0.52
3.7	-0.32	-0.42	-0.26
5.2	-0.39	0.24	-0.10
1.1	10.93	-0.13	0.45
1.8	7.42	1.17	-0.60

Comparative results were obtained using 6 or 24 observations, and 58% of the time the deviations were less using 6 than using 24 observations.

Simmons concluded that in order to obtain practical and dependable results, only a maximum of 6 samples were required. Additional samples may add some small degree of refinement to the results, but the refinement probably would not offset the effort expended in the planning, collecting, and analysing the samples and calculating the results.

The basic data required for an application of Churchill's method are as follows.

Y = D.O. drop between survey stations, mg/l.

X_1 = B.O.D. at sag point, or the station with a higher B.O.D., mg/l,

X_2 = river water temperature at the sag station, Centigrade, and

X_3 = flow in cfs at the sag point station, or the station with a higher B.O.D.

The correlation equations are based on the principle of least squares, and are formulated as follows.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3$$

$$b_1 \Sigma X_1^2 + b_2 \Sigma X_1X_2 + b_3 \Sigma X_1X_3 = \Sigma X_1Y$$

$$b_1 \Sigma X_1X_2 + b_2 \Sigma X_2^2 + b_3 \Sigma X_2X_3 = \Sigma X_2Y$$

$$b_1 \Sigma X_1X_3 + b_2 \Sigma X_2X_3 + b_3 \Sigma X_3^2 = \Sigma X_3Y$$

Using the observed Y, X_1, X_2, and X_3 values, the correlation coefficients a, b_1, b_2, and b_3 for each river stretch can be calculated.

Slight modification of these multi-linear correlation equations can be used for calculating the B.O.D. load produced at the sag point in relation to a new stream loading or waste discharges at any upstream point.

Nemerow (13) used this method and states that the method predicts with an acceptable degree of accuracy the occurrence and values of D.O. the sag point.

CHAPTER IV

ANALYSIS OF SAMPLES

The samples of River water were collected at grid points for various conditions of River flow, and more than five hundred samples were taken in all. There were three basic methods available to determine the dissolved oxygen, D.O. at each grid point.

1. Portable galvanic cell oxygen analyser
2. Portable Jarrel-Ash oxygen analyser
3. Titration by Winkler method (2)

In the preliminary D.O. tests mentioned in Chapter II, the drop in D.O. content between stations was in the order of 0.2 mg/l or less, except at two specific locations, namely, Beloeil and St. Jean. The necessity of repetitive sampling was recognized as well as the controlled analysis of these samples if statistically dependable results were to be obtained. The D.O. present in the River could be determined in the field as in the preliminary survey, but the five-day B.O.D. could only be determined in the laboratory. From the results of the preliminary survey, a total flow time from St. Jean to St. Charles was determined to be about six days, depending on the River discharge. The change in D.O. content for the same River stretch was determined to be about 10% during the six-day flow time. A change from 85% to 75% D.O. saturation at the usual temperatures was less than 1 mg/l. The five-day B.O.D. values were inherently small for the Richelieu River, and an accurate method of analysis had to be adopted.

At each grid point two identical samples were taken, using an air-tight container with two 300 ml B.O.D. bottles. The sampler was equipped with a remote control air release device which would admit River water into the bottle only when the required depth had been reached. The sampler is shown in (Figure 12). This insured that two identical samples were taken from the chosen grid point. These samples were then kept side by side during transportation to the laboratory. One was immediately analysed for D.O., and the other incubated for five days at 20°C., in order to determine B.O.D.$_5$. In the Appendix **A** the bottle numbers are given as sampled from their respective grid points in each cross section. The top number refers to the sample analysed immediately for D.O., and the bottom number refers to the sample analysed for D.O. five days later.

It was also recognized that the bottle immediately analysed for D.O. does not reflect the actual condition due to transportation time from the River to the laboratory and due to exposure to possibly higher than the River water temperatures while in transit. The main purpose of collecting

FIGURE 12

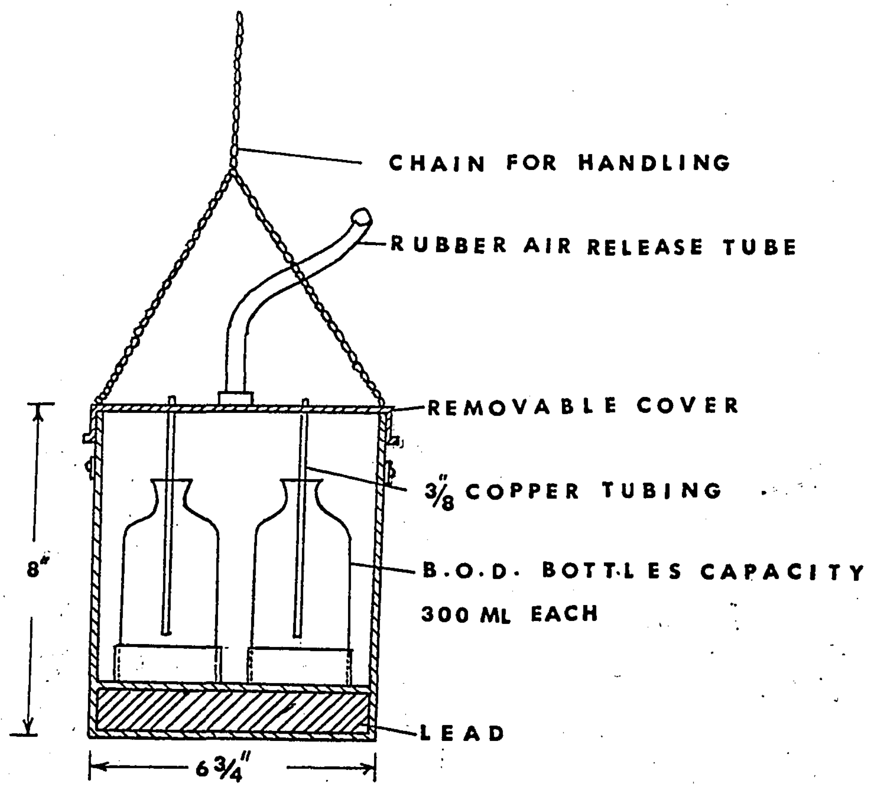


FIG 12 SAMPLER

these samples was to obtain accurate B.O.D.$_5$ values. The D.O. level at any station was determined separately by on location analysis.

Cn a normal sampling day six cases of twenty-four bottles were collected. The time required to collect 144 samples, transport them to the laboratory and analyse them, was usually 12 to 15 hours. In order to subject each sample to equal exposure time between sampling and analysis, the analysis of each sample was done in the collection order. Since the time taken to obtain a sample was within a few minutes of the time required to analyse it, each sample had identical times of exposure to elevated temperatures in transit. In the laboratory one of the two identical samples was immediately analysed for D.O., and the second sample was placed in an incubator to be analysed for D.O. five days later. Care was taken to analyse B.O.D.$_5$ samples in the order they had been placed in the incubator to insure equal incubation times. This procedure accomplished the following:

1) Each sample had equal exposure time to possibly higher than the River water temperature during the overall sampling period, transportation, and analysing time. It was also noted that the River water temperature averaged 21°C., while incubator temperature was 20°C., and the indoor laboratory temperature was within 2°C. of the outdoor temperature because the building is not air-conditioned.

2) Each sample had equal incubation time.

The reasons for adhering to the above procedures were the following.

1) The portable D.O. analysers were sensitive to vibration and handling in transportation. In the analysis for B.O.D. , the change in D.O. was sometimes in the order of 0.2 mg/l. It was noted that in transporting the D.O. analyser to the River the instrument's calibration would vary by ± 0.1 mg/l which accounted for ± 50% of the D.O. drop to be determined. Under laboratory conditions, however, the calibration of the analysers could be held to ± 0.02 or 10% of the smallest reading, and 2% of the larger readings. The determination of the D.O. level in the River by " on location " analysis gave a variance of 0.1 mg/l which accounted for only 1.35% of the total D.O. value since the average D.O. value in the River was 7.4 mg/l at 20°C., or an 80% saturation.

2) The oxygen analysers were sensitive to any trace of oil on the River surface. In lowering the electrode, which would have to be done about 72 times a day, oil film was picked up by the teflon film of the probe, resulting in an incorrect reading. Cleaning the teflon film meant a re-calibration involving at least 4 hours of laboratory time. Collecting the samples from below the water surface by using the sampler obviated the oil contamination problem. While

using the D.O. analyser in the River, the electrode was lowered into the River once at each station. In this case, the probe was protected by a sponge-rubber jacket saturated with distilled water, and this protective jacket was removed below the water surface. This procedure, while time consuming, was feasible once per station, but could not be repeated 72 times during a sampling period.

3) Regardless of how the D.O. level was determined, the B.O.D.$_5$ sample was inevitably exposed to conditions of transportation, the effect of which could not be accurately determined. Furthermore, the immedate determination of D.O. in the field using the oxygen analyser and the collection of the comparative sample for B.O.D. analysis in the laboratory would have given unequal incubation times.

The results obtained using this sampling procedure are shown in Appendix A, and

1) The B.O.D. of a sample of water was determined accurately for a five day incubation period,

2) The laboratory D.O. values were lower than those observed in the River during the preliminary survey.

3) The effect of transporting samples to the laboratory could not be directly evaluated, and

4) The samples were comparable because of their being collected in the same manner.

The analyses of sampling data for the sag curve calculations were made using Churchill and Buckingham's (5) method of multi-linear correlation, discussed in Chapter III. In this approach, the change in D.O. between stations of a river is a function of river flow, temperature, and B.O.D. only.

Since it was not known what conditions a river is subjected to between stations, either in reaeration or deoxygenation, the dissolved oxygen readings taken " on location " gave only relative concentrations of D.O. in the River. Similarly, it is not known what effect transporting the samples to the laboratory had on deoxygenation, except that samples from each station were exposed to the same time lag and temperature variations. Hence, the sampling method used for B.O.D. determination is equivalent to analysing samples taken at two stations under like conditions of flow, temperature and pollutional load. The drop in D.O. concentration expressed as % saturation would be proportional to that in the River even though the interim time lag or temperature variations are not known.

Concerning the $B.O.D._5$ value, it may be stated that the samples were incubated for exactly five days, but whether or not the analysis was done five or five-and-a-half days after collection is not important in the application of the correlation theory.

In view of the above considerations the actual levels of D.O. in the River were established by immediate analyses of D.O. in the field. The D.O. drop was determined in the laboratory and related to the actual field observations.

The oxygen sag curves obtained by this method of analysis are shown in Chapter VIII.

CHAPTER V

D.O. DISTRIBUTION ON THE RIVER CROSS SECTION

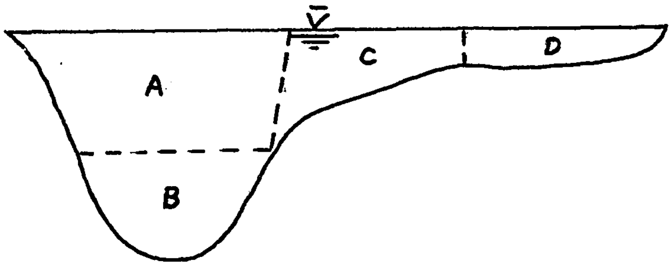
The general theoretical derivations concerning the hydrodiffusion of dissolved oxygen (D.O.) are based on the theory that the concentration of oxygen below the two-film layer is constant within a river depth, as discussed in Chapter III. A literature survey indicated that only a very few and scattered data exists concerning the actual D.O. distribution on a river cross section. While it is generally indicated that a sample of river water at about the middle of a river, one or two feet below the flow surface, would supply the D.O. data required, no supporting investigations have been made concerning this generalized assumption.

In order to obtain the actual distribution of D.O. on a river cross section, sampling grid was established to experimentally verify the actual D.O. distribution as a function of the hydrologic regime and other purely physical factors.

The D.O. values thus observed at the points of the sampling grid were analysed by developing a computer program. (See Appendix C).

A statistical method of multi-linear correlation was adopted for further investigations.

The River was separated into five general areas as shown below, (Figure 13).



Area A : The navigable part of the River
Area B : The channel bottom
Area C : The channel edge
Area D : The shore area

Area A B = E was considered to be the effective flow channel of the River. The current meter survey showed this to contain 80 to 90% of the River flow. Samples taken from each of the five areas were segregated and the correlation program run for each group. In all, eighty-nine correlations on one hundred thirty-five groupings were made. The resulting twenty-four pages of computer print-out are not enclosed here but all the computation material is available at the Municipal Laboratory of McGill University. (22).

A brief illustration of the procedure and results may be given as follows. The difference between D.O. drop calculated and observed was taken as the sample deviation, and tabulated as percent difference from the calculated D.O. drop value. For each area of the cross section a cumulative frequency distribution graph (Figure 14) was constructed of percent of total samples versus percent deviation, in accordance with Aitken (1) and Bowker (4).

The probability of less than a specified percent deviation for a given area is shown in Table (5).

TABLE 5

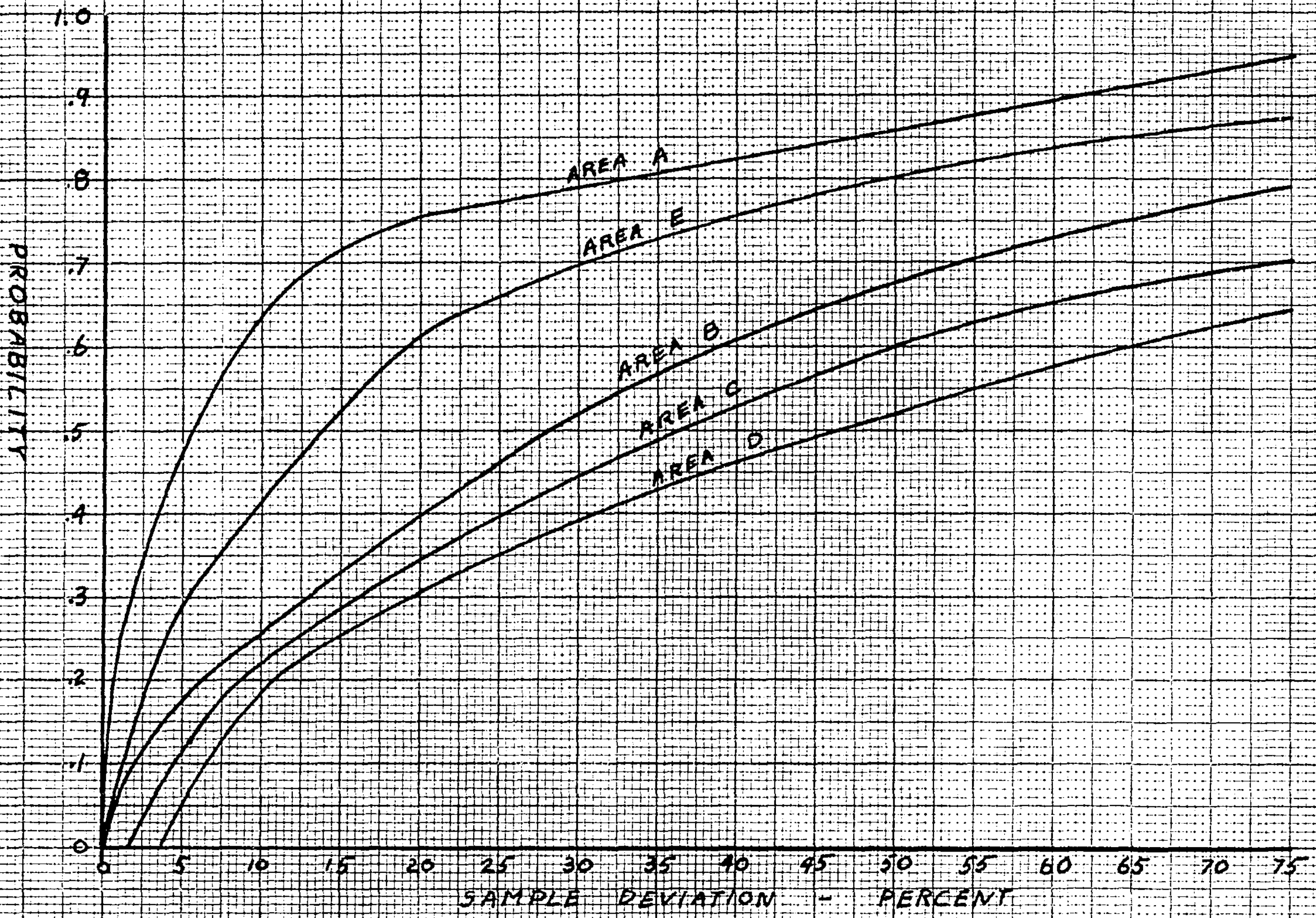
SAMPLE DEVIATION PROBABILITY IN EACH AREA

Deviation Area	5%	10%	20%	50%	75%
A	.47	.65	.76	.86	.95
E	.30	.40	.62	.80	.88
B	.17	.26	.40	.67	.80
C	.10	.24	.35	.60	.70
D	.05	.20	.30	.52	.65

It should be noted that the calculation of the deviations is based on the change in D.O. between stations, and as mentioned in Chapter IV this difference is in the

FIGURE 14

PROBABILITY OF SAMPLE DEVIATION



order of 0.2 mg/L per station. The maximum observed difference anywhere in the River from St. Jean to St. Charles was less than 10% of the saturation value observed, or 0.9 mg/l. At the 95% confidence limit the dissolved oxygen reading for a sample in Area A was D.O. ± 0.75 x 0.2 mg/L or D.O. ± 0.15 mg/l. At 20°C. this was only $\frac{.15}{9.20}$ or 1.62% of saturation value. The average saturation value of the River was 80%, and the sample deviation would then be about ± 2% at the 95% confidence limit for samples taken in Area A.

It may be concluded that the order of confidence of the sampling procedure was the highest in the area A representing mid-channel and mid-depth. The shallow portions along the River banks, Area D, had the lowest confidence limit.

CHAPTER VI

ON SHORE POLLUTIONAL LOAD

While the present conditions of the Richelieu River were readily determined by direct measurement of dissolved oxygen concentration at each station, the future conditions could not be predicted without a comprehensive study of the present and future pollutional sources. Major pollutional sources were indicated by the change in D.O. concentration in the River such as at St. Jean and Iberville where a total population of 37,000 produced a 10% decrease in the River D.O. concentration. The locations of major sewer outfalls are given in (Figures 15, 16, 17, 18).

Sources of pollution such as St. Charles with a population of 200 were considered as minor having a contributing pollutional load of 5.4% of that of St. Jean and Iberville, or an expected effect on the River D.O. concentration of 0.54%. The pollutional loading from major sources was measured by collecting composite samples at the sewer outfalls, while minor domestic waste sources were established in terms of equivalent populations. The pollutional sources investigated covered in the "on shore pollutional load" survey were as follows.

a) Towns and Villages

FIGURE 15

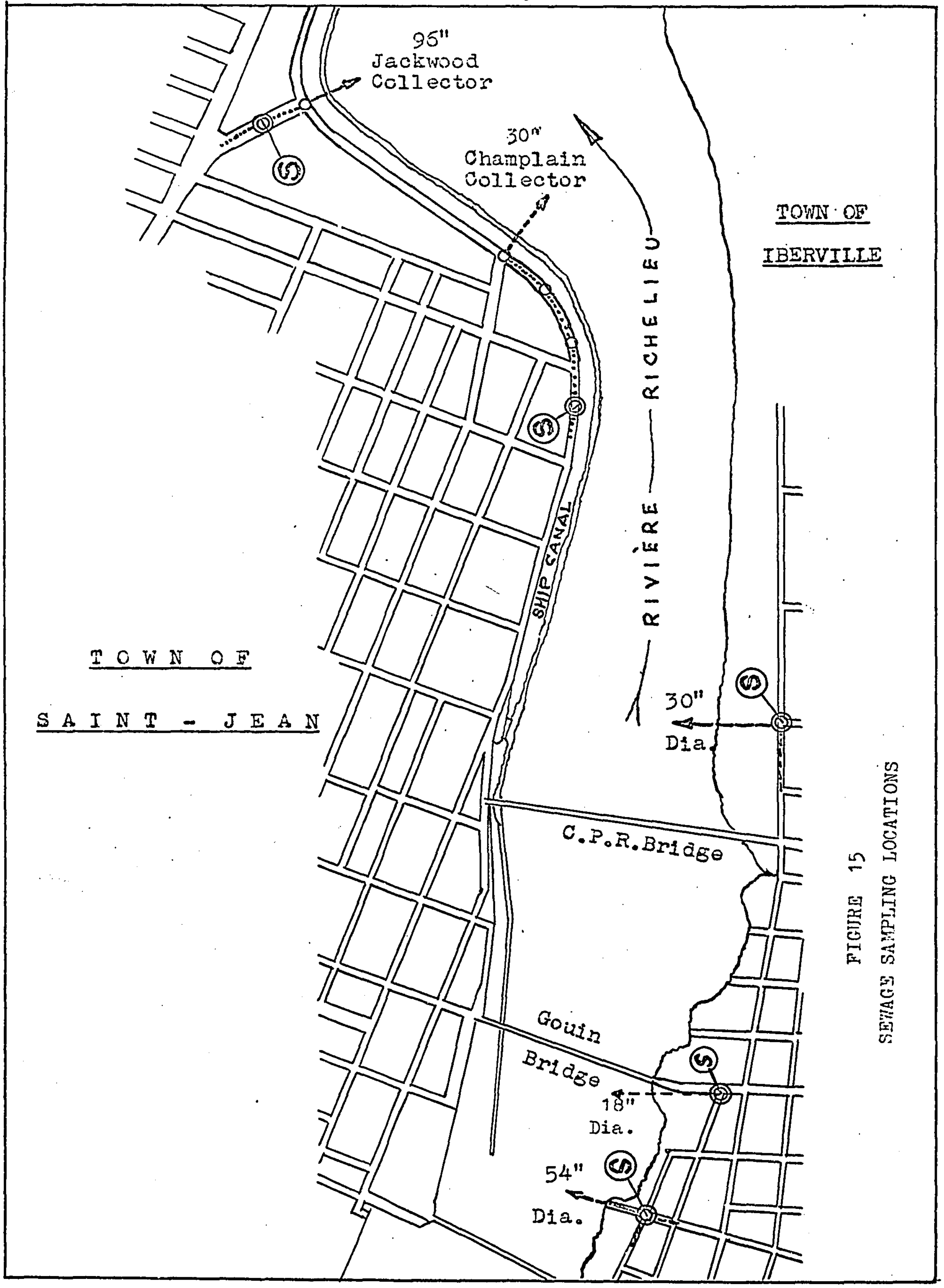


FIGURE 15
SEWAGE SAMPLING LOCATIONS

FIGURE 16

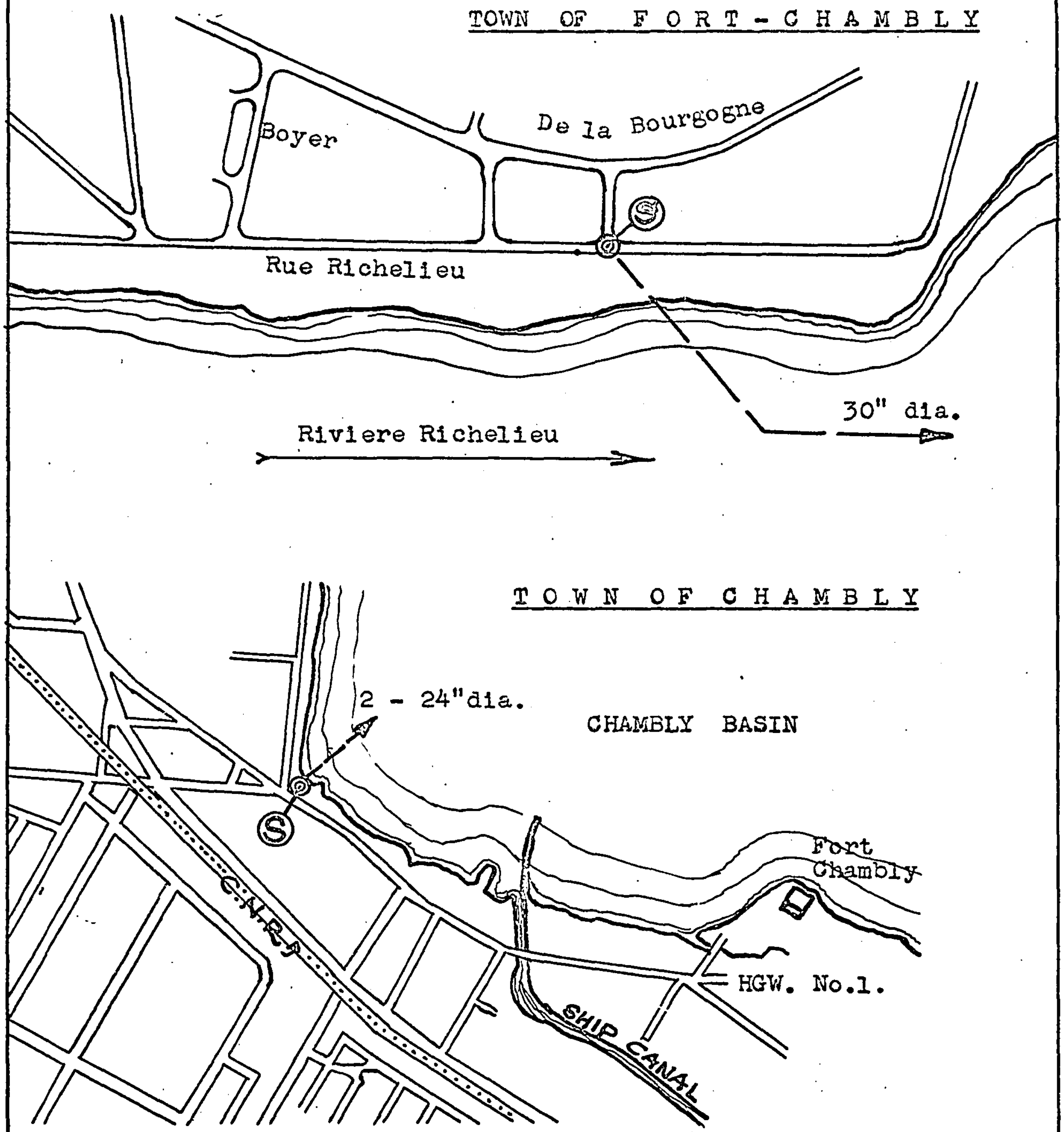


FIGURE 16
SEWAGE SAMPLING LOCATIONS

FIGURE 17

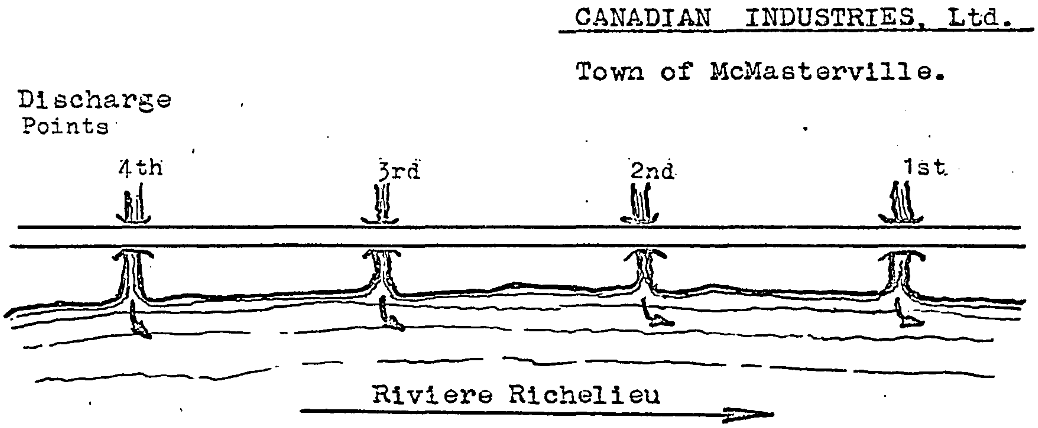


FIGURE 17
WASTE WATER SAMPLING LOCATIONS

RICHELIEU VILLAGE

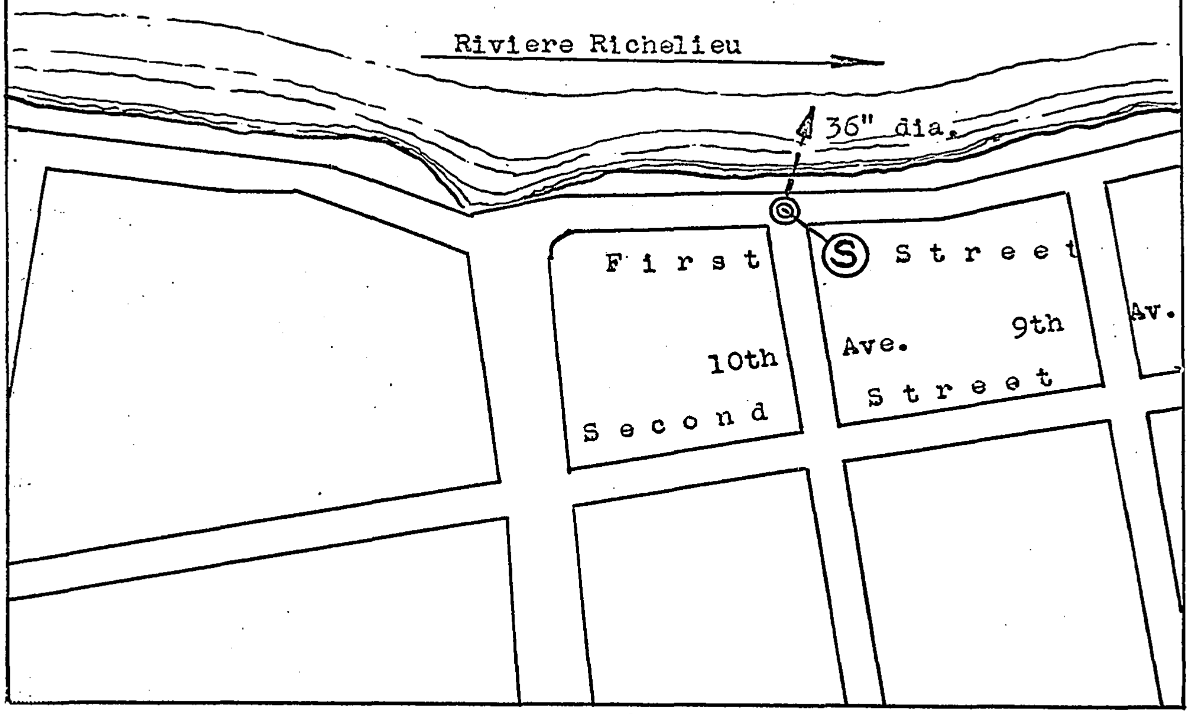


FIGURE 18

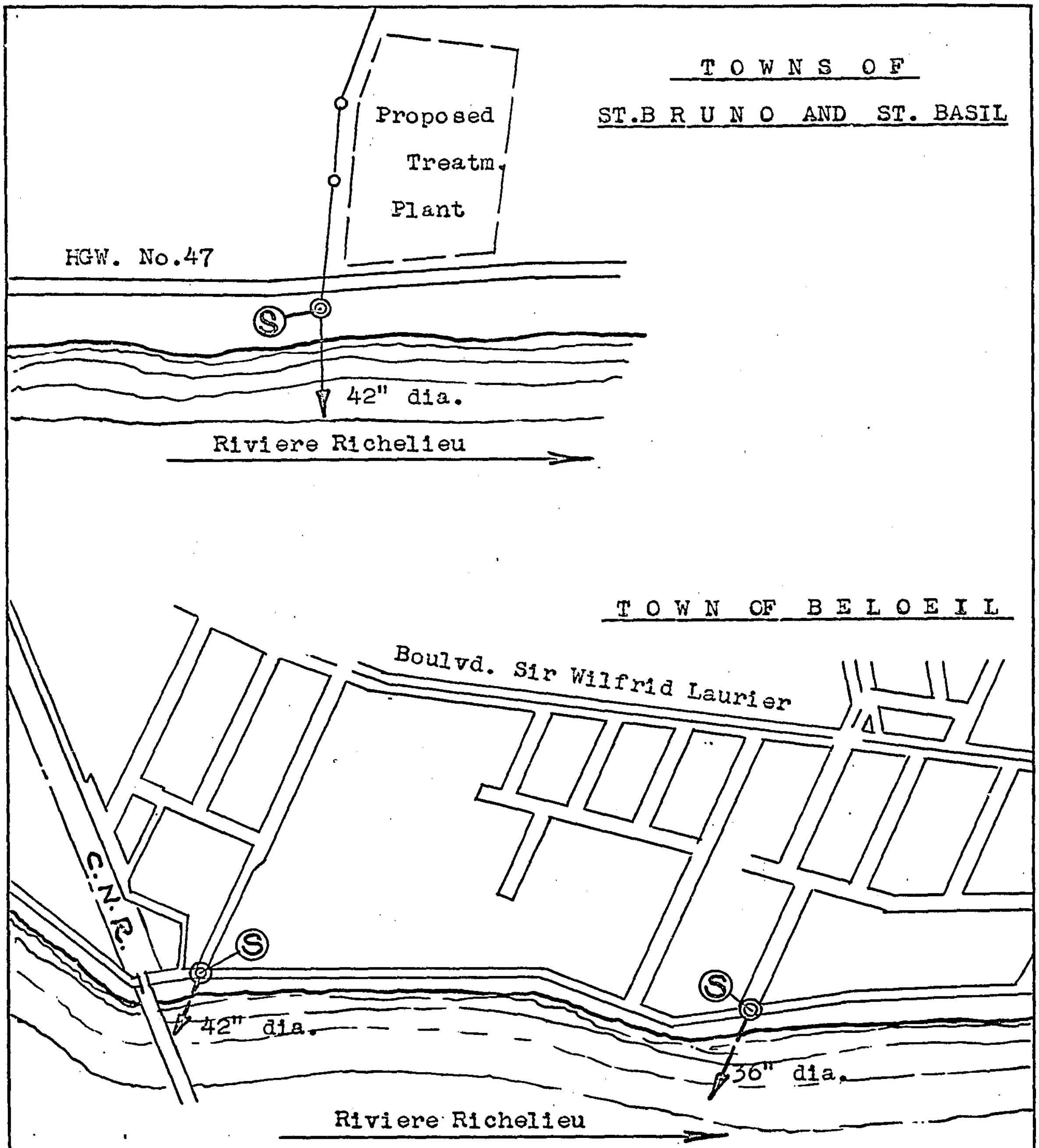


FIGURE 18

SEWAGE SAMPLING LOCATIONS

b) Scattered houses along the River banks

c) Industries

d) Tributaries, and

e) The Richelieu River above St. Jean

a) Towns and Villages

A twenty-four hour composite sample was taken at the outfall of the major sewers in each town that had a sewer system. The large towns, such as Iberville and St. Jean, were sampled twice for checking purposes. The quantity of waste water discharged at each sewer outfall was calculated by estimating the proportion of the population connected to the collector, and the water consumption of that population on the sampling date. (Table 6). The composite sample was kept ice-packed until it was analysed for B.O.D. content. The data of these analyses is given in Appendix B.

For future population forecasts, the available population data for each town was obtained and the expected future population calculated by the curvilinear method, employing a twenty year forecast period. (22).

The pollutional load from towns and villages not having a sewer system, was estimated on the basis of the population using 0.17 lbs. of oxygen /capita/ day. Where there were no records of population available, a door-to-door

TABLE 6

POPULATION AND WATER CONSUMPTION

Imperial Gallons

Town	Population 1965	Avg. Water Consumption
St. Jean	28,500	5,000,000
Iberville	8,500	675,000
Fort Chambly	5,500	266,000
Chambly	6,000	595,000
Richelieu	1,487	150,000
St. Bruno	10,250	1,230,000
St. Basile	3,000	243,000
McMasterville	2,100	97,000
Beloeil	9,600	125,000
Otterburn Park	3,200	83,500
St. Hilaire	3,139	252,000

survey was conducted. The population forecast in these towns was assumed to be proportional to the closest neighbouring town with population records. It was recognized that the accuracy of this type of survey was low, but the pollutional contribution of these towns is small.

b) Scattered Houses Along the River Banks

Houses located along the River banks were counted and the summer population determined by direct count during the weekends in July, 1964.

c) Industries

The Canadian Industries, Limited, plant at McMasterville had a significant effect on the dissolved oxygen concentration in the River. This plant, together with the surrounding population, accounted for a 10% decrease in the D.O. level in the River. The major discharge points of waste water at C.I.L. were sampled obtaining a composite sample over a twenty-four hour period, and checked twice on successive dates. The results are given in Appendix B. The discharge of each sewer outlet was determined from measured cross-sectional area and flow velocity considerations.

A composite sample of St. Hilaire Beet Sugar Refinery discharge was taken in October at the waste water discharge point of this plant, and the results are given in

Appendix B. The quantity of wastes discharged during the summer months is nil as the beet sugar refining season occurs in the late fall and early winter months. For this reason, the contributing pollutional load of this plant was omitted in the subsequent sag curve calculations.

The waste waters from Bennett, Limited, at Fort Chambly are included in the Fort Chambly waste analysis.

The waste waters from the David Lord Cannery have an indirect effect on the River. Because of the location of the ship canal at St. Jean, some of the pollutional load flows into the canal and some into the River channel. The effect on each was determined by separate investigations.

The effect on the River of the Chicken Cannery at St. Jean-Baptiste-de-Roueville, located twelve miles inland on the Huron River, is discussed under 'tributaries' below.

Industrial expansion was considered to be proportional to population growth in neighbouring towns.

d) Tributaries

The Huron River discharges into Chambly Basin. The B.O.D. of the Huron River water was determined and the volume discharge metered.

The ship canal from St. Jean to Chambly discharges into Chambly Basin. The B.O.D. of the canal water was determined and the volume discharge calculated from the volume of water in a lock and the number of lock openings per day. The B.O.D. samples were taken on a day when there was no water discharging from the canal via the spillway at Fort Chambly.

The L'Acadie or Little Montreal River discharges into the Richelieu River at the outlet to Chambly Basin. The volume discharge of this river was metered and samples for B.O.D. taken.

The Grand River discharges into the Richelieu River at Isle aux Cerfs. The B.O.D. and volume discharge were obtained as in the other rivers.

e) <u>The Richelieu River</u>

At St. Jean, station 25, extensive sampling was done to determine the initial B.O.D. of the River stretch above St. Jean. The dissolved oxygen concentration was also determined at St. Jean and Lake Champlain, and the difference was less than 0.1 mg/l.

This chapter deals with the method of determining various sources of pollution and the types of pollutional loads evaluated. The data collected in the "on shore pollutional load" survey cannot be included in this report due to its bulk. In the following chapters a sample calculation is given and the results of all the data tabulated.

CHAPTER VII

RATE CONSTANT OF BIOCHEMICAL REACTION

The basic purpose of any river pollution survey is to determine the waste receiving capacity of it, and to predict the dissolved oxygen levels which may result depending on waste load and hydrologic regime variations of the river. This essentially is a prediction of the river's performance in the terms of the self-purification influences which must be based on analysis of collected samples. The analysis of the samples supplies information concerning the drop Y in the dissolved oxygen from station to station along the surveyed river stretch. This D.O. drop is the result of interaction of two components - the deoxygenation of water due to exerted biochemical oxygen demand and in the reaeration of the river. While the deoxygenation rate can be predicted with a considerable accuracy, the reaeration time rate varies greatly from section to section of the river. Consequently, any multi-linear correlation of variables affecting the D.O. drop in the river water must be based on a latent value of K_r, appearing indirectly in the correlation factors.

It was mentioned in the previous chapter that the actual K_r cannot be determined with any accuracy under the static laboratory conditions of rigidly controlled environment.

The true disposal influences in the river are eliminated by incubating a sample in an air-tight B.O.D. bottle, and the K_r values obtained correspond to static river conditions, not existing in nature. Nevertheless, a certain analogy can be drawn and applied between the dynamic and static conditions.

Consider a sample of river water incubated at the standard 20°C., and a slug of river water moving downstream in a river, In the laboratory the initial D.O. content, its subsequent drop each day and the temperature are recorded. Similarly, the D.O. content, D.O. drop, temperature variations, and river flow on each day of the flow of a slug of river water can be recorded. It should be noted, however, that the reaeration and the true disposal influence components are present in the river.

From the laboratory observation data, the drop in D.O. can be calculated by the Churchill (5) method discussed in Chapter III where

$Y = D.O._{t-1} - D.O._t$

$X_1 =$ the D.O. measured each day

$X_2 =$ the temperature variations measured

$X_3 =$ the relation between $D.O._t$ and $D.O._o$ expressed as $D.O._t / D.O._o$

The usual observation data would show that Y, X_1, and X_3 will give decreasing values, with only a slight variation in X_2.

Applying the multi-linear correlation theory, the data of 23 composite waste discharge samples were correlated. With the above modifications the computer program written for the analysis of samples in Chapter IV was used. To correlate 828 items of the laboratory data, a Cobol program (22) was written so that once the observed data was key-punched into the computer, the computer itself would punch a data set for any correlation desired.

The correlated data, for all major waste discharges into the Richelieu River was plotted. For discussion purposes the K_1 value analysis of the wastes discharged by the 8 ft. diameter Jackwood collector of the Town of St. Jean was chosen. The observed and computed data for the Jackwood 8' collector is given in Table (7) below where Y = daily change in B.O.D.

TABLE 7

OBSERVED AND COMPUTED DATA - JACKWOOD COLLECTOR

Time Days	Y observed	Y computed from observed data	Y computed from correlated data	B.O.D. cum.
0	0			0
1	220			220
2	35	51.9	53.6	273.6
3	69	43.5	43.8	320.4

TABLE 7 (continued)

OBSERVED AND COMPUTED DATA - JACKWOOD COLLECTOR

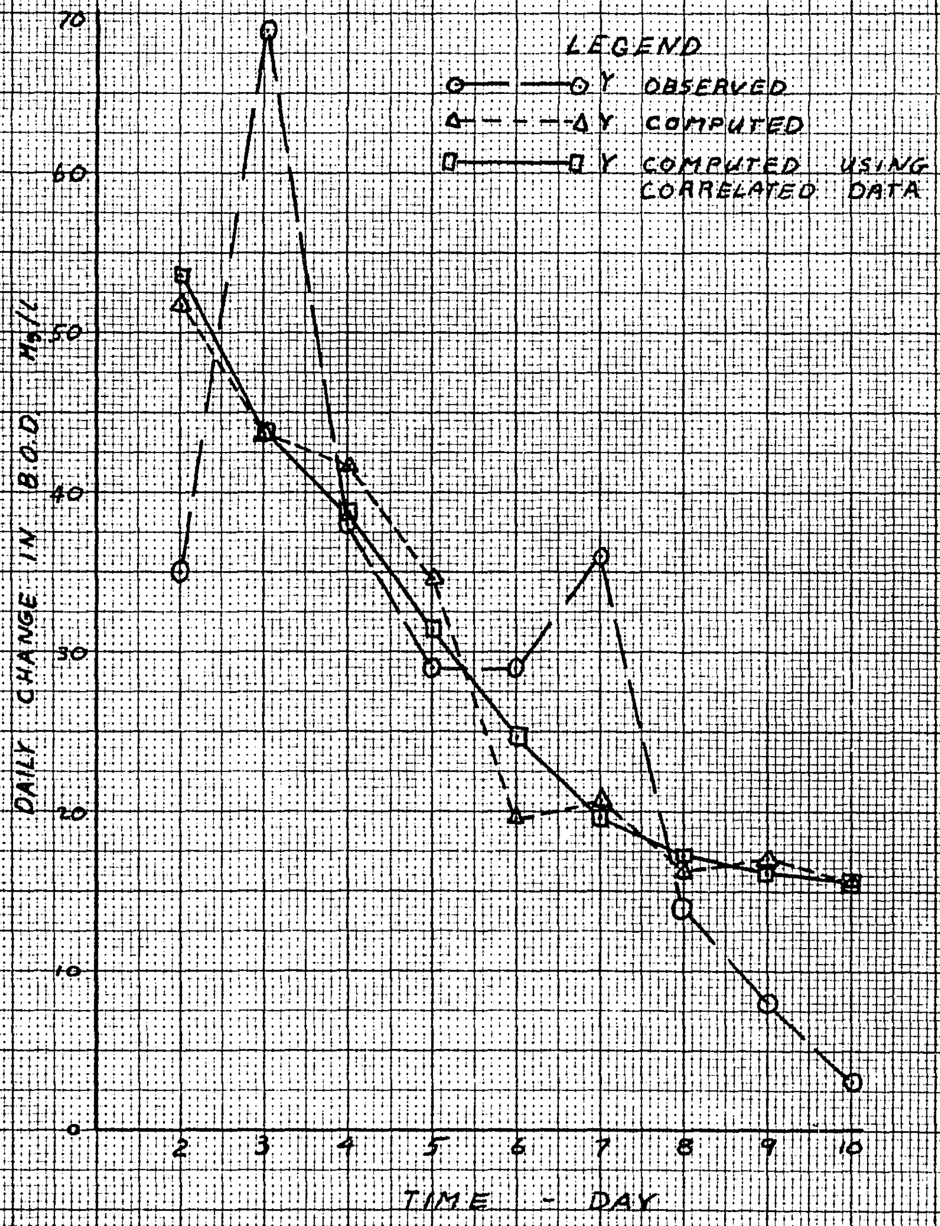
Time Days	Y observed	Y computed from observed data	Y computed from correlated data	B.O.D. cum.
4	38	41.3	38.5	358.9
5	29	34.7	31.3	390.2
6	29	19.6	24.7	414.9
7	36	20.7	19.8	434.7
8	14	16.3	17.2	451.9
9	8	17.0	16.2	468.1
10	3	15.5	15.7	483.8

The daily change in B.O.D. from the second to the tenth day is shown in (Figure 19). The three curves represent; the daily change in B.O.D., Y observed; Y computed by the multi-linear correlation theory; and Y computed by the multi-linear correlation theory having first correlated the observed values of T^oC, $D.O._t/D.O._o$ and D.O. The computer results of the five correlations are shown on the subsequent pages where; Y computed represents B.O.D., $D.O._t/D.O._o$, T, D.O., computed from observed data. In the final correlation Y computed is calculated using all correlated data.

As can be seen from Table (7) the first day B.O.D. of 220 mg/l was omitted from the correlation process. Since most of the sewers analysed contained some industrial waste,

FIGURE 19

DAILY CHANGE IN B.O.D. AT TIME T



POLLUTION OF RICHELIEU RIVER

JACKWOOD 8" COLLECTOR
ST. JEAN, QUE.

DATE 060765

B1 = .3832 B2 = -.9616 B3 = -1.1362
R = .710 A = 20.481

X1 DO mg/1x10^{-1}	X2 T. °C	X3 DO_t/DO_o x10^{-1}	Y BOD mg/1x10^{-1}	Y COMPUTED BOD mg/1x10^{-1}
28.8	20.7	5.65	3.5	5.1919
22.9	20.6	4.48	6.9	4.3566
20.4	20.6	3.88	3.8	4.1373
17.0	20.5	3.35	2.9	3.4759
13.5	21.5	2.65	2.9	1.9686
11.2	21.0	2.20	3.6	2.0794
10.1	21.3	1.97	1.4	1.6308
9.5	21.1	1.87	.8	1.7068
9.2	21.2	1.82	.3	1.5525

DATE 060765

B1 = 1.9547 B2 = .3844 B3 = -.1840
R = .999 A = -8.057

X1 DO mg/1x10^{-1}	X2 T. °C	X3 BOD mg/1	Y DO_t/DO_o x10^{-2}	Y COMPUTED DO_t/DO_o x10^{-2}
28.8	20.7	.35	56.5	56.1305
22.9	20.6	.69	44.8	44.4968
20.4	20.6	.38	38.3	39.6670
17.0	20.5	.29	33.5	32.9993
13.5	21.5	.29	26.5	26.5423
11.2	21.0	.36	22.0	21.8414
10.1	21.3	.14	19.7	19.8470
9.5	21.1	.08	18.7	18.6083
9.2	21.2	.03	18.2	18.0696

DATE 060765

B1 = -.1846 B2 = .0799 B3 = -.3224
R = .715 A = 21.494

X1 DO mg/1x10^{-1}	X2 DO_t/DO_ox10^{-2}	X3 BOD mg/1	Y T°C	Y COMPUTED T°C
28.8	56.5	.35	20.7	20.5771
22.9	44.8	.69	20.6	20.6222
20.4	38.3	.38	20.6	20.6645
17.0	33.5	.29	20.5	20.9379
13.5	26.5	.29	21.5	21.0250
11.2	22.0	.36	21.0	21.0676
10.1	19.7	.14	21.3	21.1579
9.5	18.7	.08	21.1	21.2082
9.2	18.2	.03	21.2	21.2398

18464

POLLUTION OF RICHELIEU RIVER

JACKWOOD 8' COLLECTOR
ST. JEAN, QUE.

DATE 060765

B1 = -.2315 B2 = .5094 B3 = .1618
R = .999 A = 4.901

X1	X2	X3	Y	Y COMPUTED
T°C	$DO_t/DO_o x10^{-2}$	BOD mg/l	$DO\ mg/l x10^{-2}$	$DO\ mg/l x10^{-2}$
20.7	56.5	.35	28.8	28.9448
20.6	44.8	.69	22.9	23.0633
20.6	38.3	.38	20.4	19.7022
20.5	33.5	.29	17.0	17.2659
21.5	26.5	.29	13.5	13.4688
21.0	22.0	.36	11.2	11.3036
21.3	19.7	.14	10.1	10.0271
21.1	18.7	.08	9.5	9.5544
21.2	18.2	.03	9.2	9.2685

DATE 060765

B1 = .2806 B2 = -9.1798 B3 = 7.0813
R = .982 A = 194.945

X1	X2	X3	Y	Y COMPUTED
$DO\ mg/l x10^{-1}$	T°C	$DO_t/DO_o x10^{-1}$	BOD mg/l	BOD mg/l
28.9	20.6	5.61	51.9	53.6772
23.1	20.6	4.45	43.6	43.8359
19.7	20.7	3.97	41.4	38.5648
17.3	20.9	3.30	34.8	31.3103
13.5	21.0	2.65	19.7	24.7235
11.3	21.1	2.18	20.8	19.8602
10.0	21.2	1.98	16.3	17.1610
9.6	21.2	1.86	17.1	16.1982
9.3	21.2	1.81	15.5	15.7602

the possibility of an immediate oxygen demand (I.O.D.) was recognized. The time rate constant for the immediate oxygen demand is significantly different from the biochemical oxidation rate and by using data from the second to tenth day better correlations were obtained. The cumulative B.O.D. was calculated by summing the daily B.O.D. changes including the first day B.O.D. This summation is the B.O.D. at any time t. A plot of B.O.D. versus the log of time is shown in (Figure 20). The immediate oxygen demand does not affect the shape of the curve but its plot position only. In this way a better value for the time rate constant of biochemical oxidation is obtainable.

In the usual B.O.D. determinations, D.O. versus time is plotted on semi-log paper, the D.O. is plotted on the log scale and time on the linear scale.

Reversing this process, the B.O.D. is plotted on the linear scale, while the time is plotted on the log scale. This plot is shown in (Figure 20).

The K_{Lab} and K_{river} values may show considerable deviations, the causes of which were outlined in Chapter III. Consequently, the plot of B.O.D. versus log of time does not show a straight line relation during the early days of incubation.

Plotting log of B.O.D. versus the log of time, the B.O.D. exerted during the early days of incubation is

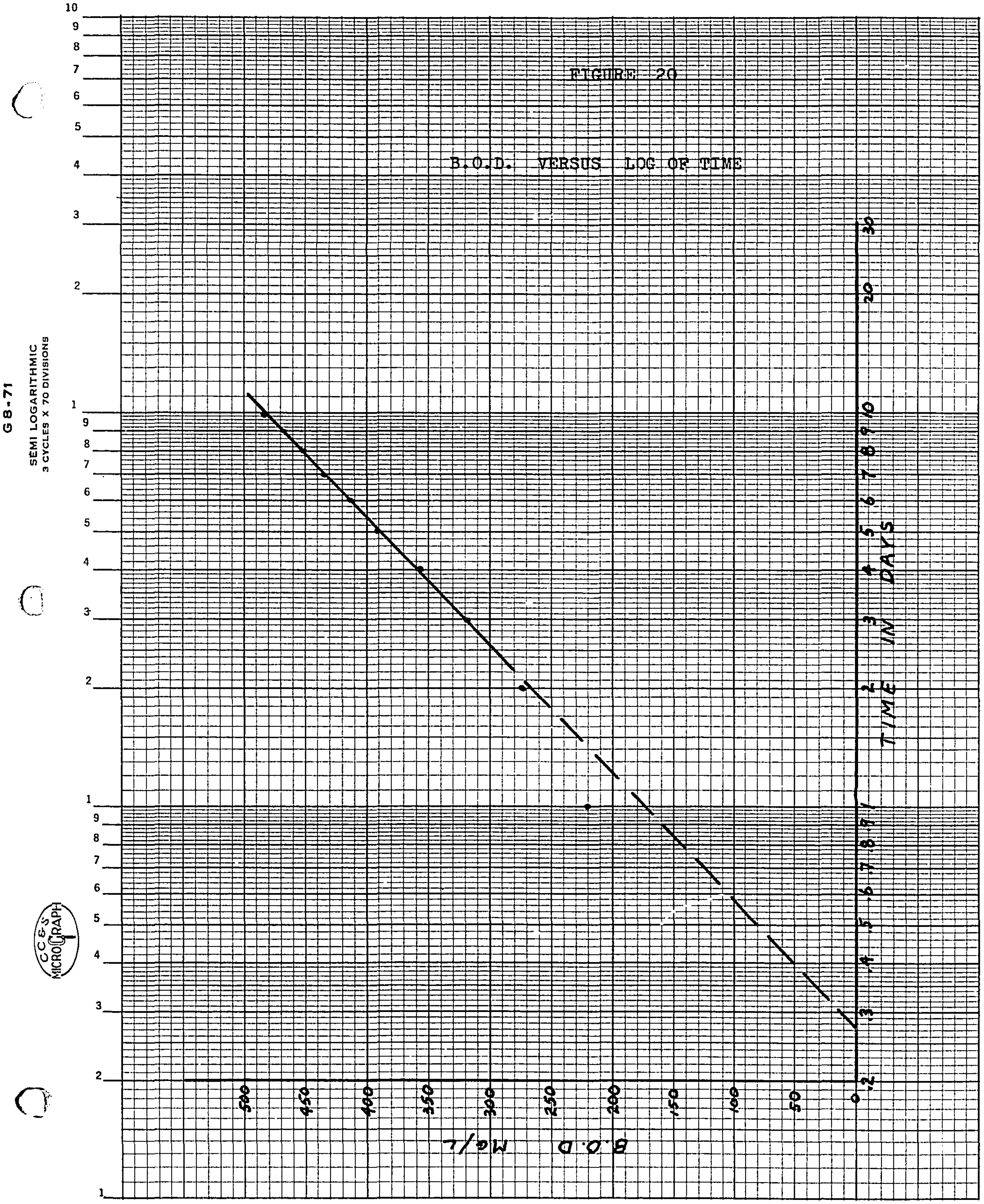


FIGURE 20

B.O.D. VERSUS LOG OF TIME

better defined, and a much closer correlation obtained, as shown in (Figure 21).

From (Figure 20) it can be seen that the line of best fit intersects the time axis at 0.27 days, indicating that the monomolecular reaction has this time lag. As mentioned previously, the early stages of biochemical reaction are better defined by a log-log plot as shown in (Figure 21). The value of 0.27 days in (Figure 21) has a value of 145 mg/l. The immediate oxygen demand was then determined as having a B.O.D. of 145 mg/l at 0.27 days.

The application of the multi-linear correlation theory, on the observed data obtained in the analysis of sewage samples, produced the results of B.O.D. at time t as shown in Table (7). The computed data was considerably less irregular than the observed data, and, therefore, it was used for further calculations.

Klein (11) illustrated the Thomas method of calculating the time rate constant of biochemical oxidation and the ultimate B.O.D. using the input data of B.O.D. at time t.

The K_1 value and B.O.D. ultimate were calculated by the Thomas method for each sewage analysis. The immediate oxygen demand and its time of development were determined as discussed previously. The method used involved 69 graphs and 38 pages of computer print-out. The data cannot be enclosed due to its bulk (22) but the results are given in Table (8).

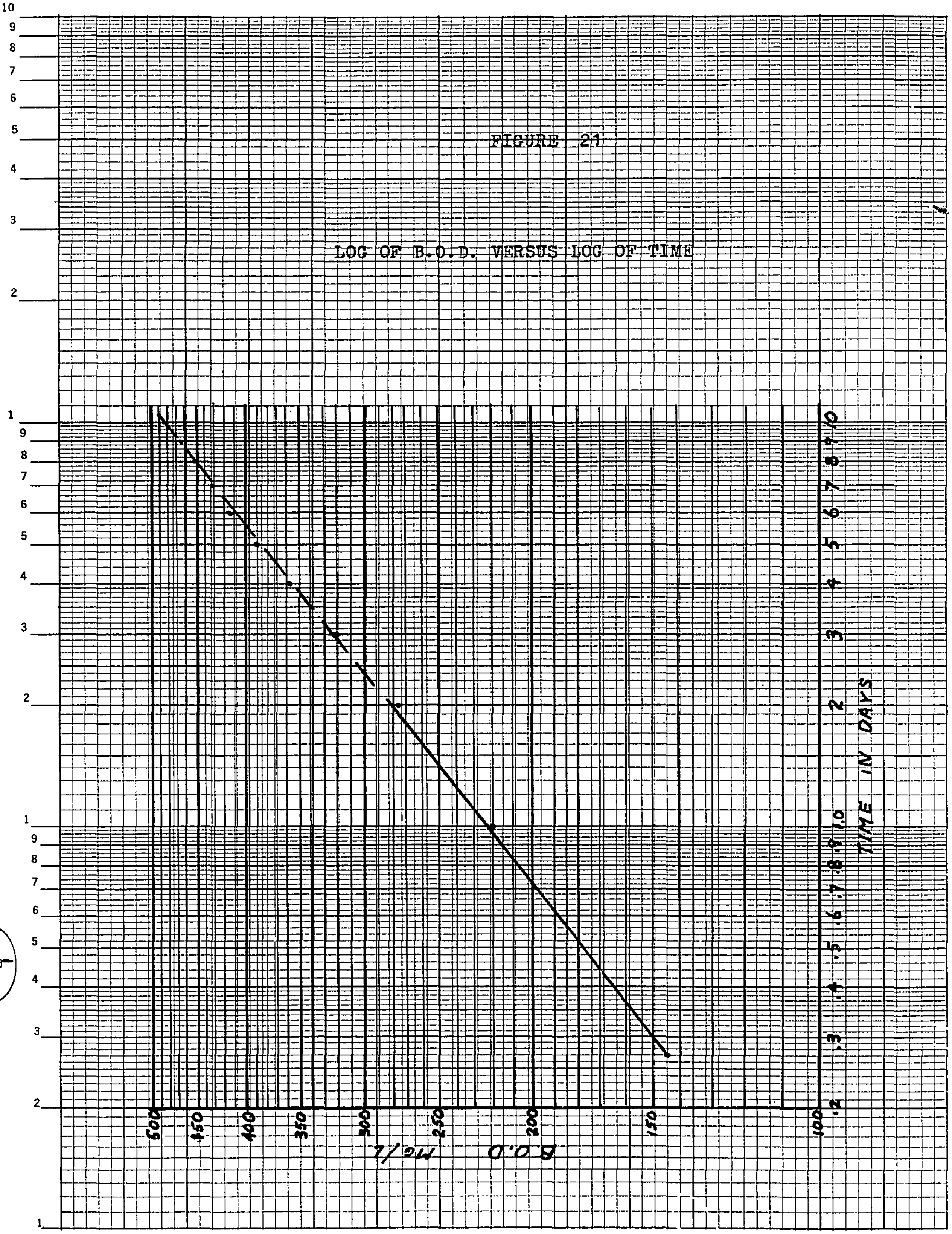


FIGURE 21

LOG OF B.O.D. VERSUS LOG OF TIME

TABLE 8

RESULTS OF SEWAGE ANALYSIS

Town and Collector		K_1	B.O.D. ult. mg/1	I.O.D. mg/1	Lag time Days
St. Jean	96" Jackwood	.120	730	145	.27
	30" Champlain	.17	565	127	.18
Iberville	54"	.10	275	42	1.4
	30"	.12	240	31	.7
	18"	.15	330	60	1.4
Fort Chambly	30"	.19	658	180	.25
Chambly Twin	24"	.28	415	89	1.0
Richelieu	36"	.18	430	25	.17
St. Bruno, St. Basile		.18	119	25	.50
C.I.L.	1st discharge	.18	135	23	.90
	2nd discharge	.28	116	26	.10
	3rd discharge	.20	112	26	1.0
	4th discharge	.28	85	19	.20
McMasterville	54"	.20	168	45	.10
Beloeil	36"	.18	430	25	.17
St. Hilaire	30"	.24	200	60	.15
Beet Sugar Refinery		.16	135	23	1.0

CHAPTER VIII

OXYGEN SAG CURVES

The data collected and analysed as described in Chapters II, VI and VII can now be used to calculate the effect of the pollutional load on the River both at present and in the future. The physical River parameters, including the hydrologic regime were established as well as the on-shore load.

Streeter and Phelps (18) proposed a single mathematical expression for the sag curve if the deoxygenation and reaeration coefficients were known. The deoxygenation coefficient can be determined in the laboratory but the reaeration coefficient was more difficult to establish.

Velz (20, 21) proposed separate evaluation of reaeration and deoxygenation coefficients and a subsequent combination of the two in the solution of the Streeter - Phelps (18) equation.

Phelps proposed a graphical solution to Fick's Law of hydrodiffusion and Velz was able to express the relationship as follows.

$$D = 100 - \left[(1 - \frac{B}{100}) \times 81.06 \left(e^{-K} + \frac{e^{-9K}}{9} + \frac{e^{-25K}}{25} + \cdots\right)\right]$$

where D = final D.O. content (average for the depth as % of saturation/mix)

B = initial average D.O. as % of saturation

$K = \frac{\pi^2 a t}{4L^2}$

t = time of exposure in hours

L = depth of water in centimeters

a = diffusion coefficient for a specific temperature

The above variables can be determined easily except for t, or the time of exposure. Gannon and Downs (9) have shown that the mix interval can be related to stream depth with a polynominal of the sixth degree if stream depth varies between 3 to 30 feet. A linear relationship exists for stream depths less than 3 feet. Gannon and Downs gave the equation in the form of a computer program, and have developed a program for D.O. sag curve calculations. They have also shown that the calculated D.O. sag curve satisfactorily describes a river such as the Willamette River in Oregon, with a discharge of 3800 cfs. The Richelieu River is quite similar to the Willamette, having a normal summer discharge of 3000 to 4000 cfs.

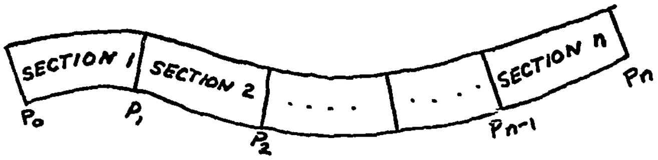
Fortunately, Gannon and Downs have been able to express the oxygen sag curve in a mathematical form for which a computer program could be written and have eliminated the graphical approach to the temperature corrections, reaeration coefficient, and time of exposure. They have also determined the constants required to convert the normal physical river parameters, such as c.f.s., miles between stations, areas in sq. ft., and others, into the corresponding units of measure given in the Velz (20,21) formulation.

Although the computer program developed by Gannon and Downs (9) could not be used, their approach could be applied to write, compile and execute the program included in the Appendix C. This computer program was written for the Honeywell H 200 computer with a core memory of 16K.

For execution of the program all that is required is one card for general river conditions and one card for each of the stations in the river, as shown in (Figure 22).

Computer Program Parameters

The portion of the stream under study was partitioned into n. sections, as in the diagram.

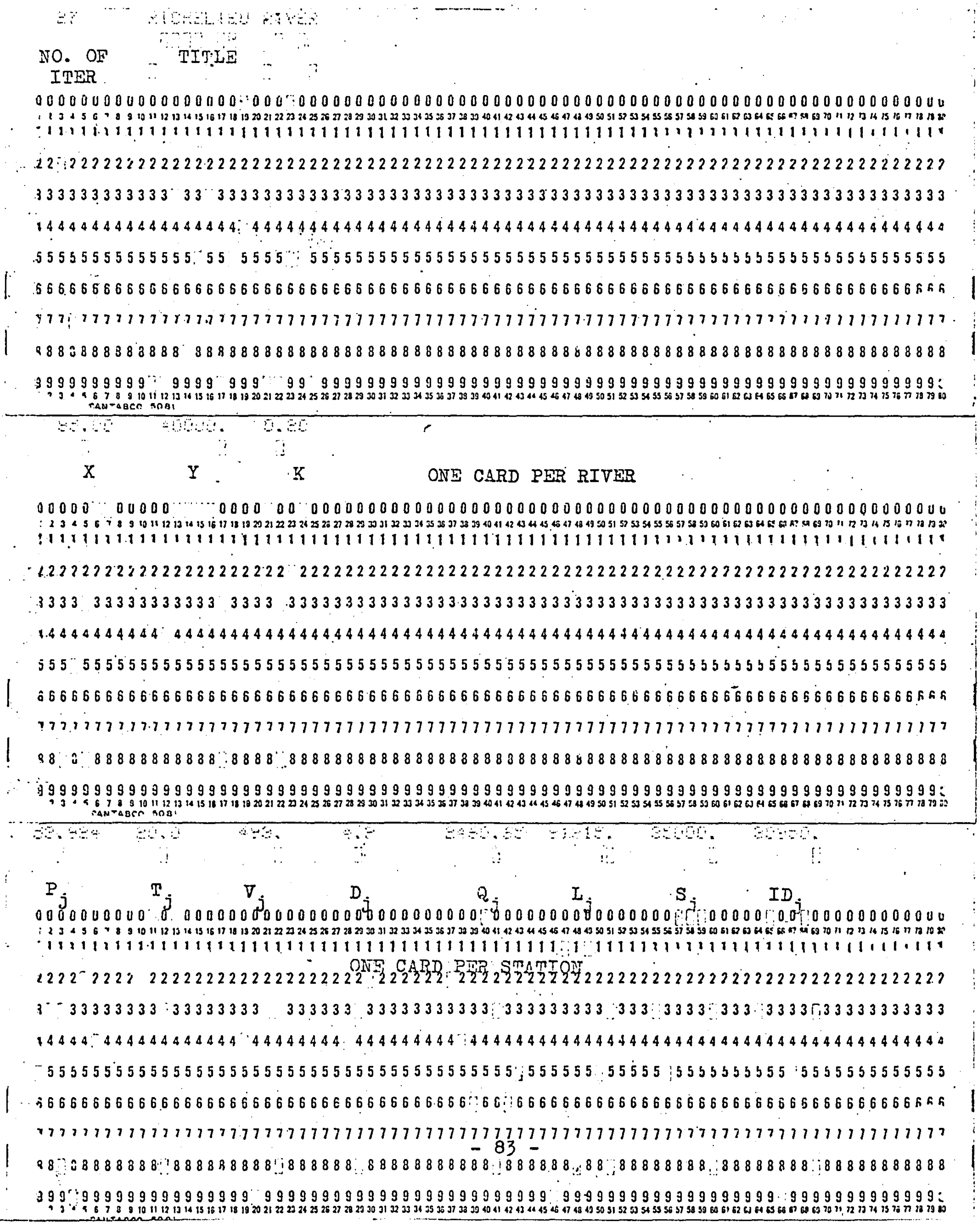


→ direction of stream flow

The following information was needed as input data for the computer.

P_j = distance from point j to the mouth of the River in miles, $0 \le j \le n$

FIGURE 22


27 RICHELIEU RIVER
NO. OF ITER
TITLE
85.00 40000. 0.20
X
Y
K
ONE CARD PER RIVER
Pj
Tj
Vj
Dj
Qj
Lj
Sj
IDj
ONE CARD PER STATION
CANTABCO 5081

T_j=temperature in ^{o}C at point j, $1 \leq j \leq n$

V_j= volume of water between the points j-1 and j (in millions of U.S. gallons) for $1 \leq j \leq n$

D_j= average depth in feet for the section included between points j-1 and j for $1 \leq j \leq n$

Q_j= the runoff past the point j (in cfs) $1 \leq j \leq n$

S_j= the "sludge" (in population equivalents) at the point j, $1 \leq j \leq n$

ID_j= amount of immediate oxygen demand at the point j (in population equivalents) where $1 \leq j \leq n$

L_j = amount of oxygen required to oxidize the organic wastes (in population equivalents) introduced at point j which does not require oxygen immediately $1 \leq j \leq n$

X = that percentage of the oxygen saturation value which is actually realized in the stream at P_o

Y = initial waste load (in population equivalents) introduced at the initial point P where the analysis begins

K = the time rate constant of biochemical oxidation

The parameters were determined as follows.

P_j - The mileage from the mouth of the River to each station was determined from the data in Chapter II and is given in Table (9). In the computer print-out the No. of ITER refers to the number of sections that the River was divided into. Chambly Basin was divided by three more hypothetical stations at the inlet, middle, and outlet respectively. This was done to evaluate the effect of Chambly Basin on reaeration and the pollutional effect of the Huron River which discharges near the mid point of the Chambly Basin shore line. There was no station markers established for these stations and therefore there are no corresponding station numbers.

TABLE 9

STATION IDENTIFICATION BY MILEPOINT

Station No.	Milepoint	No. of ITER	Location
25	55.77		above St. Jean
24	53.92	1	
23	51.64	2	
22	49.74	3	
21	48.88	4	Fryers Island
20	55.26	5	Richelieu-Chambly Bridge
	44.05	6	Inlet Chambly Basin
	43.25	7	Middle Chambly Basin
	42.44	8	Outlet Chambly Basin
19	41.81	9	
18	40.86	10	
17	39.92	11	
16	38.97	12	
15	38.03	13	

TABLE 9 (continued)

STATION IDENTIFICATION BY MILEPOINT

Station No.	Milepoint	No. of ITER	Location
14	37.09	14	above C.I.L.
13	36.14	15	
12	35.15	16	Beloeil
11	34.25	17	
10	33.34	18	
9	32.40	19	
8	31.45	20	
7	30.51	21	
6	29.56	22	Isle aux Cerfs
5	28.42	23	
4	27.48	24	
3	26.54	25	
2	25.64	26	
1	24.70	27	St. Charles

T_j - The temperatures of the River water were determined by field measurement at the time of sampling (22).

V_j - The volume of the included water between two consecutive stations was calculated for each flow condition from the data obtained in the hydrologic regime studies (22).

D_j - The average depth was determined from data obtained in Chapter II (22).

Q_j - The River flow at each station was determined from the data given in the preliminary survey (22).

S_j - The ultimate B.O.D. was determined by the Thomas method given in Chapter VII and the method of segregating the immediate oxygen demand, (I.O.D.) from the total B.O.D. was discussed. B.O.D. total minus the I.O.D. was considered to be the oxygen requirement of the organic wastes undergoing biochemical oxidation in the form of suspended and settleable organic matter. Phelps (15), Fair and Geyer (8), and Klein (11) agree that about 35% of the B.O.D. of domestic sewage is attributable to sludge. The exact proportion between B.O.D. suspended and B.O.D. settleable was not the governing factor in this calculation. The approximate value for sludge was required to evaluate the effectiveness of treatment of wastes in the ten and twenty year forecasts of the River condition.

ID_j- The immediate oxygen demand was determined as given in Chapter VII.

L_j - The total B.O.D. minus sludge and immediate oxygen demand was considered to be the B.O.D. of the organic wastes carried in suspension.

The above are the parameters needed for each station card in the computer data deck. The calculations are

```
                                       TABLE  10
*****  POLLUTIONAL LOAD 1965          FLOW 2470

  27          RICHELIEU RIVER
    X               Y            K
  84.00         40000.        0.10
  84.00         40000.        0.20

    P          T           V          D           Q          L          S           ID
53.924      20.0         493.       4.2       2460.65     91815.     35000.      30950.
51.639      20.0         647.       4.5       2464.93       340.     0.0         0.0
49.744      20.0         743.       9.0       2468.25     420.       0.          0.
48.88       20.0         241.       6.5       2470.00     515.       0.          0.
45.258      20.0         835.       4.0       2471.80     136.       0.          0.
44.05       20.0         110.       4.0       2475.30     52900.     2338.       2212.
43.250      20.0         190.       4.8       2500.00     5308.      1600.       1700.
42.443      20.0         190.       4.8       2550.00     276.       0.          0.
41.809      20.0         212.       11.5      2573.30     1200.      0.          0.
40.863      20.0         317.       9.35      2574.07     5512.      0.          0.
39.917      20.0         334.       11.0      2574.23     4928.      52.         1295.
38.970      20.0         313.       10.30     2576.06     128.       0.          0.
38.025      20.0         240.       8.30      2576.46     48.        0.          0.
37.090      20.0         263.       7.65      2580.13     3200.      0.          0.
36.144      20.0         153.       4.55      2580.51     23540.     18175.      10215.
35.149      20.0         156.       4.47      2581.61     7586.      4650.       1064.
34.249      20.0         253.       9.30      2582.09     665.       735.        700.
33.344      20.0         328.       12.       2582.60     30.        0.          0.
32.393      20.0         323.       10.9      2584.90     366.       0.          0.
31.452      20.0         322.       10.20     2585.30     164.       0.          0.
30.506      20.0         351.       11.6      2586.13     80.        0.          0.
29.560      20.0         365.       11.35     2587.71     84.        0.          0.
28.424      20.0         432.       10.8      2601.46     148.       0.          0.
27.478      20.0         238.       11.9      2603.17     900.       0.          0.
26.542      20.0         288.       10.95     2603.40     168.       0.          0.
25.635      20.0         267.       9.25      2606.72     468.       0.          0.
24.700      20.0         292.       9.0       2607.13     260.       0.          0.
```

```
                                       TABLE  11

*****  POLLUTIONAL  LOAD  1965     FLOW  3000

   27        RICHELIEU  RIVER

      X            Y            K
   85.00       40000.        0.10
   85.00       40000.        0.20

     P            T             V          D            Q          L           S            ID
53.924       20.0         500.85     4.30        2918.87    91815.     35000.       30950.
51.639       20.0         646.50     4.60        2923.97    340.       0.           0.
49.744       20.0         734.47     9.15        2927.92    420.       0.           0.
48.883       20.0         241.65     6.90        2930.00    515.       0.           0.
45.258       20.0         809.32     4.0         2932.14    136.       0.           0.
44.053       20.0         120.       4.0         2940.0     52900.     2338.        2212.
43.250       20.0         280.       5.0         3000.      5308.      1600.        1700.
42.443       20.0         300.       9.0         3025.00    276.       0.           0.
41.81        20.0         215.00     11.70       3054.24    1200.      0.           0.
40.863       20.0         325.10     9.60        3055.16    5512.      0.           0.
39.917       20.0         340.50     11.5        3055.47    4928.      52.          1295.
38.971       20.0         330.37     10.80       3057.63    128.       0.           0.
38.025       20.0         300.37     8.5         3062.42    48.        0.           0.
37.090       20.0         285.30     8.50        3066.78    3200.      0.           0.
36.144       20.0         182.10     5.40        3067.24    23540.     18175.       10215.
35.149       20.0         166.95     4.75        3068.56    7586.      4650.        1064.
34.249       20.0         262.20     9.60        3069.13    665.       735.         700.
33.344       20.0         335.17     12.20       3069.74    30.        0.           0.
32.398       20.0         334.42     11.30       3070.50    366.       0.           0.
31.452       20.0         333.30     10.80       3072.95    164.       0.           0.
30.506       20.0         288.00     9.5         3073.93    80.        0.           0.
29.560       20.0         379.27     11.80       3078.80    84.        0.           0.
28.424       20.0         438.90     10.60       3091.55    148.       0.           0.
27.478       20.0         313.42     12.30       3091.58    900.       0.           0.
26.542       20.0         307.87     11.50       3091.85    168.       0.           0.
25.635       20.0         282.00     9.78        3095.80    468.       0.           0.
24.700       20.0         289.47     9.25        3096.29    260.       0.           0.
```

```
                                TABLE  12

*****  POLLUTIONAL LOAD 1965    FLOW 3660

  27          RICHELIEU RIVER

    X           Y           K
  86.00       40000.      0.10
  86.00       40000.      0.20

    P         T             V         D             Q        L          S           ID
  53.924    20.0          500.        4.4       3646.14   91815.     35000.      30950.
51.639      20.0        645.        4.7        3652.49   340.         0.          0.
49.744      20.0        730.        9.3        3657.42   420.        0.          0.
48.883      20.0        240.        7.1        3660.     515.        0.          0.
45.258      20.0        840.        4.0        3662.66   136.        0.          0.
44.053      20.0        114.        4.0        3664.     52900.      2338.       2212.
43.250      20.0        370.        5.2        3810.     5308.       1600.       1700.
42.443      20.0        370.        5.2        3814.00   276.        0.          0.
41.809      20.0        232.        12.0       3814.86    1200.      0.          0.
40.863      20.0        342.        10.1       3815.90   5512.       0.          0.
39.917      20.0        347.        11.8       3816.29    4928.      52.          1295.
38.971      20.0        338.        11.0       3818.99   128.        0.          0.
38.025      20.0         320.       9.1         3819.58    48.       0.          0.
37.090      20.0        295.        8.5        3825.03   3200.       5000.       8000.
36.144      20.0        203.        6.5        3825.60   23540.      18175.      10215.
35.149      20.0         186.       5.4        3827.24   7586.       4650.       1064.
34.249      20.0        280.        10.2       3827.24   665.        735.        700.
33.344      20.0        353.        12.9       3827.95   30.          0.          0.
32.398      20.0        360.        11.9       3832.16    366.       0.          0.
31.452      20.0        351.        11.4       3832.72   164.        0.          0.
30.506      20.0        380.        12.6       3833.97   80.         0.          0.
29.560      20.0        398.        12.5       3836.30   84.         0.          0.
28.424      20.0        462.        11.3       3854.75   148.        0.          0.
27.478      20.0        367.        12.9       3857.39   900.        0.          0.
26.542      20.0        325.        12.0       3857.72   168.        0.          0.
25.635      20.0        299.        10.3       3862.66   468.        0.          0.
24.700      20.0        310.        9.6        3863.27   260.        0.          0.
```

quite extensive and are not enclosed. They are on file at McGill (22). The computer data listings are given in Tables (10, 11, 12).

The single data card required to describe the River as a whole had the following parameters.

No. = The number of iterations or sections analysed = 27 and was constant for all calculations.

X = The initial dissolved oxygen saturation at station P_o. An analysis of the dissolved oxygen readings taken in the field at station 25 under various conditions of flow gave the results in Table (13).

TABLE 13

DISSOLVED OXYGEN CONCENTRATION AT STATION 25

Flow cfs	D.O. % Saturation	Y
3660	86.0	39,000
3400	85.7	38,000
3000	85.0	40,500
2470	84.	42,000

Y = The initial waste load was determined from B.O.D. and flow considerations at Station 25. As can be seen from Table (13) the calculated values ranged from 38,000 to 42,000 and averaged 39,900. For calculation purposes the pollutional loads from sewer outfalls were considered to be constant during the sampling period. An initial pollutional load Y was therefore taken to be 40,000 in population equivalents.

K = The time rate constant of biochemical oxidation. Phelps (15) suggests that the K value for a river such as the Richelieu River is normally between 0.10 and 0.20. The computer program was run for k values from 0.10 to 1.50 (22). The curves computed with a K value of 0.2 best describe the observed D.O. concentrations further downstream. While it was recognized that the K value was not constant throughout the whole River stretch, the computation of the sag curve based on K=0.2 produced a closely representative mathematical model of the observed sag curves. This mathematical model was then used for calculating future conditions. The evaluation of the X, Y and K values completed the input data required to run the computer program.

A sample calculation of the pollutional load (in population equivalents) for the Jackwood Collector in St. Jean is given as follows.

From the data obtained in Chapter VI the present population of St. Jean was 28,500. A detailed sewer layout map (22) showed that 68% of this population was serviced by the Jackwood Collector or a total connected population of 19,400. Table (6) shows that the total population serviced in St. Jean used 5 million imperial gallons per day and therefore the population connected to the Jackwood Collector used 68% of this or 3.4 million gallons per day.

In Chapter VII the ultimate B.O.D. of the sewage in the Jackwood Collector was determined as 730 mg/l with an immediate oxygen demand of 145 mg/l at 0.27 days.

The total oxygen requirements were 730 x 3.4 x 10 = 24,800 lbs., or in lbs./capita/day $= \frac{24,800}{19,400} = 1.28$. Gannon and Downs (9) in setting up the computer program for D.O. sag curve calculations have used 0.24 lbs./capita/day as the unit population equivalent. This value was applied in the calculations and the resulting population equivalent for the Jackwood Collector was determined as $\frac{1.28}{.24} \times 19,400 = 103,460$.

The immediate oxygen demand from Chapter VII was 145 mg/l or $\frac{145}{730} \times 103,460 = 20,500$ in population equivalents. The remaining B.O.D. was attributed to the suspended and settleable organic wastes. Phelps (15), Fair (8) and Klein (11) suggest that about 35% of this organic waste, in terms of B.O.D., is sludge. The values of ID, L, S were thus determined in population equivalents as 20,500, 53,960 and 29,000 respectively.

Similar calculations (22) were carried out for the Champlain Collector in St. Jean and the three major sewer outfalls in Iberville. The summation of all the pollutional sources in terms of ID, L and S for St. Jean and Iberville are the values appearing at milepoint 53.92 in Tables (10, 11, 12).

It should be noted that in Tables (10, 11, 12) the computations were done for three basic River discharges of 2470, 3000, and 3660 cfs. These three flow values are closely representative of the 20, 10, and 5 year return period of a one month drought as shown in Table (3). Also, the computations were standardized at 20°C. for the purpose of comparing the observed values of D.O. concentration which were standardized to 20°C and the three critical minimum River flows.

Where large population equivalent figures are shown in Tables (10, 11, 12), the value was determined for the River section or iteration number and includes all the contributing pollutional load within the River section.

The smaller population equivalent figures represent the pollutional effect of the scattered houses along the River banks. As discussed in Chapter VI all contributing pollutional loads have been considered and applied in the computer program. The computer program was run using the input data given in Tables (10, 11, 12) and the results are shown in Tables (14, 15, 16).

TABLE 14

```
          OXYGEN PROFILE OF RICHELIEU RIVER  1965  FLOW 2470 cfs

NUMBER OF STATIONS    27

NORMAL VALUE OF PERCENT OXYGEN SATURATION      84.00
INITIAL WASTE LOAD AT PO  40000.00
BOD AMORTIZATION RATE           .20



  NO. OF      MILEPOINT       PERCENT        TRUE PERCENT
  ITER.                      SATURATION       SATURATION

       1          53.92         81.23            75.90
       2          51.64         78.72            78.72
       3          49.74         78.05            78.05
       4          48.88         78.60            78.60
       5          45.26         85.11            85.11
       6          44.05         85.32            84.90
       7          43.25         84.79            84.48
       8          42.44         84.73            84.73
       9          41.81         84.04            84.04
      10          40.86         83.39            83.39
      11          39.92         82.59            82.35
      12          38.97         81.79            81.79
      13          38.03         81.69            81.69
      14          37.09         81.78            81.78
      15          36.14         79.26            77.41
      16          35.15         77.51            77.32
      17          34.25         76.96            76.83
      18          33.34         76.30            76.30
      19          32.40         76.08            76.08
      20          31.45         76.08            76.08
      21          30.51         75.99            75.99
      22          29.56         76.06            76.06
      23          28.42         76.42            76.42
      24          27.48         76.55            76.55
      25          26.54         76.83            76.83
      26          25.64         77.36            77.36
      27          24.70         77.99            77.99
```

TABLE 15

OXYGEN PROFILE OF RICHELIEU RIVER 1965 FLOW 3000 cfs

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 85.00
INITIAL WASTE LOAD AT PO 40000.00
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	82.42	77.83
2	51.64	80.13	80.13
3	49.74	79.70	79.70
4	48.88	80.05	80.05
5	45.26	85.20	85.20
6	44.05	85.44	85.09
7	43.25	85.13	84.86
8	42.44	84.33	84.33
9	41.81	83.87	83.87
10	40.86	83.44	83.44
11	39.92	82.86	82.66
12	38.97	82.22	82.22
13	38.03	82.17	82.17
14	37.09	82.19	82.19
15	36.14	79.90	78.33
16	35.15	78.36	78.20
17	34.25	77.94	77.83
18	33.34	77.45	77.45
19	32.40	77.28	77.28
20	31.45	77.22	77.22
21	30.51	77.39	77.39
22	29.56	77.39	77.39
23	28.42	77.67	77.67
24	27.48	77.74	77.74
25	26.54	77.91	77.91
26	25.64	78.28	78.28
27	24.70	78.73	78.73

TABLE 16

OXYGEN PROFILE OF RICHELIEU RIVER 1965 FLOW 3660 cfs

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 86.00
INITIAL WASTE LOAD AT PO 40000.00
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	83.72	79.95
2	51.64	81.77	81.77
3	49.74	81.58	81.58
4	48.88	81.82	81.82
5	45.26	85.89	85.89
6	44.05	86.05	85.77
7	43.25	85.95	85.75
8	42.44	86.12	86.12
9	41.81	85.78	85.78
10	40.86	85.43	85.43
11	39.92	85.00	84.84
12	38.97	84.50	84.50
13	38.03	84.38	84.38
14	37.09	83.75	82.75
15	36.14	80.73	79.46
16	35.15	79.36	79.23
17	34.25	79.02	78.93
18	33.34	78.63	78.63
19	32.40	78.48	78.48
20	31.45	78.41	78.41
21	30.51	78.31	78.31
22	29.56	78.27	78.27
23	28.42	78.45	78.45
24	27.48	78.49	78.49
25	26.54	78.60	78.60
26	25.64	78.86	78.86
27	24.70	79.21	79.21

Observed Dissolved Oxygen Concentration

The method of Churchill and Buckingham (5) discussed in Chapter III and IV was used to calculate the D.O. drop between stations. This method requires a considerable amount of calculation and Table (17) summarizes the calculated results available in detail at McGill (22).

In Table (18) a summary of the observed D.O. concentrations for various stations is given. The analysis was done using two portable dissolved oxygen analysers in the field. At each station multiple readings were taken on each instrument and the average at each station, standardized to 20°C, is given in the Table.

In Table (19) the dissolved oxygen values were determined by the Winkler method. Although samples were analysed in the laboratory the elapsed time from collection to analysis was less than two hours. Care was taken to keep the samples as cold as possible during transportation so that the analysis would be representative of the River condition.

The basic flow referred to in Tables (18, 19) is the flow at Fryers Island on the sample date. Since it was not possible to obtain samples during flow periods identical to the flow values used in the computer program, a correction was introduced to obtain the % saturation at a flow of 3660 cfs. Table (13) shows an approximate relationship of 1% increase in flow for each 600 cfs increase in flow. This relationship was applied for corrections in D.O. when the difference between basic flow and the desired flow of 3660 was less than 300 cfs. The tabulated values are given to the nearest ½%.

The results of the computed D.O. sag curves given in Tables (14, 15, 16) and the observed D.O. sag curves given in Tables (17, 18, 19) are plotted in (Figures 23, 24, 25).

Forecast Oxygen Sag Curves for Ten and Twenty Years

The computed oxygen sag curves agree with the observed dissolved oxygen saturation to ± 2% which was determined previously as the 95% confidence limit. The computed curve therefore described the actual conditions sufficiently well and was used to calculate the oxygen sag curve for future conditions of flow, pollutional load, and reduction in pollutional load by waste water treatment.

In Chapter II the return period of the critical one month drought flow was determined as 3000 cfs once in ten years and 2500 cfs once in twenty years. River flow data was previously established for 3000, and 2470 cfs and these values were used for the ten and twenty year return periods respectively. The error introduced by using 2470 cfs instead of 2500 cfs for the twenty year return period was approximately 0.05% of the dissolved oxygen saturation value as determined from Table (13). Since the increase in population and pollutional loading is a function of time, the critical conditions within the ten and twenty year return periods were evaluated for the tenth year (1975) and twentieth year (1985) at River flow values of 3000 and 2470 cfs respectively.

In Chapter VI the population forecasts were determined and the pollutional loads were calculated for 1975 and 1985 by the same method as illustrated for the Jackwood Collector in St. Jean. The results of these calculations with no treatment of wastes are given in Table (20, 22).

The calculation of pollutional loads after waste water treatment was based on the following considerations.

Phelps (15) gives the efficiencies of primary treatment plants as: 50% reduction in B.O.D. of suspended organic wastes,

30% reduction in B.O.D. of settleable organic wastes, and

2 hours detention time in treatment.

In the case of the Jackwood Collector, the reduction in ID_j was the detention time in treatment divided by the development time of the ID or 2 hours out of .27 days = 31%. Reduction in L_j = 50% and the reduction in S_j = 30%.

The remaining pollutional loads were calculated in population equivalents and are given in Tables (21, 23).

Phelps (15) gives the general efficiencies of secondary treatment as follows. Total removal of ID_j, 70% removal of L_j and 70% removal of S_j. The calculations are the same as before and the results are given in Table (24).

Since it was not known what degree of treatment, if any, would be provided for the towns along the River the computer input data were calculated assuming that all waste discharges would be treated similarly. The computer results of the oxygen sag curve calculations are given in Tables (25, 26, 27, 28, 29) and are plotted in (Figures 26, 27, 28, 29, 30).

TABLE 17

COMPUTED Y DROP STATION TO STATION BY CHURCHILL METHOD

Stations	Basic flow cfs	Y drop %	Change in Sat. %
17 to 15	2470	-1	83 to 82
15 to 11	2470	-6	82 to 76
11 to 9	2470	0	76 to 76
5 to 3	2470	1	76 to 77
21 to 20	3000	6	83 to 87
20 to 19	3000	-3	87 to 84
19 to 18	3000	-2	84 to 82

TABLE 17 (continued)

COMPUTED Y DROP STATION TO STATION BY CHURCHILL METHOD

Stations	Basic flow cfs	Y drop %	Change in Sat. %
16 to 14	3000	-1	81 to 80
14 to 12	3000	-2	80 to 78
12 to 10	3000	-2	78 to 76
10 to 8	3000	0	76 to 76
4 to 2	3000	4	76 to 80
25 to 21	3660	-4	86 to 82
20 to 12	3660	-6	86 to 80
12 to 1	3660	0	80 to 80

TABLE 18

OBSERVED D.O. % SATURATION - OXYGEN ANALYSERS

Station	Basic Flow	D.O. % Sat.	D.O. % Sat. at Flow 3660
1	3580	78	78.5
1	3670	80	80.0
6	3670	79	78.5
10	3670	79	78.5
12	3670	79	78.5
19	3660	85	85.0

TABLE 19

D.O. % SATURATION - WINKLER METHOD

Station	Basic Flow	D.O. % Sat.	D.O. % Sat. at Flow 3660
25	3956	88	87
24	3662	80	80
22	3662	81	81
20	3872	87	86.5
19	3788	86.5	86
19	3872	88.0	87
17	3788	85.5	85
17	3830	86	85

TABLE 20

********** POLLUTIONAL LOAD - 1975 - NO TREATMENT

X	Y	K
83.00	60000.	0.10
83.00	60000.	0.20
83.00	60000.	0.30
83.00	60000.	0.40
83.00	60000.	0.50
83.00	60000.	0.75
83.00	60000.	1.00

P	T	V	D	Q	L	S	ID
53.924	22.5	500.85	4.30	2918.87	105410.	63665.	35560.
51.639	22.1	646.50	4.60	2923.97	510.	0.	0.
49.744	22.8	734.47	9.15	2927.92	630.	0.	0.
48.883	21.5	241.65	6.9	2930.0	770.	0.	0.
45.258	22.5	809.32	4.0	2932.14	202.	0.	0.
44.053	21.0	120.	4.0	2940.0	99750.	9360.	8909.
43.250	20.0	280.	5.0	3000.	8350.	2520.	2680.
42.443	19.5	300.	9.0	3025.0	415.	0.	0.
41.810	19.1	215.	11.7	3054.24	1800.	0.	0.
40.863	19.0	325.10	9.6	3055.16	8317.	0.	0.
39.917	19.5	340.5	11.5	3055.4	11192.	3000.	600.
38.971	19.5	330.38	10.8	3057.6	192.	0.	0.
38.025	19.3	300.37	8.5	3062.42	72.	0.	0.
37.090	19.1	285.30	8.50	3066.78	5000.	0.	0.
36.144	19.0	182.1	5.40	3067.24	45505.	44050.	15020.
35.149	18.9	166.9	4.75	3068.56	17000.	10200.	2800.
34.249	19.0	262.20	9.60	3069.13	2100.	900.	1500.
33.344	19.0	335.18	12.2	3069.74	45.	0.	0.
32.398	19.8	334.42	11.3	3070.50	550.	0.	0.
31.452	19.4	333.30	10.8	3072.95	245.	0.	0.
30.506	19.6	288.00	9.5	3073.93	120.	0.	0.
29.560	19.5	379.27	11.8	3078.80	124.	0.	0.
28.424	19.5	438.90	10.6	3091.55	222.	0.	0.
27.478	19.5	313.42	12.3	3091.58	1350.	0.	0.
26.542	19.5	307.87	11.5	3091.85	250.	0.	0.
25.635	19.7	282.00	9.78	3095.80	700.	0.	0.
24.700	21.2	289.47	9.25	3096.29	390.	0.	0.

TABLE 21

********** POLLUTIONAL LOAD - 1975 - PRIMARY TREATMENT

X	Y	K
86.50	30000.	0.10
86.50	30000.	0.20
86.50	30000.	0.30
86.50	30000.	0.40
86.50	30000.	0.50
86.50	30000.	0.75
86.50	30000.	1.00

P	T	V	D	Q	L	S	ID
53.924	22.5	500.85	4.30	2918.87	52660.	44660.	23182.
51.639	22.1	646.50	4.60	2923.97	510.	0.	0.
49.744	22.8	734.47	9.15	2927.92	630.	0.	0.
48.883	21.5	241.65	6.9	2930.0	770.	0.	0.
45.258	22.5	809.32	4.0	2932.14	202.	0.	0.
44.053	21.0	120.	4.0	2940.0	50875.	1750.	5930.
43.250	20.0	280.	5.0	3000.	4175.	1770.	2560.
42.443	19.5	300.	9.0	3025.0	415.	0.	0.
41.810	19.1	215.	11.7	3054.24	1800.	0.	0.
40.863	19.0	325.10	9.6	3055.16	4317.	0.	0.
39.917	19.5	340.5	11.5	3055.4	5692.	2100.	0.
38.971	19.5	330.38	10.8	3057.6	192.	0.	0.
38.025	19.3	300.37	8.5	3062.42	72.	0.	0.
37.090	19.1	285.30	8.50	3066.78	5000.	0.	0.
36.144	19.0	182.1	5.40	3067.24	17855.	34680.	11980.
35.149	18.9	166.9	4.75	3068.56	8500.	7150.	2200.
34.249	19.0	262.20	9.60	3069.13	1050.	630.	1200.
33.344	19.0	335.18	12.2	3069.74	45.	0.	0.
32.398	19.8	334.42	11.3	3070.50	550.	0.	0.
31.452	19.4	333.30	10.8	3072.95	245.	0.	0.
30.506	19.6	288.00	9.5	3073.93	120.	0.	0.
29.560	19.5	379.27	11.8	3078.80	124.	0.	0.
28.424	19.5	438.90	10.6	3091.55	222.	0.	0.
27.478	19.5	313.42	12.3	3091.58	800.	0.	0.
26.542	19.5	307.87	11.5	3091.85	250.	0.	0.
25.635	19.7	282.00	9.78	3095.80	700.	0.	0.
24.700	21.2	289.47	9.25	3096.29	390.	0.	0.

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TABLE 22

**********   POLLUTIONAL LOAD - 1985 - NO TREATMENT

X	Y	K
77.00	100000.	0.10
77.00	100000.	0.20
77.00	100000.	0.30
77.00	100000.	0.40
77.00	100000.	0.50
77.00	100000.	0.75
77.00	100000.	1.00

P	T	V	D	Q	L	S	ID
53.924	22.5	493.0	4.20	2460.65	128030.	49005.	43350.
51.639	22.1	647.0	4.5	2464.93	850.	0.	0.
49.744	22.8	743.0	9.0	2468.25	1050.	0.	0.
48.880	21.5	241.0	6.5	2470.0	1920.	0.	0.
45.258	22.5	835.	4.0	2471.80	508.	0.	0.
44.050	21.0	110.0	4.0	2475.30	144700.	10800.	10280.
43.250	20.0	190.	4.8	2500.	10600.	3200.	3400.
42.443	19.5	190.	4.8	2550.	690.	0.	0.
41.809	19.1	212.	11.5	2573.30	3000.	0.	0.
40.863	19.0	317.	9.35	2574.07	11130.	0.	0.
39.917	19.5	334.	11.0	2574.23	19320.	6650.	0.
38.970	19.5	313.	10.3	2576.06	320.	0.	0.
38.025	19.3	240.	8.30	2576.46	120.	0.	0.
37.090	19.1	263.0	7.65	2580.13	8000.	0.	0.
36.144	19.0	153.	4.55	2580.51	59245.	45253.	24752.
35.149	18.9	156.	4.47	2581.61	33156.	20360.	4654.
34.249	19.0	253.	9.3	2582.09	3617.	1050.	2333.
33.344	19.0	328.	12.0	2582.60	75.	0.	0.
32.398	19.8	323.	10.9	2584.90	920.	0.	0.
31.452	19.4	322.	10.2	2585.30	410.	0.	0.
30.506	19.6	351.	11.6	2586.13	420.	0.	0.
29.560	19.5	365.	11.35	2587.71	210.	0.	0.
28.424	19.5	432.	10.8	2601.46	370.	0.	0.
27.478	19.5	238.	11.9	2603.17	1900.	0.	0.
26.542	19.5	288.	10.9	2603.40	420.	0.	0.
25.635	19.7	267.0	9.25	2606.72	117.	0.	0.
24.700	21.2	292.	9.0	2607.13	650.	0.	0.

TABLE 23

```
**********     POLLUTIONAL LOAD - 1985 - PRIMARY TREATMENT

     X        Y           K
   83.50   50000.        0.10
   83.50   50000.        0.20
   83.50   50000.        0.30
   83.50   50000.        0.40
   83.50   50000.        0.50
   83.50   50000.        0.75
   83.50   50000.        1.00

    P         T         V         D           Q         L       S         ID
53.924    22.5      493.0     4.20       2460.65  63615.   33995.    28110.
51.639    22.1      647.0     4.5        2464.93  850.     0.        0.
49.744    22.8      743.0     9.0        2468.25  1050.    0.        0.
48.880    21.5      241.0     6.5        2470.0   1920.    0.        0.
45.258    22.5      835.      4.0        2471.80  508.     0.        0.
44.050    21.0      110.0     4.0        2475.30  70350.   7550.     6820.
43.250    20.0      190.      4.8        2500.    5300.    2540.     3150.
42.443    19.5      190.      4.8        2550.    690.     0.        0.
41.809    19.1      212.      11.5       2573.30  3000.    0.        0.
40.863    19.0      317.      9.35       2574.07  5830.    0.        0.
39.917    19.5      334.      11.0       2574.23  9820.    4650.     0.
38.970    19.5      313.      10.3       2576.06  320.     0.        0.
38.025    19.3      240.      8.30       2576.46  120.     0.        0.
37.090    19.1      263.0     7.65       2580.13  8000.    0.        0.
36.144    19.0      153.      4.55       2580.51  29615.   31590.    33670.
35.149    18.9      156.      4.47       2581.61  16600.   14200.    3700.
34.249    19.0      253.      9.3        2582.09  1808.    735.      1870.
33.344    19.0      328.      12.0       2582.60  75.      0.        0.
32.398    19.8      323.      10.9       2584.90  920.     0.        0.
31.452    19.4      322.      10.2       2585.30  410.     0.        0.
30.506    19.6      351.      11.6       2586.13  420.     0.        0.
29.560    19.5      365.      11.35      2587.71  210.     0.        0.
28.424    19.5      432.      10.8       2601.46  370.     0.        0.
27.478    19.5      238.      11.9       2603.17  1200.    0.        0.
26.542    19.5      288.      10.9       2603.40  420.     0.        0.
25.635    19.7      267.0     9.25       2606.72  117.     0.        0.
24.700    21.2      292.      9.0        2607.13  650.     0.        0.
```

```
                               TABLE 24

**********       POLLUTIONAL LOAD - 1985 - SECONDARY TREATMENT

    X        Y         K
  86.50    30000.   0.10
  86.50    30000.   0.20
  86.50    30000.   0.30
  86.50    30000.   0.40
  86.50    30000.   0.50
  86.50    30000.   0.75
  86.50    30000.   1.00
   P       T        V       D         Q         L        S        ID
53.924   22.5     493.0     4.20    2460.65   38265.   14702.   0.
51.639   22.1     647.0     4.5     2464.93   850.     0.       0.
49.744   22.8     743.0     9.0     2468.25   1050.    0.       0.
48.880   21.5     241.0     6.5     2470.0    1920.    0.       0.
45.258   22.5     835.      4.0     2471.80   508.     0.       0.
44.050   21.0     110.0     4.0     2475.30   42860.   3250.    0.
43.250   20.0     190.      4.8     2500.     3180.    960.     0.
42.443   19.5     190.      4.8     2550.     690.     0.       0.
41.809   19.1     212.     11.5     2573.30   3000.    0.       0.
40.863   19.0     317.      9.35    2574.07   3530.    0.       0.
39.917   19.5     334.     11.0     2574.23   6020.    2000.    0.
38.970   19.5     313.     10.3     2576.06   320.     0.       0.
38.025   19.3     240.      8.30    2576.46   120.     0.       0.
37.090   19.1     263.0     7.65    2580.13   8000.    0.       0.
36.144   19.0     153.      4.55    2580.51   18725.   13580.   0.
35.149   18.9     156.      4.47    2581.61   10000.   6000.    0.
34.249   19.0     253.      9.3     2582.09   1080.    300.     0.
33.344   19.0     328.     12.0     2582.60   75.      0.       0.
32.398   19.8     323.     10.9     2584.90   920.     0.       0.
31.452   19.4     322.     10.2     2585.30   410.     0.       0.
30.506   19.6     351.     11.6     2586.13   420.     0.       0.
29.560   19.5     365.     11.35    2587.71   210.     0.       0.
28.424   19.5     432.     10.8     2601.46   370.     0.       0.
27.478   19.5     238.     11.9     2603.17   1020.    0.       0.
26.542   19.5     208.     10.9     2603.40   420.     0.       0.
25.635   19.7     267.0     9.25    2606.72   117.     0.       0.
24.700   21.2     292.      9.0     2607.13   650.     0.       0.
```

TABLE 25

OXYGEN PROFILE OF RICHELIEU RIVER 1975 NO TREATMENT

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 83.00
INITIAL WASTE LOAD AT PO 60000.00
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	76.71	71.33
2	51.64	75.47	75.47
3	49.74	75.33	75.33
4	48.88	76.03	76.03
5	45.26	83.42	83.42
6	44.05	82.60	81.15
7	43.25	80.82	80.41
8	42.44	81.19	81.19
9	41.81	80.86	80.86
10	40.86	80.60	80.60
11	39.92	79.95	79.89
12	38.97	79.62	79.62
13	38.03	79.71	79.71
14	37.09	79.84	79.84
15	36.14	76.34	74.94
16	35.15	74.84	74.59
17	34.25	74.42	74.28
18	33.34	73.93	73.93
19	32.40	73.92	73.92
20	31.45	73.93	73.93
21	30.51	74.22	74.22
22	29.56	74.29	74.29
23	28.42	74.68	74.68
24	27.48	74.81	74.81
25	26.54	75.05	75.05
26	25.64	75.52	75.52
27	24.70	75.67	75.67

TABLE 26

OXYGEN PROFILE OF RICHELIEU RIVER 1975 PRIMARY TREATMENT

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 86.50
INITIAL WASTE LOAD AT PO 30000.00
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	82.71	79.20
2	51.64	83.02	83.02
3	49.74	83.62	83.62
4	48.88	84.21	84.21
5	45.26	89.51	89.51
6	44.05	89.65	88.68
7	43.25	88.50	88.10
8	42.44	87.43	87.43
9	41.81	87.32	87.32
10	40.86	87.32	87.32
11	39.92	87.03	87.03
12	38.97	86.99	86.99
13	38.03	87.17	87.17
14	37.09	87.34	87.34
15	36.14	84.54	83.43
16	35.15	83.42	83.22
17	34.25	83.27	83.16
18	33.34	83.12	83.12
19	32.40	83.27	83.27
20	31.45	83.43	83.43
21	30.51	83.72	83.72
22	29.56	83.89	83.89
23	28.42	84.26	84.26
24	27.48	84.43	84.43
25	26.54	84.65	84.65
26	25.64	84.99	84.99
27	24.70	84.23	84.23

TABLE 27

OXYGEN PROFILE OF RICHELIEU RIVER 1985 NO TREATMENT

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 77.00
INITIAL WASTE LOAD AT PO * .10E+06
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	73.12	65.54
2	51.64	69.89	69.89
3	49.74	68.52	68.52
4	48.88	69.42	69.42
5	45.26	79.87	79.87
6	44.05	78.56	76.58
7	43.25	75.53	74.90
8	42.44	76.40	76.40
9	41.81	75.57	75.57
10	40.86	74.81	74.81
11	39.92	73.18	73.18
12	38.97	72.51	72.51
13	38.03	72.44	72.44
14	37.09	72.61	72.61
15	36.14	68.75	66.04
16	35.15	65.10	64.59
17	34.25	64.10	63.84
18	33.34	62.98	62.98
19	32.40	62.80	62.80
20	31.45	62.72	62.72
21	30.51	62.63	62.63
22	29.56	62.72	62.72
23	28.42	63.27	63.27
24	27.48	63.46	63.46
25	26.54	63.90	63.90
26	25.64	64.76	64.76
27	24.70	65.04	66.04

TABLE 28

OXYGEN PROFILE OF RICHELIEU RIVER 1985 PRIMARY TREATMENT

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 83.50
INITIAL WASTE LOAD AT PO 50000.00
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	81.43	76.51
2	51.64	80.65	80.65
3	49.74	80.72	80.72
4	48.88	81.42	81.42
5	45.26	88.24	88.24
6	44.05	87.20	85.89
7	43.25	85.33	84.74
8	42.44	84.81	84.81
9	41.81	84.48	84.48
10	40.86	84.27	84.27
11	39.92	83.43	83.43
12	38.97	83.24	83.24
13	38.03	83.34	83.34
14	37.09	83.59	83.59
15	36.14	80.84	77.15
16	35.15	76.56	76.16
17	34.25	76.12	75.91
18	33.34	75.68	75.68
19	32.40	75.84	75.84
20	31.45	76.04	76.04
21	30.51	76.20	76.20
22	29.56	76.46	76.46
23	28.42	77.00	77.00
24	27.48	77.22	77.22
25	26.54	77.60	77.60
26	25.64	78.21	78.21
27	24.70	78.07	78.07

TABLE 29

OXYGEN PROFILE OF RICHELIEU RIVER 1985 SECONDARY TREATMENT

NUMBER OF STATIONS 27

NORMAL VALUE OF PERCENT OXYGEN SATURATION 86.50
INITIAL WASTE LOAD AT PO 30000.00
BOD AMORTIZATION RATE .20

NO. OF ITER.	MILEPOINT	PERCENT SATURATION	TRUE PERCENT SATURATION
1	53.92	87.35	87.35
2	51.64	89.81	89.81
3	49.74	89.63	89.63
4	48.88	89.84	89.84
5	45.26	93.45	93.45
6	44.05	92.92	92.92
7	43.25	92.46	92.46
8	42.44	90.31	90.31
9	41.81	90.10	90.10
10	40.86	89.97	89.97
11	39.92	89.55	89.55
12	38.97	89.43	89.43
13	38.03	89.50	89.50
14	37.09	89.66	89.66
15	36.14	88.61	88.61
16	35.15	88.42	88.42
17	34.25	88.25	88.25
18	33.34	87.95	87.95
19	32.40	87.82	87.82
20	31.45	87.80	87.80
21	30.51	87.73	87.73
22	29.56	87.74	87.74
23	28.42	87.86	87.86
24	27.48	87.91	87.91
25	26.54	88.04	88.04
26	25.64	88.29	88.29
27	24.70	89.67	89.67

FIGURE 23

OXYGEN SAG CURVE 1965 -FLOW 2470- NO TREATMENT OF WASTES

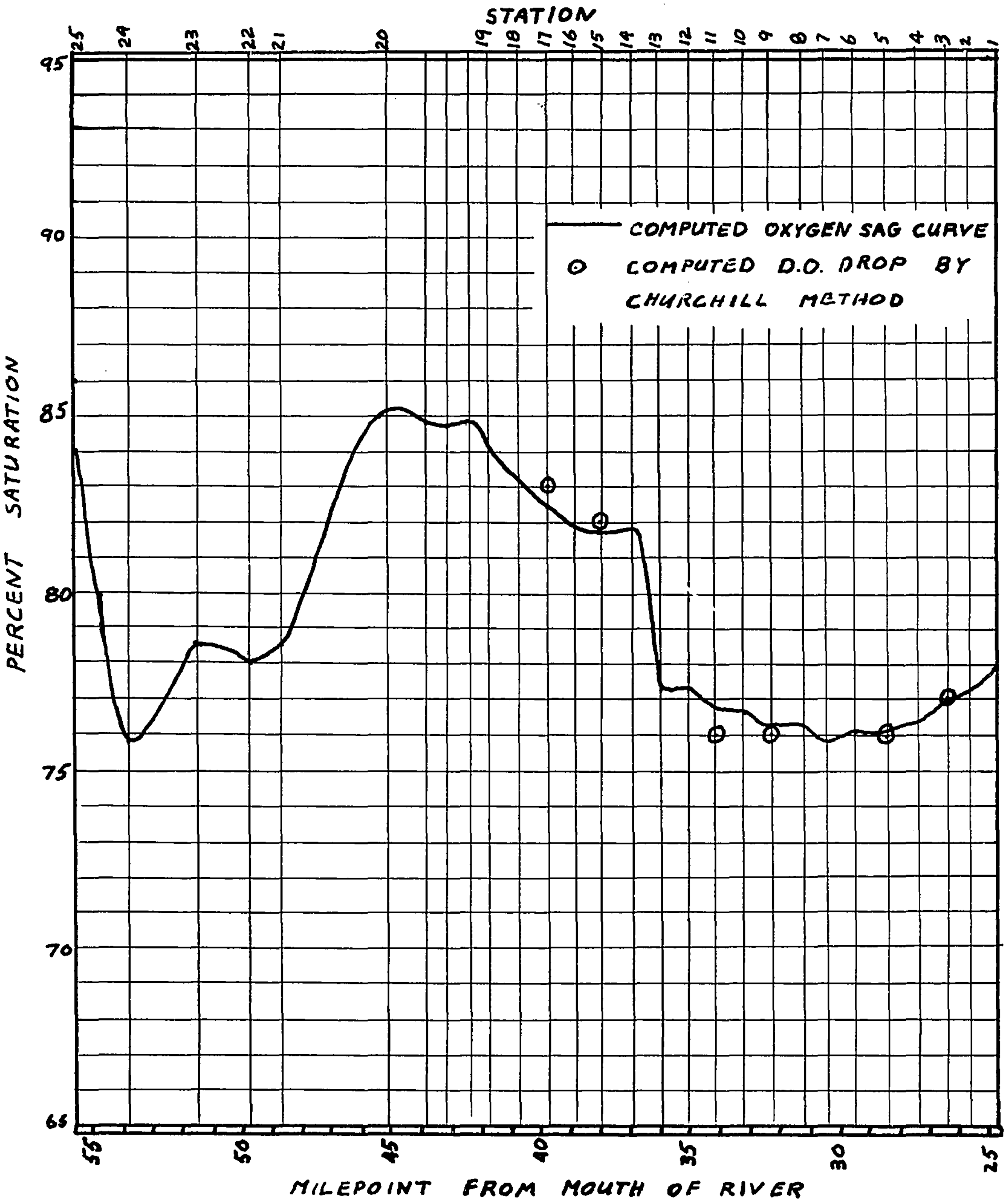


FIGURE 24

OXYGEN SAG CURVE 1965 -FLOW 3000 cfs- NO TREATMENT OF WASTES

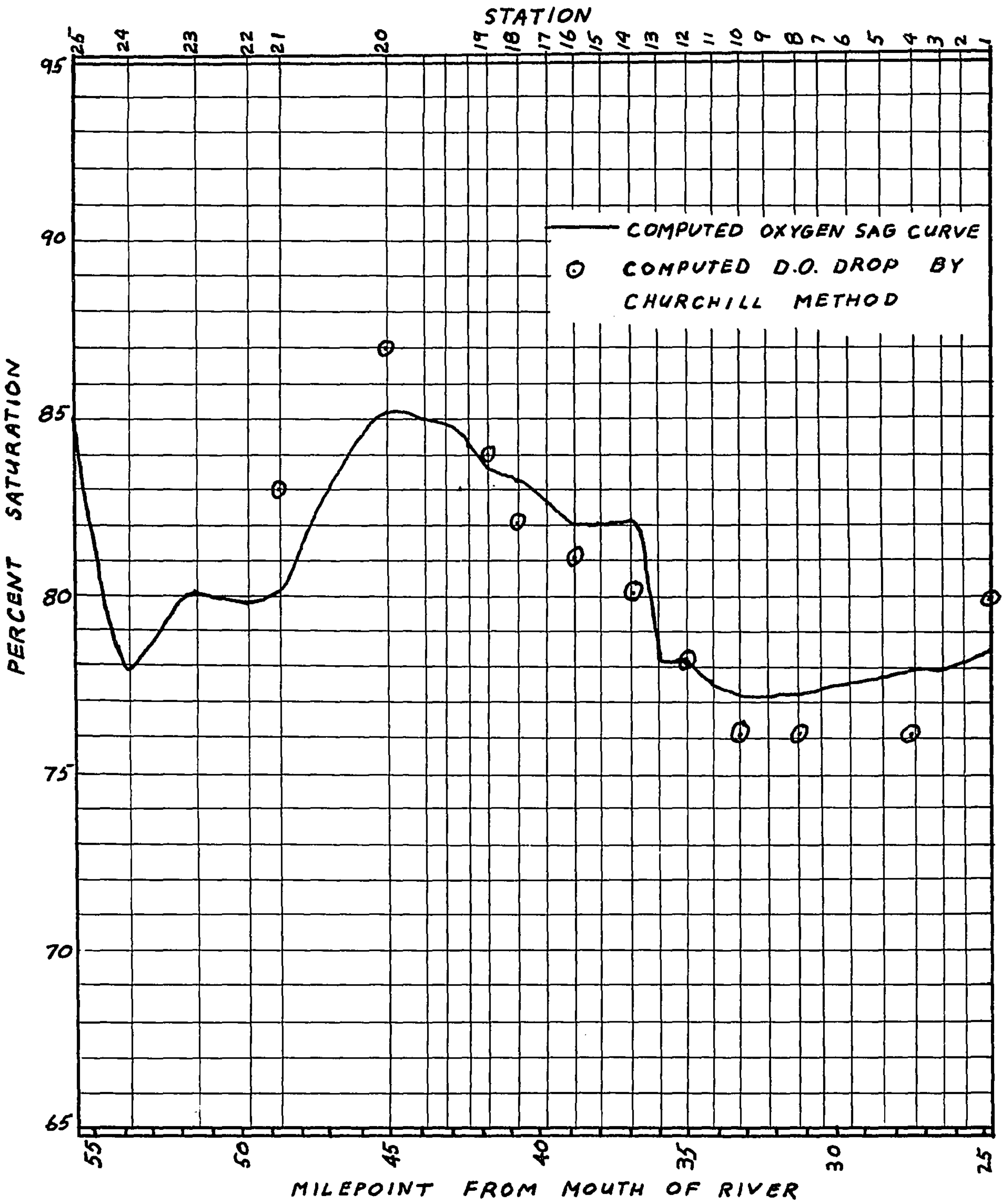


FIGURE 25

OXYGEN SAG CURVE 1965 -FLOW 3660 cfs- NO TREATMENT OF WASTES

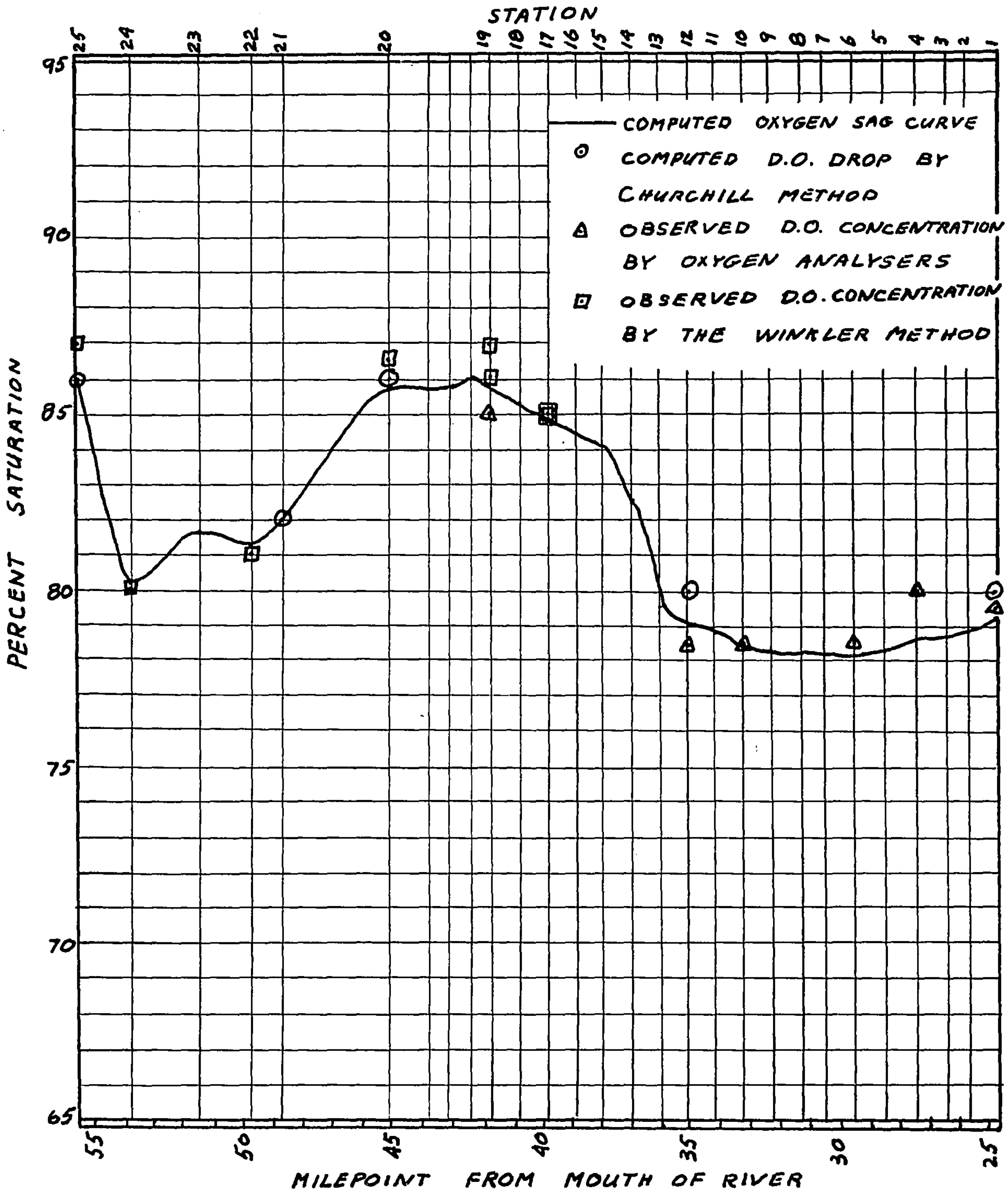


FIGURE 26

COMPUTED OXYGEN SAG CURVE 1975 -FLOW 3000 cfs- NO TREATMENT OF WASTES

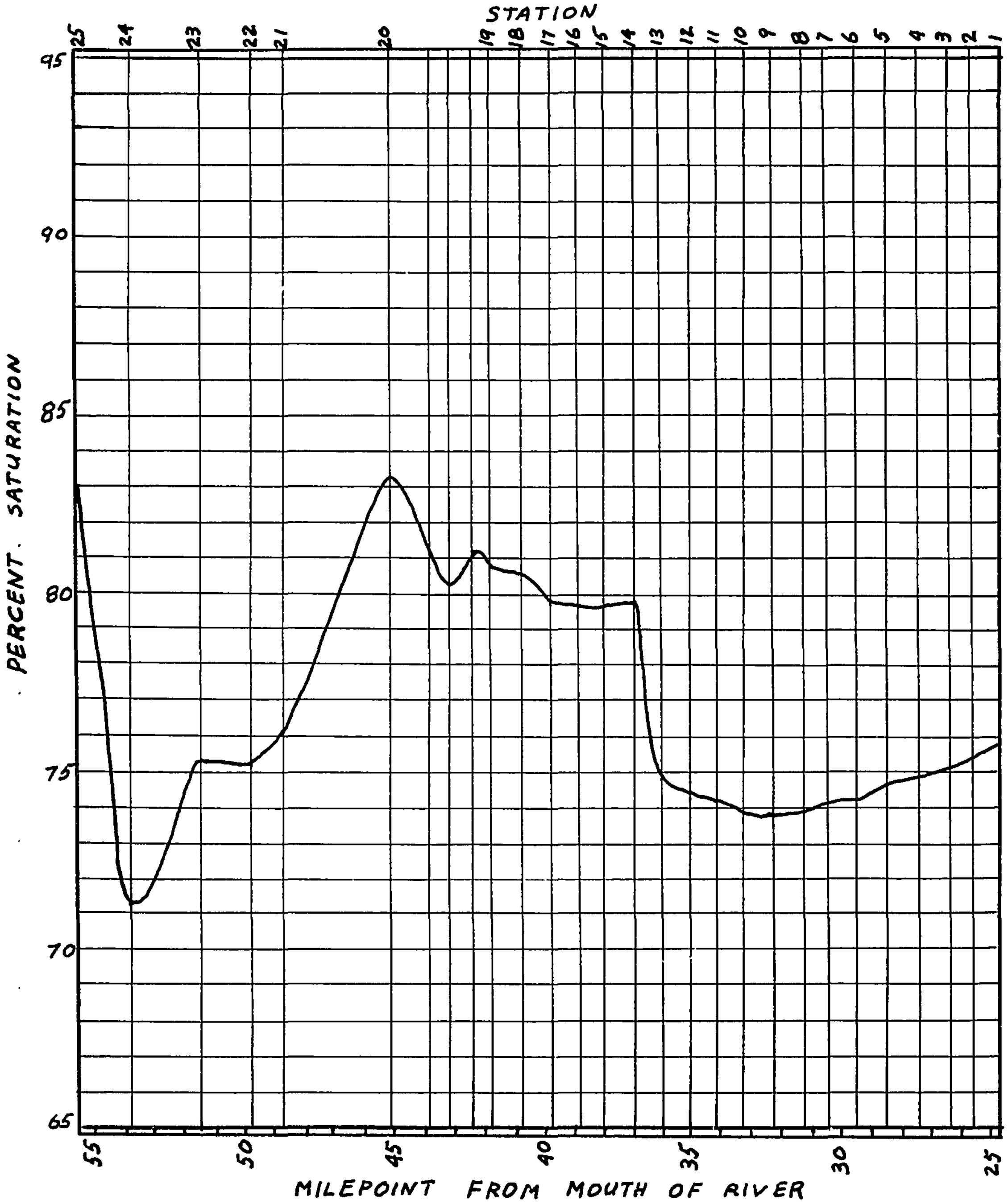


FIGURE 27

COMPUTED OXYGEN SAG CURVE 1975 -FLOW 3000 cfs- PRIMARY TREATMENT

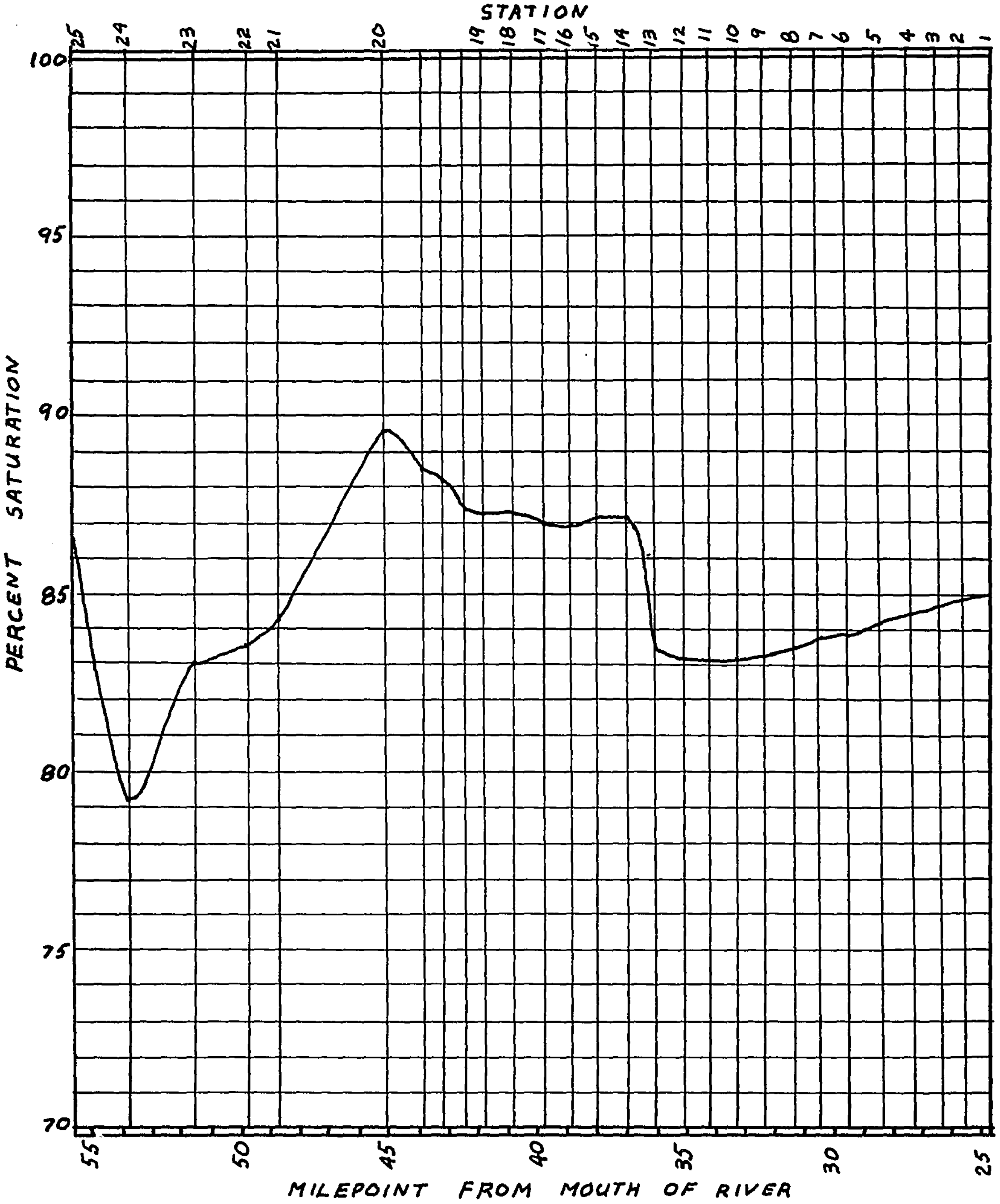


FIGURE 28

COMPUTED OXYGEN SAG CURVE 1985 -FLOW 2470cfs- NO TREATMENT

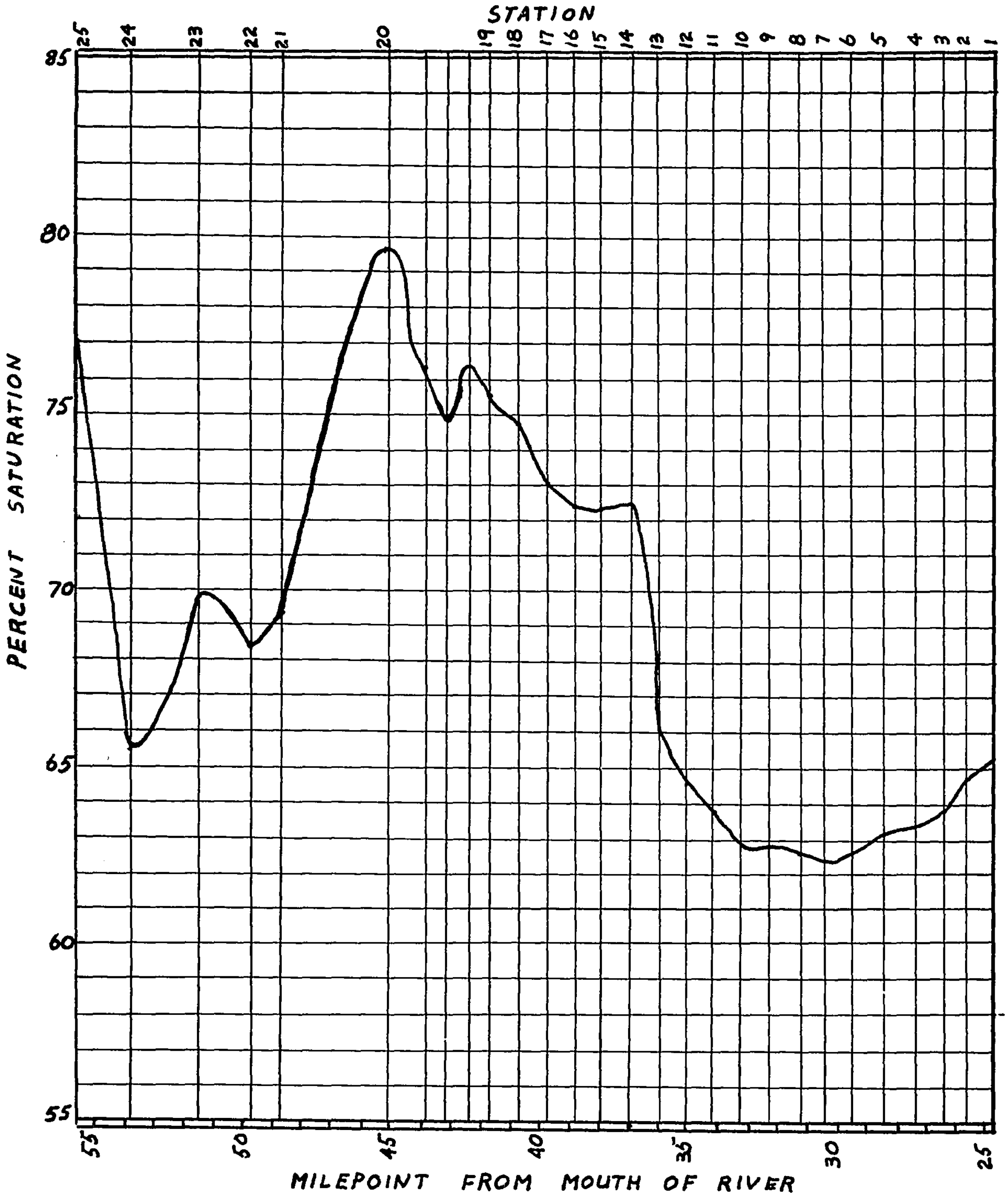


FIGURE 29

COMPUTED OXYGEN SAG CURVE 1985 -FLOW 2470 cfs- PRIMARY TREATMENT

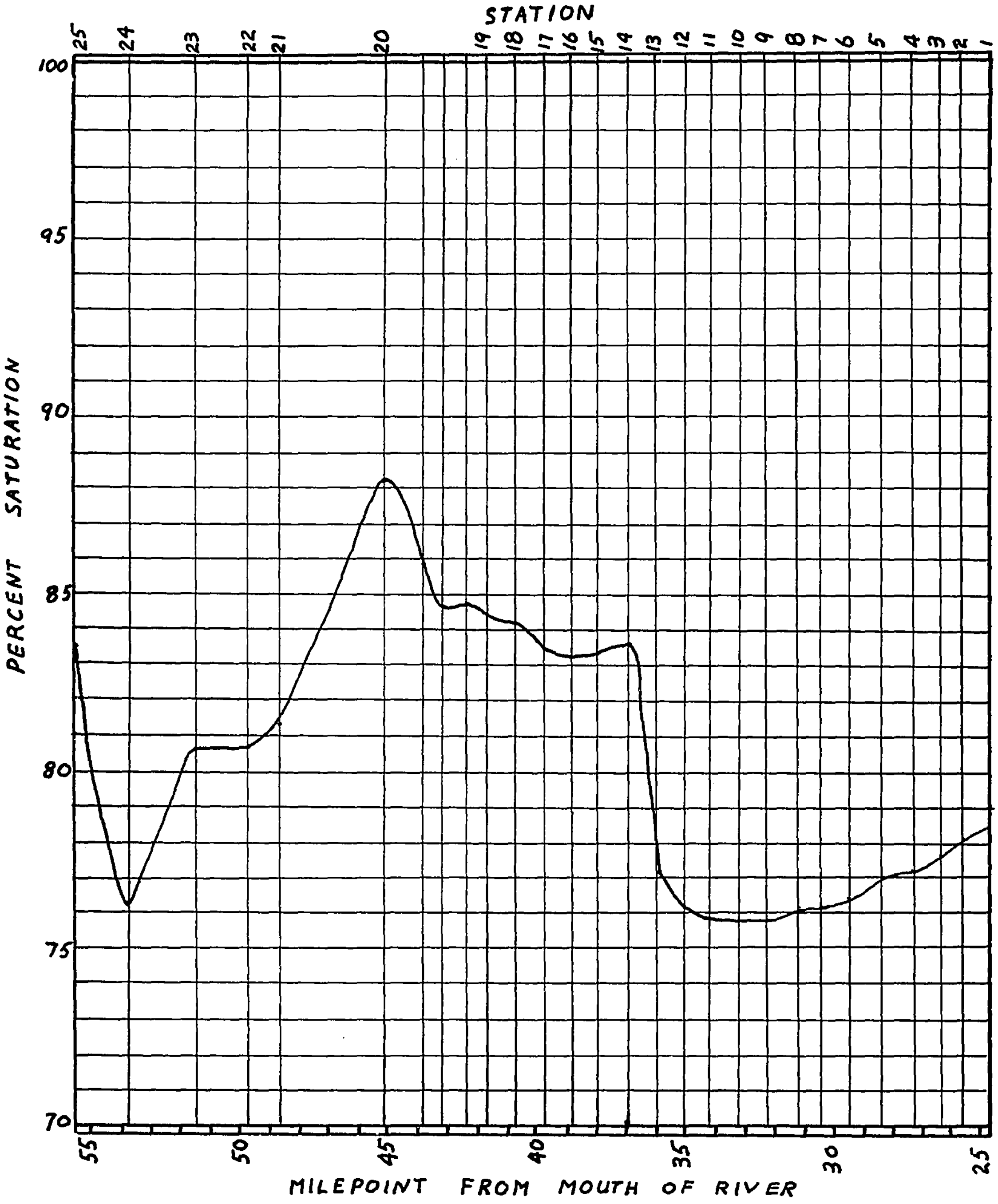
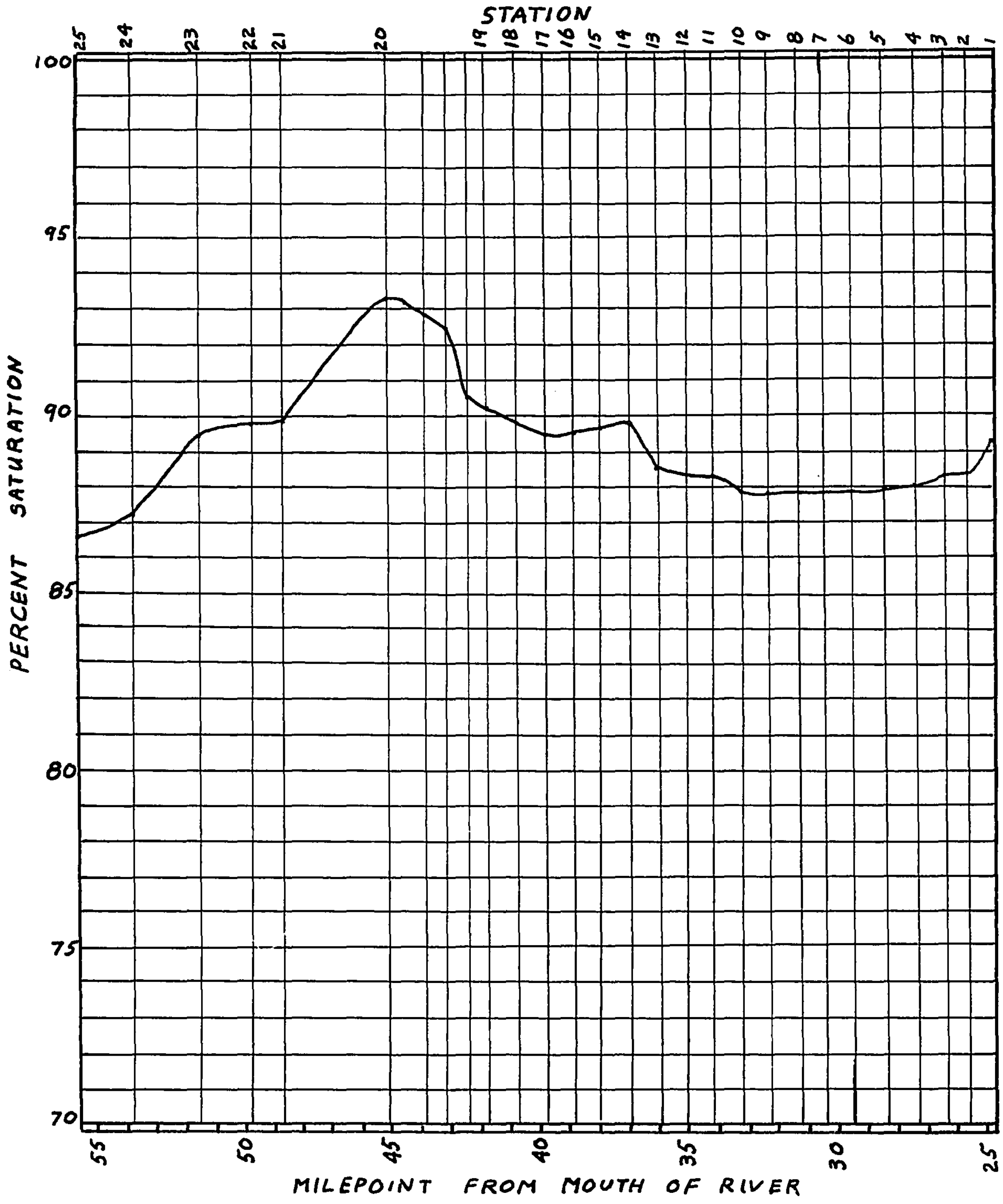


FIGURE 30

COMPUTED OXYGEN SAG CURVE 1985 -FLOW 2470 cfs- SECONDARY TREATMENT



CHAPTER IX

CONCLUSIONS

The dissolved oxygen concentration in the River and the pollutional loads causing these oxygen sag curves have been analysed and the following may be concluded.

1. The most obvious oxygen sag points occurred just below St. Jean, Chambly and McMasterville. These three regions are the most heavily populated and industrialized areas between St. Jean and St. Charles.

2. The recovery of the oxygen sag curve below St. Jean is completed at Chambly Basin. The oxygen sag curve at McMasterville is only slightly recovered at St. Charles.

3. The observed dissolved oxygen concentrations at the outlet of Chambly Basin were about one percent higher than those calculated. The effect of the dam at Fort Chambly affects the reaeration in the River to this extent.

4. The pollutional load imposed on the River at present does not lower dissolved oxygen concentrations below 75% saturation.

5. The ten and twenty year forecast pollutional load with no treatment would cause dissolved oxygen concentrations of not less than 70% and 60% respectively.

6. If primary treatment of all waste discharges is provided, the ten and twenty year forecast oxygen sag curve would reach a minimum at 79% and 75% saturation respectively.

7. Secondary treatment of the forecasted twenty year pollutional load would cause a minimum value in the oxygen sag curve of 86% saturation.

8. The analysis of a few River water samples showed a negative B.O.D. where the total B.O.D. was very small. This condition was a result of measuring a B.O.D. value beyond the sensitivity of the analysing instruments. Samples exhibiting a very small or negative B.O.D. could not have been taken from a sag station and therefore did not affect the calculation of the oxygen sag curve by the Churchill method.

9. The modified multi-linear correlation was successfully applied to the data for the computation of K_1 values of wastes.

10. The data analysed for the D.O. distribution within the cross section of the River showed that samples taken from the ship channel were representative of the whole cross section to ± 2% at the 95% confidence limit.

In this analysis the negative B.O.D. values were included to evaluate all the variations affecting the reliability of the sampling procedure. The program was written to accommodate negative B.O.D. values.

11. The method of evaluating the on-shore pollutional load was sufficiently accurate to obtain observed and computed sag curve agreement to better than ± 2% as established at the 95% confidence limit.

12. For small variations in River flow, the oxygen sag curve remains relatively unchanged. The general relationship of 1% increase in D.O. saturation for each 600 cfs increase in flow holds true for observed and computed D.O. concentrations.

13. An average K_1 value for the River water of 0.20 produced a computed oxygen sag curve that agreed well with the observed oxygen sag curve.

14. The effectiveness in reaeration of the shallow turbulent flow of the River between St. Jean and Chambly is shown by the rapid recovery of the oxygen sag curve in this region.

15. From D.O. and B.O.D. considerations the Richelieu River can be classified, according to Phelps (15), as Class A, or can serve as a source of public water supply after filtration.

BIBLIOGRAPHY

1. Aitkens, A.C. Statistical Mathematics, Oliver and Boyd Interscience Publishers Ltd., Eighth edition (1962).

2. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. American Public Health Association Inc., Eleventh edition (1960).

3. Bonin, R. Representative Sampling and Analytical Methods in Stream Studies. Sewage and Industrial Waste Journal. 30, 6: 812 (1958).

4. Bowker, A.H., and Leiberman, G.J. Engineering Statistics. Prentice Hall Inc., (1961)

5. Churchill, M.A., and Buckingham, R.A. Statistical Methods for Analysis of Stream Purification Capacity. Sewage and Industrial Waste Journal, 28, 4: 517 (1956).

6. Croxton, F.E., and Cowden, D.J. Applied General Statistics. Prentice Hall, Inc., (1958).

7. Eckenfelder, W.W., and O'Connor, D.J. Biological Waste Treatment. Pergamon Press, New York, (1961).

8. Fair, G.M., and Geyer, J.C. Water Supply and Waste Water Disposal. John Wiley, New York, (1956).

9. Gannon, J.J., and Downs, T.D. Programming River D.O. Calculations. Water and Sewage Works. 110, October: 124 (1963).

10. Gumbel, E.J. Statistics of Extremes. Columbia University Press. (1958).

11. Klein, L. Aspects of River Pollution. Butterworths Scientific Publications. (1957).

12. Liebman, J.C., and Loucks, D.P. A Note on Oxygen Sag Equation. Water Purification Central Federation Journal, Vol. 38, No. 12, (1966).

13. Nemerow, N.L. Theories and Practices of Industrial Waste Treatment. Addison-Wesley, (1963).

14. O'Connor, D.J., and Dobbins, W.E. Transactions of American Society of Civil Engineers, 123, page 641 (1958).

15. Phelps, E.B. Stream Sanitation. John Wiley and Sons, New York, (1944).

16. Purdy, R.W. Oxygen Data Collection from Rivers. Water and Sewage Works. 109, 10: 391 (1962).

17. Simmons, J.D., Nemerow, N.L., and Armstrong, T.F. Modified River Sampling for Computing Dissolved Oxygen Sag. Sewage and Industrial Wastes, 29, 8: 936, (1957).

18. Streeter, H.W., and Phelps, E.B. Study of the Pollution and Natural Purification of the Ohio River. Public Health Bulletin, 146, U.S. Public Health Service, (1925).

19. Thomas, H.A. Pollutional Load Capacity of Streams. Water and Sewage Works, 95, 11: 409, (1948).

20. Velz, C.J. Deoxygenation and Reoxygenation, Transactions of American Society of Civil Engineers, 104, (1939).

21. Velz, C.J. Factors Influencing Self-Purification and the Relation to Pollution Abatement. Sewage Works Journal, XIX, 4: 629, (1947).

22. DATA relating to the Richelieu River Pollution Survey. Available at the Municipal Engineering Laboratory, McGill University.

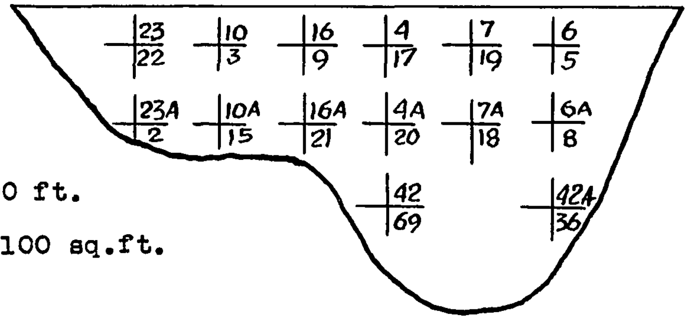
APPENDIX A

RESULTS OF THE ANALYSIS OF RIVER WATER SAMPLES

THE TOP NUMBER AT ANY GRID POINT WITHIN THE CROSS SECTION REFERS TO THE SAMPLE ANALYSED IMMEDIATELY FOR D.O.. THE BOTTOM NUMBER AT THE SAME GRID POINT REFERS TO THE SAMPLE ANALYSED FOR $B.O.D._5$.

SCALE OF DRAWINGS HORIZONTAL 1" = 200'
VERTICAL 1" = 8'

SECTION 25



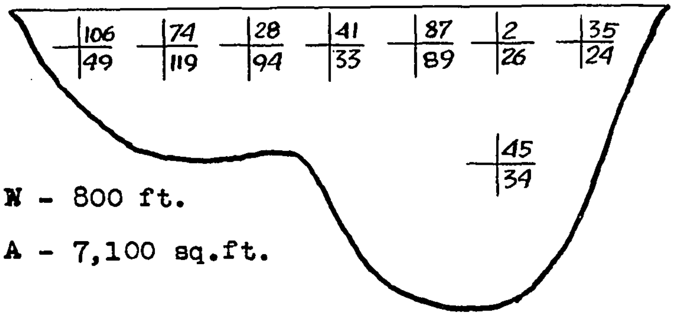
W - 800 ft.

A - 7,100 sq.ft.

July 12 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
23	7.5	24.8	6.15	22	6.0	20.0	6.00	.15
10	6.7	24.0	5.60	3	5.2	20.0	5.20	.40
16	6.9	24.4	5.75	9	5.2	20.3	5.15	.60
4	7.3	24.8	6.00	17	5.2	20.4	5.10	.90
7	7.1	24.8	5.80	19	5.0	20.0	5.00	.80
6	6.7	24.5	5.60	5	5.0	19.8	5.15	.45
23A	7.5	24.8	6.15	2	5.9	20.0	5.90	.25
10A	6.7	24.0	5.65	15	4.1	19.5	4.30	1.35
16A	6.9	24.4	5.75	21	5.3	20.0	5.30	.45
4A	7.3	24.8	6.00	20	4.9	19.8	5.05	.95
7A	7.1	24.8	5.80	18	4.5	19.4	4.75	1.05
6A	6.7	24.5	5.60	8	5.0	20.2	4.95	.65
42	6.8	24.4	5.65	69	4.2	20.2	4.15	1.50
42A	6.8	24.4	5.65	36	5.0	20.0	5.00	.65

SECTION 25



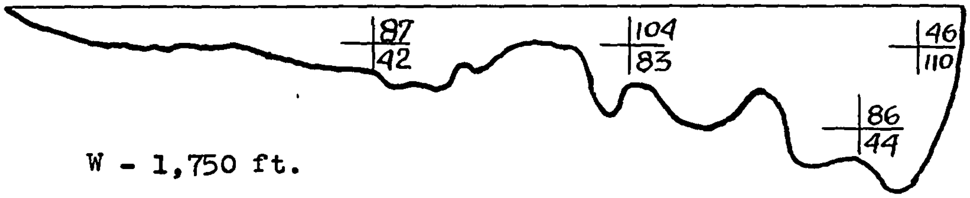
N - 800 ft.

A - 7,100 sq.ft.

August 12 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
106	5.0	23.5	4.25	49	4.2	22.6	3.70	.55
74	5.0	23.5	4.25	119	4.0	22.0	3.65	.60
28	4.9	23.4	4.20	94	4.3	21.6	3.95	.25
41	5.1	23.2	4.40	33	4.3	21.2	4.05	.35
87	4.7	23.5	4.00	89	4.1	21.0	3.90	.10
2	4.8	23.5	4.10	26	4.0	21.0	3.80	.30
35	4.9	23.5	4.20	24	3.9	20.5	3.80	.40
45	4.8	23.4	4.10	34	4.0	22.8	3.50	.60

SECTION 24



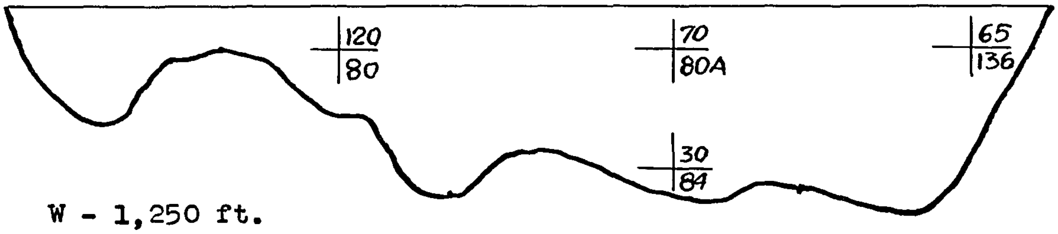
W - 1,750 ft.

A - 6,800 sq.ft.

August 6 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
87	5.7	24.8	4.70	42	4.9	20.9	4.70	.0
104	5.0	24.8	4.10	83	4.8	20.9	4.60	-.50
46	4.4	25.0	3.60	110	4.1	22.5	3.65	-.05
86	4.6	25.0	3.75	44	4.6	21.5	4.30	-.55

SECTION 23



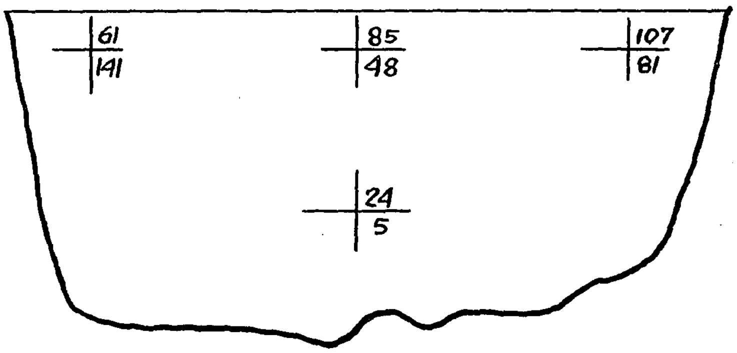
W - 1,250 ft.

A - 7,800 sq.ft.

August 6 1965

NO.	$D.O._o$	T°C	$D.O._o$ Corr	NO.	$D.O._5$	T°C	$D.O._5$ Corr	$B.O.D._5$
120	4.9	25.0	4.0	80	4.4	22.5	3.90	.10
70	3.8	24.9	3.1	80A	3.3	20.5	3.20	-.10
65	3.2	24.9	2.65	136	2.5	20.5	2.45	.20
30	4.2	24.8	3.45	84	3.9	20.5	3.80	-.35

SECTION 22



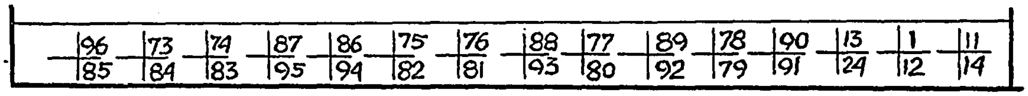
W - 882 ft.

A - 12,000 sq.ft.

August 6 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
61	5.2	24.6	4.30	141	4.8	20.5	4.70	-.40
85	5.1	24.7	4.20	48	4.6	21.1	4.35	-.15
24	5.3	24.5	4.40	5	4.9	21.5	4.60	-.20
107	5.2	24.6	4.30	81	4.8	21.5	4.50	-.20

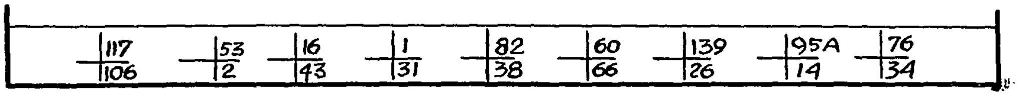
Fryers Island Dam



W - 1184 ft. A - 2,400 sq.ft.

July 12 1965

NO.	$D.O._0$	T°C	$D.O._0$ Corr	NO.	$D.O._5$	T°C	$D.O._5$ Corr	$B.O.D._5$
96	6.1	22.1	5.55	85	5.0	19.7	5.20	.35
73	6.0	21.5	5.60	84	5.0	19.5	5.25	.35
74	5.9	21.5	5.50	83	5.1	19.8	5.25	.25
87	6.3	21.7	5.85	95	5.0	19.8	5.15	.70
86	6.1	21.8	5.60	94	5.0	19.5	5.25	.35
75	6.1	21.9	5.60	82	4.8	19.4	5.05	.55
76	6.0	21.5	5.60	81	4.8	19.5	5.05	.55
88	6.0	21.0	5.70	93	4.6	19.5	4.85	.85
77	5.9	21.7	5.45	80	4.7	19.5	4.95	.50
89	6.0	21.6	5.55	92	4.7	20.0	4.70	.85
78	5.9	21.5	5.50	79	4.8	20.0	4.80	.70
90	5.8	21.4	5.40	91	4.4	19.7	4.60	.80
13	5.9	21.4	5.50	24	4.4	19.5	4.65	.85
1	5.8	21.8	5.30	12	4.7	20.2	4.65	.65
11	5.9	22.0	5.35	14	4.6	19.8	4.75	.60



Fryers Island Dam

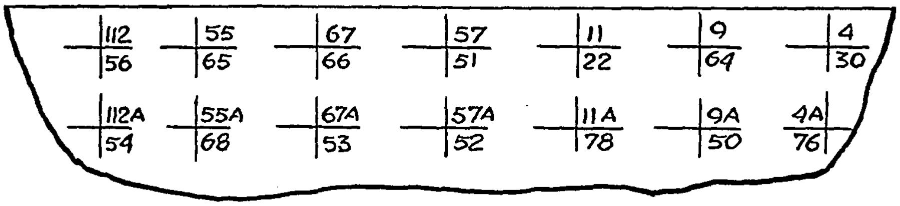
32 gate openings, 30 ft. wide each

W - 1,184 ft.

A - 2,400 sq.ft.

August 12 1965

NO.	D.O.$_{o}$	T°C	D.O.$_{o}$ Corr	NO.	D.O.$_{5}$	T°C	D.O.$_{5}$ Corr	B.O.D.$_{5}$
117	6.0	23.6	5.10	106	5.3	21.2	5.00	.10
53	5.8	23.6	4.90	2	5.3	21.3	5.00	-.10
16	6.4	23.5	5.50	43	5.7	22.0	5.15	.35
1	5.3	23.7	4.50	31	5.9	22.0	5.35	-.85
82	6.5	23.6	5.50	38	6.0	22.0	5.45	.05
60	6.0	24.2	5.00	66	5.9	22.5	5.30	-.30
139	6.3	24.5	5.25	26	5.8	22.8	5.10	.15
95A	6.3	24.5	5.25	14	6.0	22.9	5.25	.00
76	6.4	23.3	5.50	34	6.2	23.0	5.40	.10

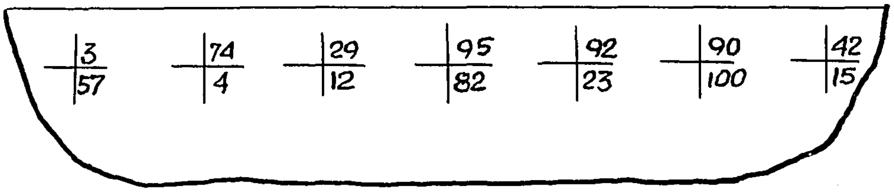


W - 1,050 ft. A - 9,650 sq.ft.

July 12 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
112	6.1	22.5	5.45	56	5.3	20.0	5.30	.15
55	6.2	23.6	5.25	65	4.9	20.0	4.90	.35
67	6.3	23.2	5.40	66	4.8	20.0	4.85	.55
57	6.3	23.3	5.40	51	5.3	20.6	5.15	.25
11	6.4	24.0	5.40	22	4.8	20.3	4.75	.65
9	6.4	23.6	5.40	64	5.1	19.5	5.40	.00
4	6.4	23.3	5.50	30	5.2	20.3	5.15	.35
112A	6.1	22.5	5.45	54	4.9	19.5	5.15	.30
55A	6.2	23.6	5.25	68	4.4	19.5	4.65	.60
67A	6.3	23.2	5.40	53	4.8	19.5	5.05	.35
57A	6.3	23.3	5.40	52	4.0	19.5	4.20	.20
11A	6.4	24.0	5.40	78	4.8	19.8	4.95	.45
9A	6.4	23.6	5.40	50	4.6	19.5	4.85	.55
4A	6.4	23.3	5.50	76	4.1	20.0	4.10	1.40

SECTION 20



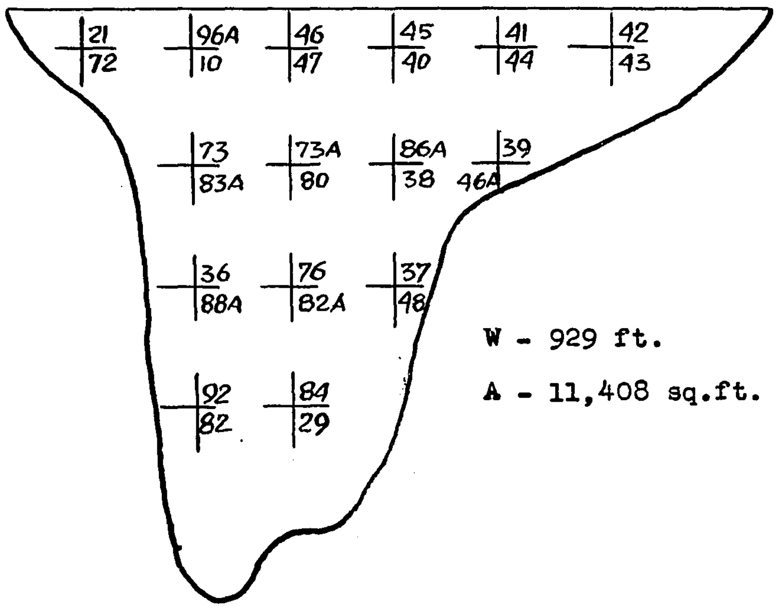
W - 1,050 ft.

A - 9,650 sq.ft.

August 12 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
3	6.8	24.5	5.65	57	6.3	22.2	5.65	.00
74	6.5	24.5	5.40	4	5.8	22.5	5.20	.20
29	6.6	24.5	5.50	12	6.0	22.8	5.25	.25
95	6.3	24.6	5.20	82	6.4	23.2	5.50	-.30
92	6.3	24.9	5.15	23	5.8	23.4	4.95	.30
90	6.5	24.6	5.35	100	5.9	23.5	5.05	.30
42	6.2	25.2	5.05	15	5.0	23.6	4.25	.80

SECTION 19

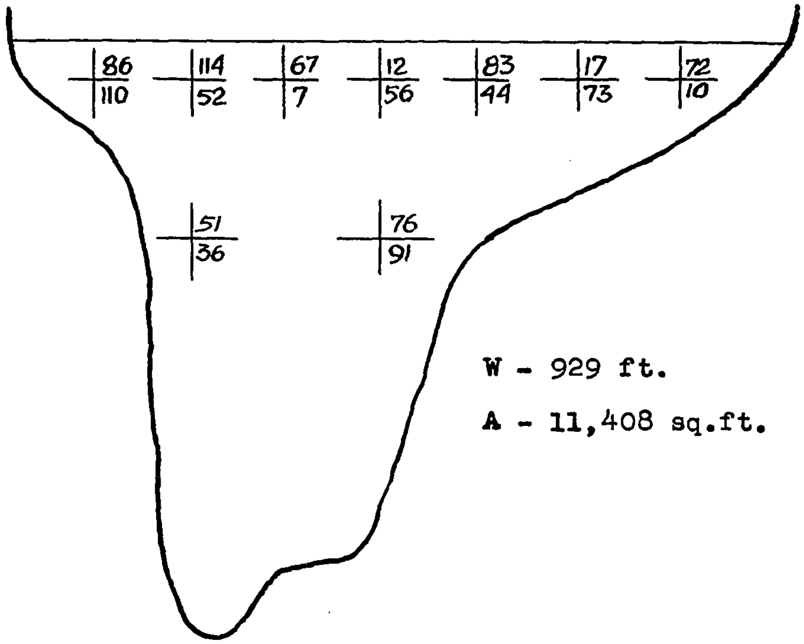


W - 929 ft.

A - 11,408 sq.ft.

July 21 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
21	5.0	23.0	4.35	72	4.3	20.0	4.30	.05
96A	4.8	22.5	4.30	10	4.3	20.3	4.25	.05
46	4.6	22.6	4.10	47	4.4	19.8	4.50	- .40
45	4.9	23.2	4.25	40	4.5	20.2	4.55	- .20
41	5.2	23.2	4.50	44	4.4	20.1	4.40	.10
42	4.8	22.9	4.20	43	4.3	19.8	4.45	- .25
73	5.0	22.6	4.40	83A	4.2	19.5	4.45	- .05
73A	5.0	22.7	4.40	80	4.4	19.9	4.25	.15
86A	4.5	22.7	4.00	38	4.0	19.8	4.15	- .15
39	5.0	22.5	4.45	46A	4.4	20.5	4.65	- .20
36	4.6	22.5	4.10	88A	4.4	20.2	4.35	- .25
76	5.4	23.0	4.70	82A	4.4	20.2	4.35	.35
37	5.6	22.8	4.90	48	4.2	20.0	4.20	.70
92	5.1	22.6	4.50	82	4.6	20.7	4.45	.05
84	5.0	22.3	4.50	29	4.4	19.9	4.40	.10

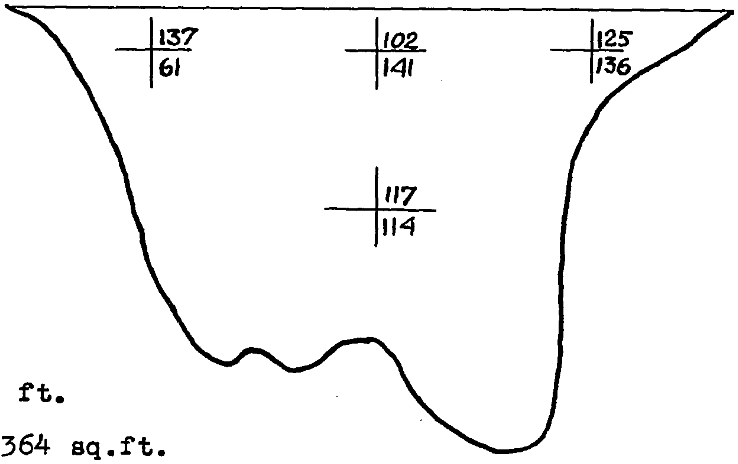


W - 929 ft.

A - 11,408 sq.ft.

August 12 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
86	6.0	25.3	4.90	110	5.2	20.0	5.20	-.30
114	6.0	25.5	4.85	52	4.7	20.5	4.60	.25
67	6.0	25.5	4.85	7	4.6	20.9	4.40	.45
12	6.0	25.5	4.85	56	5.2	21.5	4.85	.00
83	6.0	25.5	4.85	44	5.5	21.6	5.10	-.25
17	6.4	25.5	5.20	73	5.2	21.9	4.80	.40
72	6.2	25.5	5.00	10	5.0	22.2	4.50	.50
51	6.3	25.2	5.10	36	5.8	22.4	5.15	-.05
76	5.6	25.2	4.55	91	5.7	22.6	5.05	.50

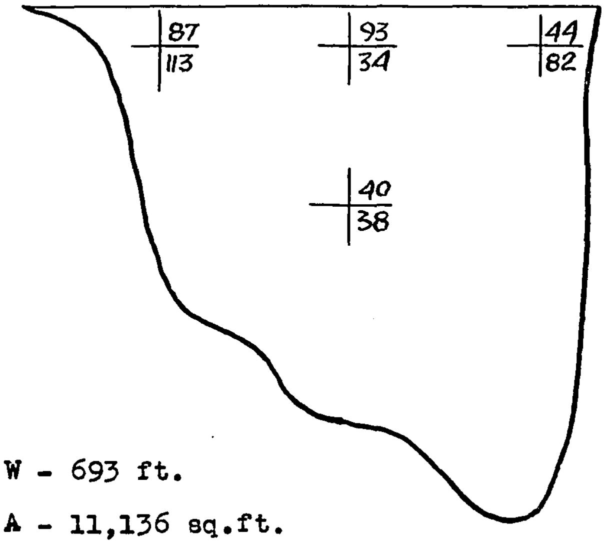


W - 881 ft.

A - 10,364 sq.ft.

July 26 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
137	6.0	24.6	4.95	61	3.4	20.5	3.30	1.65
102	5.7	23.9	4.85	141	3.9	20.0	3.90	.95
125	5.8	24.0	4.85	136	4.0	20.1	4.00	.85
117	5.6	24.1	4.70	114	3.8	19.9	3.95	.75



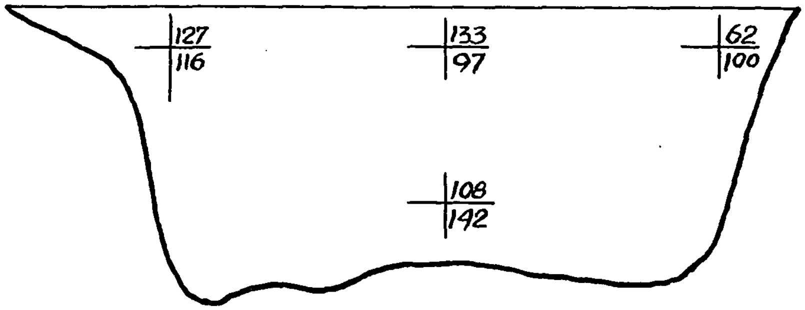
W - 693 ft.

A - 11,136 sq.ft.

August 6 1965

NO.	$D.O._o$	T°C	$D.O._o$ Corr	NO.	$D.O._5$	T°C	$D.O._5$ Corr	$B.O.D._5$
87	4.8	25.2	3.90	113	4.3	20.5	4.20	-.30
93	5.6	25.1	4.55	34	5.2	20.9	5.00	-.45
44	5.4	25.2	4.40	82	4.8	21.0	4.55	-.15
40	5.6	25.0	4.50	38	4.7	21.0	4.45	.05

SECTION 16



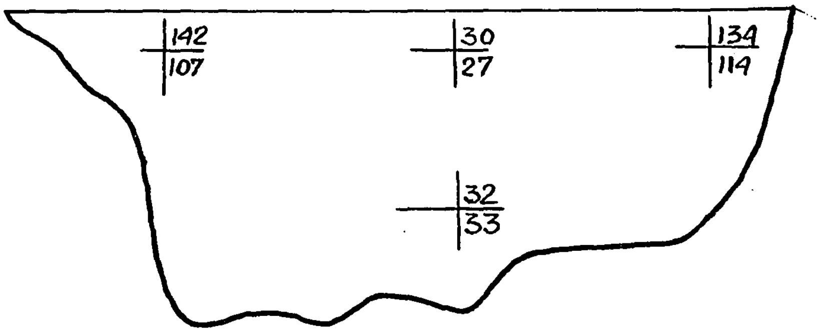
W - 941 ft.

A - 9,940 sq.ft.

July 26 1965

NO.	D.O.$_0$	T°C	D.O. Corr^0	NO.	D.O.$_5$	T°C	D.O. Corr^5	B.O.D.$_5$
127	5.6	23.8	4.75	116	4.0	19.7	4.15	.60
133	5.6	24.0	4.70	97	3.6	20.0	3.60	1.20
62	5.2	24.2	4.35	100	4.0	20.2	3.95	.40
108	5.4	24.9	4.40	142	3.9	19.6	4.15	.25

SECTION 15

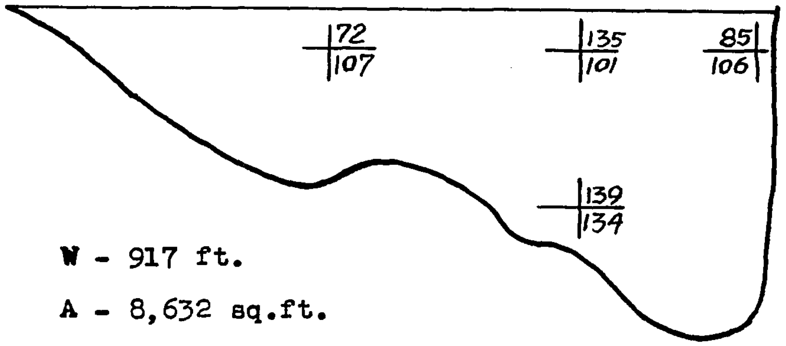


W - 953 ft.

A - 10,632 sq.ft.

August 6 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
142	4.8	25.3	3.90	107	3.8	20.0	3.8	0.10
30	5.5	25.5	4.45	27	4.4	20.0	4.4	0.05
134	5.3	25.5	4.30	114	4.3	20.0	4.3	0.00
32	5.6	25.5	4.50	33	4.4	20.0	4.4	0.10



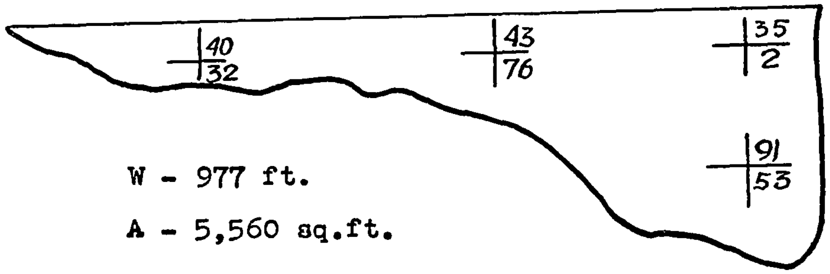
W - 917 ft.

A - 8,632 sq.ft.

July 26 1965

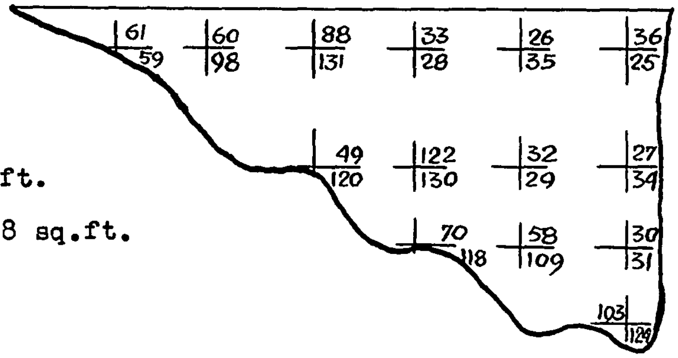
NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
72	4.8	24.5	4.00	107	3.6	19.7	3.75	.25
135	5.4	24.2	4.50	101	4.0	20.0	4.00	.50
85	5.7	24.9	4.65	106	2.4	19.5	2.55	2.10
139	4.8	23.2	4.15	134	4.0	19.6	4.15	.00

SECTION 13



August 6 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
40	6.8	26.0	5.35	22	5.7	20.0	5.70	-.35
43	6.2	25.8	5.00	76	5.0	20.1	5.00	.00
35	5.7	25.7	4.55	2	4.7	20.1	4.70	-.15
91	6.1	25.6	4.90	53	4.5	20.2	4.45	.45

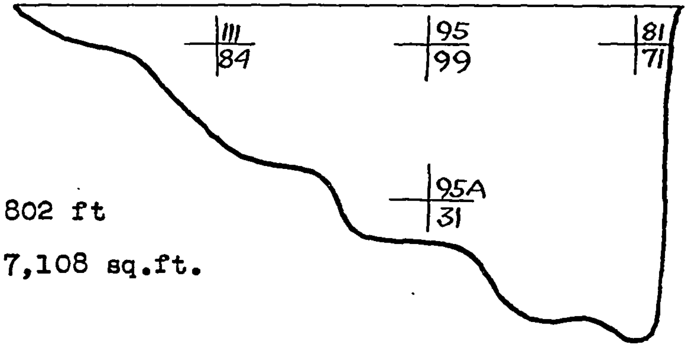


W - 802 ft.

A - 7,108 sq.ft.

July 21 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
61	5.1	24.2	4.25	59	3.7	21.5	3.45	.80
60	5.1	24.4	4.25	98	4.0	20.8	3.85	.40
88	5.0	24.4	4.15	131	4.0	21.0	3.80	.35
33	4.9	24.3	4.10	28	4.0	21.1	3.80	.30
26	4.6	24.4	3.85	35	3.9	21.5	3.65	.20
36	4.9	24.8	4.05	25	3.6	20.9	3.45	.60
49	5.2	24.6	4.30	120	4.2	21.0	4.00	.30
122	5.0	25.0	4.05	130	4.1	20.7	3.80	.25
32	5.1	24.4	4.25	29	4.2	21.0	4.00	.25
27	5.0	24.6	4.15	34	4.2	21.0	4.00	.15
70	4.8	24.2	4.00	118	4.5	21.2	4.20	- .20
58	4.6	24.5	3.85	109	3.9	21.0	3.70	.15
30	5.0	24.7	4.15	31	4.3	21.1	4.10	0.05
103	5.4	24.6	4.45	124	3.8	21.4	3.55	.90

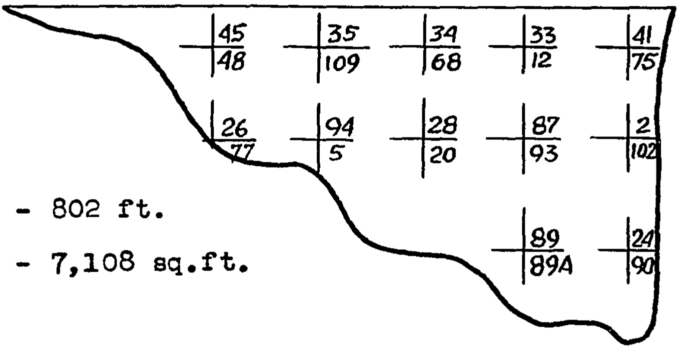


W - 802 ft

A - 7,108 sq.ft.

July 26 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
111	4.9	25.0	4.00	84	4.3	20.1	4.30	- .30
95	5.3	24.2	4.45	99	3.9	20.1	3.90	.55
81	4.6	24.9	3.80	71	4.0	20.4	3.90	- .10
95A	5.3	24.7	4.40	31	4.0	20.0	4.00	.40



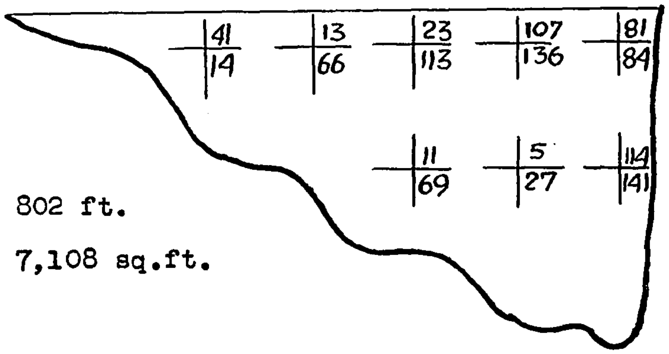
W - 802 ft.

A - 7,108 sq.ft.

August 4 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
45	4.8	22.6	4.25	48	4.4	21.9	4.00	.25
35	4.5	22.8	3.95	109	4.0	21.2	3.75	.20
34	5.1	22.5	4.55	68	3.8	23.6	3.20	2.35
33	4.6	22.5	4.10	12	3.7	20.0	3.70	.40
41	5.3	23.0	4.60	75	3.6	20.9	3.65	.95
26	5.1	22.9	4.45	77	4.2	20.7	3.85	.60
94	5.4	22.5	4.85	5	4.0	22.1	3.60	1.25
28	5.1	22.5	4.55	20	3.8	21.6	3.50	1.05
87	4.8	22.5	4.30	93	3.9	21.6	3.60	.70
2	4.6	23.0	4.00	102	3.6	20.5	3.55	.45
89	5.1	23.0	4.45	89A	3.6	20.5	3.55	.90
24	4.8	23.0	4.15	90	4.4	20.5	4.30	-.15

SECTION 12



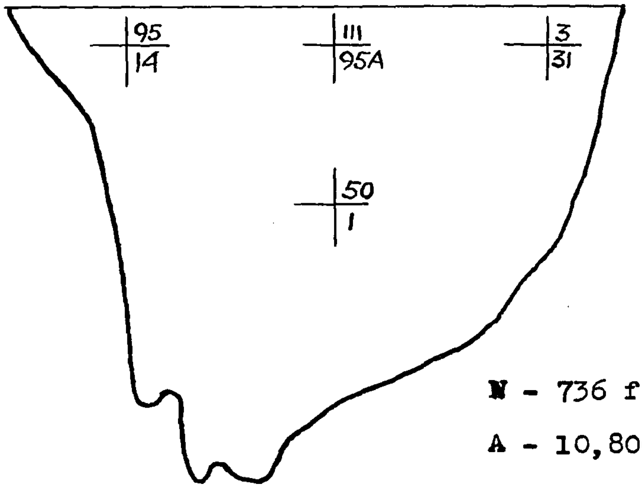
W - 802 ft.

A - 7,108 sq.ft.

August 12 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
41	5.3	25.6	4.25	14	5.0	20.5	4.90	-.65
13	5.6	25.8	4.50	66	4.7	21.0	4.50	.00
22	5.3	25.2	4.30	113	4.4	21.5	4.10	.20
107	6.0	25.3	4.90	136	2.6	21.5	2.45	2.45
81	5.6	26.2	4.45	84	2.7	21.8	2.50	1.95
11	5.5	26.4	4.35	69	4.8	22.0	4.35	.00
5	5.6	26.3	4.45	27	5.0	22.5	4.45	.00
114	5.5	26.2	4.35	141	4.9	22.6	4.35	.00

SECTION 11



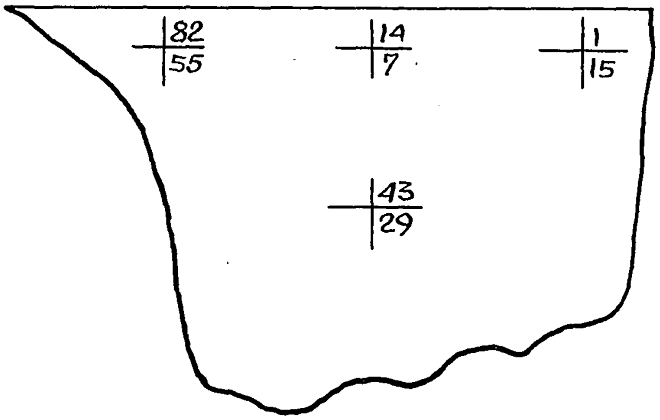
W - 736 ft.

A - 10,800 sq.ft.

August 6 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
95	5.1	25.5	4.10	14	3.6	20.1	3.45	.65
111	5.0	25.6	4.00	95A	3.7	20.3	3.65	.35
3	5.1	25.5	4.10	31	4.2	20.5	4.10	.00
50	4.8	25.7	3.85	1	3.8	20.5	3.70	.15

SECTION 10



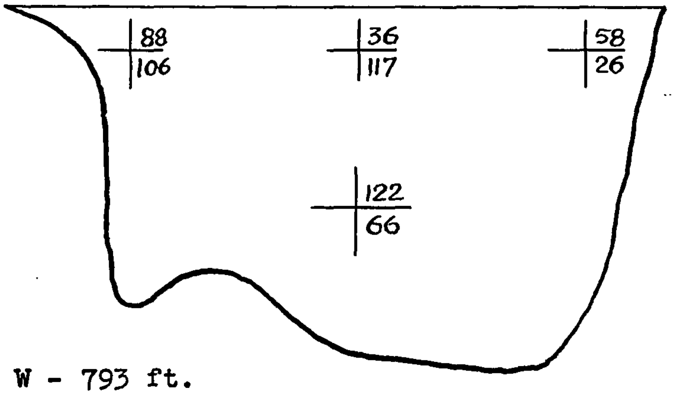
W - 789 ft.

A - 10,580 ft.

July 26 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
82	5.5	25.0	4.45	55	3.8	20.1	3.80	.65
14	4.8	24.9	3.95	7	3.8	20.1	3.80	.15
1	5.2	24.6	4.30	15	3.9	20.0	3.90	.40
43	4.9	24.6	4.05	29	4.0	20.1	4.00	.05

SECTION 9



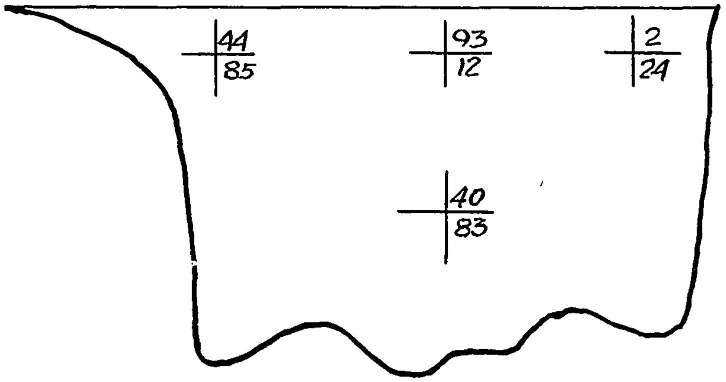
W - 793 ft.

A - 10,032 sq.ft.

August 6 1965

NO.	$D.O._0$	T°C	$D.O._0$ Corr	NO.	$D.O._5$	T°C	$D.O._5$ Corr	$B.O.D._5$
88	4.4	25.6	3.55	106	3.8	20.8	3.65	-.10
36	5.2	25.5	4.20	117	3.8	20.2	3.75	.45
58	4.6	25.5	3.70	26	3.7	21.5	3.60	.10
122	5.0	25.5	4.05	66	4.0	20.6	3.90	.15

SECTION 8



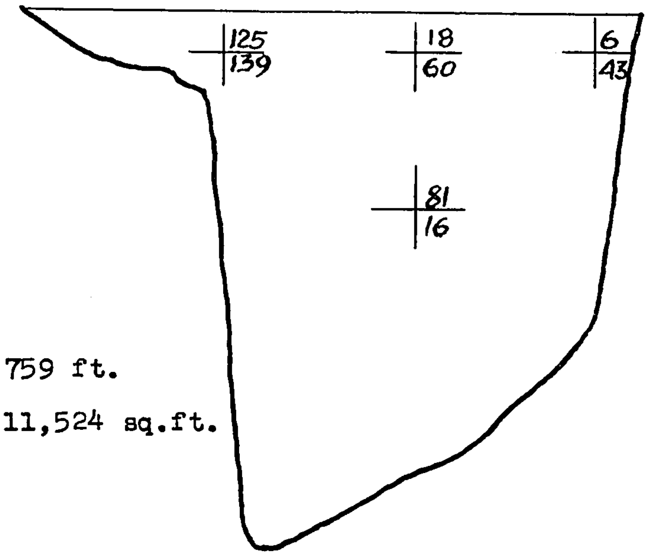
W - 848 ft.

A - 10,600 sq.ft.

July 26 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
44	4.9	24.9	4.00	85	3.8	20.2	3.80	.20
93	5.2	24.5	4.35	12	3.8	19.8	3.90	.45
2	5.3	24.9	4.35	24	3.9	20.1	3.90	.45
40	5.2	25.0	4.25	83	4.0	20.1	4.00	.25

SECTION 7



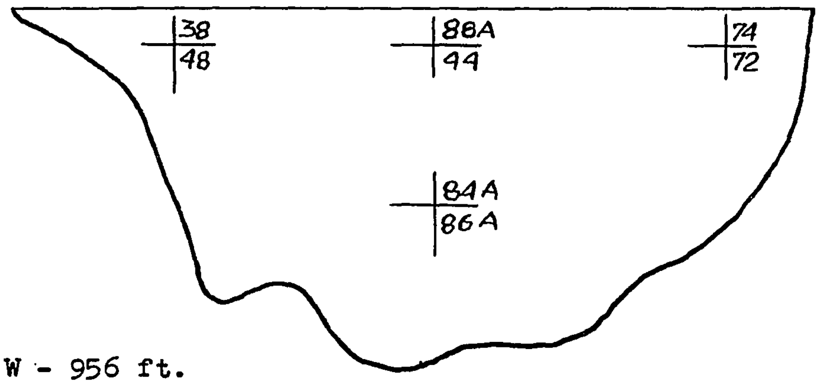
W - 759 ft.

A - 11,524 sq.ft.

August 6 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
125	5.4	24.5	4.50	139	5.0	21.0	4.75	-.25
18	5.3	24.4	4.40	60	4.6	21.5	4.30	.10
6	5.3	24.5	4.40	43	5.0	22.0	4.55	-.15
81	5.3	24.5	4.40	16	4.4	21.0	4.20	.20

SECTION 6



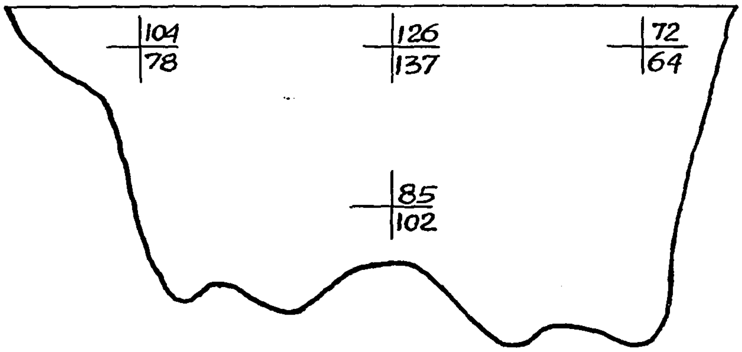
W - 956 ft.

A - 11,616 sq.ft.

July 26 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
38	6.0	25.0	4.90	48	3.5	20.0	3.50	1.40
88A	5.4	24.9	4.45	44	4.0	20.1	4.00	.95
74	5.2	24.6	4.30	72	4.0	20.0	4.00	.30
84A	6.1	24.6	5.05	86A	3.9	20.0	3.90	1.15

SECTION 5

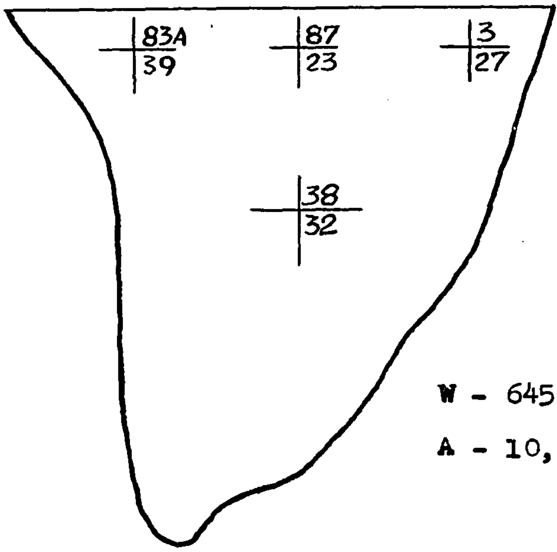


W - 873 ft.

A - 10,968 sq.ft.

August 6 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
104	6.4	25.5	5.15	78	4.9	20.9	4.65	.50
126	6.3	25.5	5.10	137	4.7	20.5	4.60	.50
72	6.3	25.6	5.05	64	5.3	20.5	5.15	-.10
85	6.6	25.5	5.30	102	5.1	20.8	4.90	.40



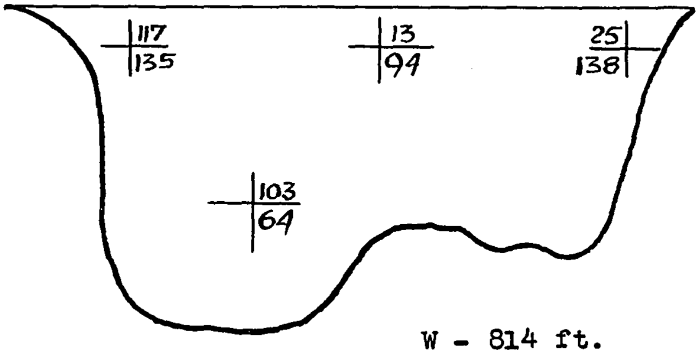
W - 645 ft.

A - 10,284 sq.ft.

July 26 1965

NO.	$D.O._{o}$	T°C	$D.O._{o}$ Corr	NO.	$D.O._{5}$	T°C	$D.O._{5}$ Corr	$B.O.D._{5}$
3	5.1	24.7	4.20	27	3.8	20.3	3.75	.45
87	5.3	24.8	4.35	23	3.7	20.0	3.70	.65
83A	5.7	24.7	4.70	39	4.0	20.4	3.90	.80
38	5.8	24.6	4.80	32	4.1	20.2	4.05	.75

SECTION 3

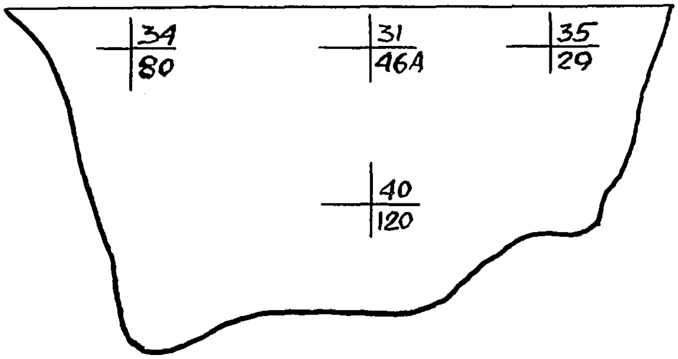


W - 814 ft.

A - 8,760 sq.ft.

August 6 1965

NO.	$D.O._o$	T°C	D.O. $Corr_o$	NO.	$D.O._5$	T°C	D.O. $Corr_5$	$B.O.D._5$
117	6.5	25.6	5.20	135	4.4	20.2	4.35	.85
13	6.5	25.5	5.25	94	4.6	20.2	4.55	.80
25	6.3	25.6	5.05	138	4.3	20.5	4.20	.85
103	6.4	25.5	5.15	64	4.7	20.6	4.55	.60

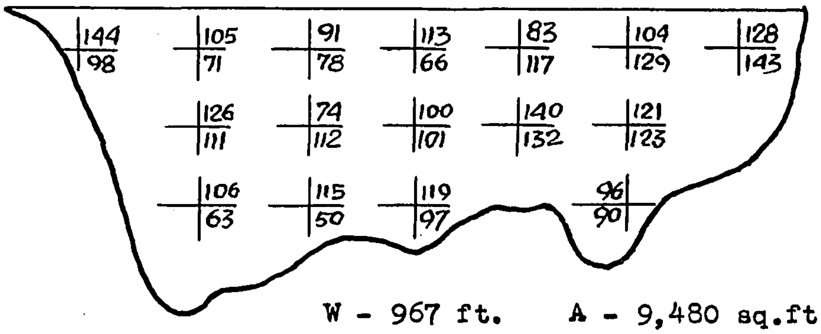


W - 794 ft.

A - 9,580 sq.ft.

July 26 1965

NO.	D.O.$_o$	T°C	D.O.$_o$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
34	5.8	25.0	4.70	80	3.9	19.6	4.05	.65
31	5.9	24.9	4.85	46A	4.0	19.7	4.15	.60
35	6.3	24.8	5.15	29	4.0	20.5	3.90	1.25
40	6.4	24.8	5.25	120	4.0	19.9	4.10	1.15

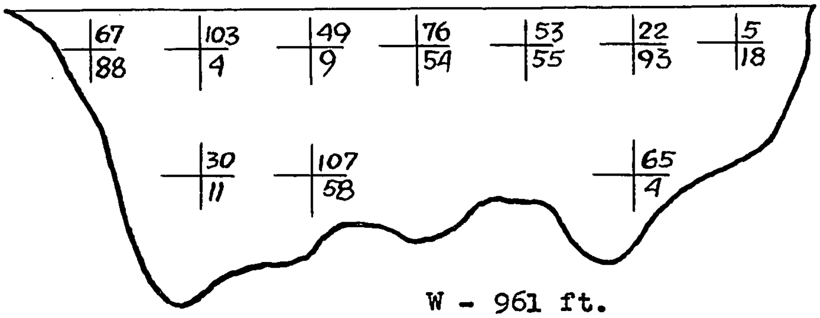


W - 967 ft. A - 9,480 sq.ft.

July 21 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
144	4.9	24.6	4.05	98	3.1	21.0	2.95	1.10
105	5.0	24.9	4.10	71	3.9	21.3	3.70	0.40
91	5.1	24.6	4.20	78	4.2	21.0	4.00	0.20
113	4.9	24.8	4.00	66	4.0	20.9	3.85	0.15
83	5.3	24.9	4.35	117	4.1	21.2	3.85	0.50
104	5.0	24.6	4.15	129	3.8	20.8	3.65	0.50
128	5.2	24.9	4.25	143	3.9	21.9	3.55	0.70
126	5.3	25.2	4.30	111	4.0	21.7	3.70	0.60
74	5.1	24.9	4.15	112	4.2	22.0	3.80	0.35
100	5.2	25.0	4.20	101	4.0	21.5	3.75	0.45
140	5.0	24.8	4.10	132	4.1	21.3	3.85	0.25
121	5.3	25.2	4.30	123	4.0	21.7	3.70	0.60
106	5.0	24.6	4.10	63	4.0	22.0	3.65	0.45
115	5.0	24.9	4.10	50	4.0	21.7	3.70	0.40
119	5.2	24.8	4.25	97	3.9	21.0	3.70	0.55
96	5.2	24.6	4.30	90	3.9	21.5	3.70	0.60

SECTION 1



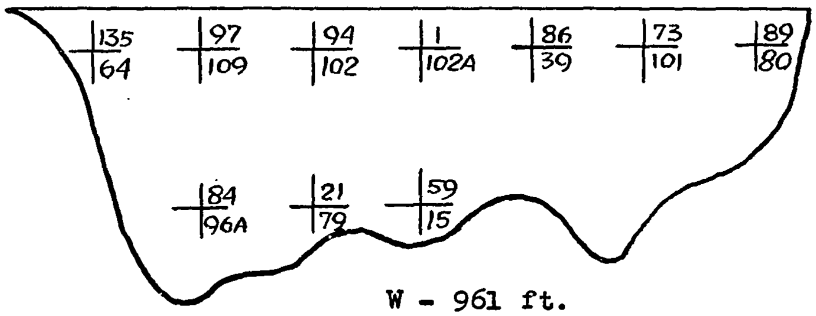
W - 961 ft.

A - 9,480 sq.ft.

August 4 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
67	5.5	23.0	4.75	88	4.1	21.0	3.90	.85
103	4.9	23.0	4.25	4	3.5	21.0	3.35	.90
49	4.3	23.2	3.70	9	3.7	21.5	3.35	.35
76	5.2	23.0	4.50	54	3.5	21.5	3.30	1.20
53	5.0	23.6	4.20	55	3.7	20.0	3.70	.50
22	4.9	23.5	4.20	93	3.8	22.0	3.45	.75
5	4.8	23.2	4.15	18	3.7	21.5	3.30	.85
30	5.1	23.1	4.45	11	4.2	20.5	4.05	.40
107	5.8	23.0	5.40	58	3.8	21.5	3.55	.85
65	4.6	23.0	4.00	4	3.7	20.5	3.60	.40

SECTION 1



W - 961 ft.

A - 9,480 sq.ft.

August 12 1965

NO.	D.O.$_0$	T°C	D.O.$_0$ Corr	NO.	D.O.$_5$	T°C	D.O.$_5$ Corr	B.O.D.$_5$
135	5.4	26.5	4.25	64	4.7	20.8	4.50	- .25
97	5.5	26.5	4.30	109	4.5	21.1	4.30	.00
94	5.2	26.6	4.10	102	4.4	21.5	4.10	.00
1	6.7	26.6	5.25	102A	4.9	21.8	4.50	.75
86	5.3	26.5	4.15	39	3.8	22.0	3.45	.70
73	5.2	26.5	4.10	101	4.2	22.2	3.80	.30
89	5.4	26.8	4.25	80	4.8	22.4	4.25	.00
84	5.1	26.5	4.00	96A	4.4	22.6	3.90	.10
21	5.0	26.7	3.95	79	4.7	22.8	4.15	.20
59	5.5	26.5	4.30	15	4.5	23.0	3.90	.40

APPENDIX B

RESULTS OF THE ANALYSIS OF RIVER WATER AND SEWAGE SAMPLES FOR THE COMPUTATION OF B.O.D. ULTIMATE AND K_1 VALUES

ST JEAN

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

8' JACKWOOD COLLECTOR

July 6 1965 Dilution Rate 0.87%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	$T^{o}C$	D.O. Corr	D.O.	$T^{o}C$	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.60	22.0	5.10	5.60	22.0	5.10	5.10		0
1	3.50	20.8	3.21	3.38	21.5	3.15	3.18	0.622	220
2	3.00	20.5	2.94	2.90	20.7	2.82	2.88	0.565	255
3	2.25	20.8	2.16	2.50	20.6	2.43	2.29	0.448	324
4	2.00	21.2	1.88	2.10	20.6	2.04	1.96	0.383	362
5	1.75	20.3	1.65	1.80	20.5	1.76	1.70	0.335	391
6	1.40	21.5	1.31	1.50	21.5	1.40	1.35	0.265	420
7	1.15	21.1	1.09	1.20	21.0	1.14	1.12	0.220	456
8	1.05	21.4	.98	1.10	21.3	1.04	1.01	0.197	470
9	1.00	21.0	.95	1.00	21.1	.95	.95	0.187	478
10	1.00	21.0	.95	.95	21.2	.90	.92	0.182	481

ST JEAN

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

30" CHAMPLAIN COLLECTOR

July 6 1965 Dilution Rate 1%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.75	22.4	5.14	5.75	22.4	5.14	5.14		
1	3.05	20.8	2.93	2.95	20.6	2.86	2.89	0.562	225
2	2.40	20.5	2.35	2.45	20.5	2.40	2.37	0.460	277
3	1.90	20.8	1.85	1.75	20.9	1.68	1.76	0.342	338
4	1.50	20.5	1.47	1.40	20.5	1.37	1.42	0.277	372
5	1.35	20.2	1.33	1.25	20.2	1.26	1.30	0.252	384
6	1.15	21.7	1.06	1.10	20.4	1.08	1.07	0.207	407
7	1.05	20.5	1.03	.90	20.1	.90	.96	0.186	418
8	.80	20.8	.77	.80	20.8	.77	.77	0.150	437
9	.70	20.4	.67	.60	20.7	.58	.62	0.122	452
10	.57	20.2	.56	.58	20.4	.57	.56	0.109	458

IBERVILLE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

54" COLLECTOR

September 25 1965 Dilution Rate 2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.40	20.0	4.40	4.40	20.0	4.40	4.40		
1	3.95	20.5	3.86	3.90	21.0	3.72	3.79	.862	30
2	3.40	20.8	3.26	3.40	20.7	3.30	3.28	.747	56
3	3.10	20.8	3.98	3.05	20.7	2.96	2.97	.676	71
4	2.70	20.7	2.62	2.65	20.8	2.55	2.58	.587	91
5	2.00	20.5	1.96	2.50	20.6	2.41	2.18	.496	111
6	1.80	20.5	1.76	1.90	20.4	1.86	1.81	.413	129
7	1.60	20.5	1.57	1.50	20.3	1.48	1.52	.345	144
8	1.30	20.7	1.26	1.40	20.7	1.36	1.31	.298	154
9	1.05	20.6	1.02	1.10	20.7	1.07	1.04	.237	168
10	1.00	20.5	.98	1.00	20.4	.98	.98	.223	171

IBERVILLE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

30" COLLECTOR

September 25 1965 Dilution Rate 2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.50	20.7	4.37	4.50	20.7	4.36	4.36		
1	3.60	20.7	3.50	3.70	21.0	3.52	3.51	.805	42
2	3.20	20.2	3.17	3.25	20.3	3.22	3.20	.735	58
3	2.85	20.3	2.82	2.90	20.0	2.90	2.86	.656	75
4	2.50	20.3	2.48	2.75	20.6	2.67	2.57	.590	89
5	2.30	20.4	2.25	2.50	20.9	2.40	2.32	.531	102
6	2.20	20.4	2.16	2.40	20.5	2.35	2.26	.518	105
7	2.00	20.2	1.98	1.80	19.5	1.90	1.94	.445	121
8	1.65	20.1	1.65	1.70	20.2	1.67	1.66	.381	135
9	1.40	20.2	1.38	1.45	20.2	1.43	1.40	.321	148
10	1.25	20.5	1.22	1.25	20.4	1.22	1.22	.280	157

IBERVILLE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

18" COLLECTOR

September 25 1965 Dilution Rate 1.5%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T^oC	D.O. Corr	D.O.	T^oC	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.45	20.7	4.32	4.45	20.7	4.32	4.32		
1	3.70	21.2	3.50	3.60	21.0	3.42	3.46	.801	57.2
2	3.20	21.0	3.05	3.25	20.7	3.15	3.10	.720	81.5
3	2.90	20.8	2.79	2.80	20.2	2.77	2.78	.643	102.5
4	2.40	20.3	2.38	2.55	20.6	2.48	2.43	.563	126.0
5	2.30	20.5	2.25	2.25	20.9	2.20	2.22	.510	140.0
6	2.00	20.8	1.92	1.90	20.6	1.85	1.88	.430	163.0
7	1.70	20.8	1.64	1.60	20.5	1.57	1.60	.371	181.0
8	1.30	20.8	1.25	1.40	20.8	1.34	1.30	.298	201.0
9	1.00	20.5	.98	1.10	20.7	1.06	1.02	.236	220.0
10	.85	20.5	.84	.85	20.6	.82	.83	.192	232.0

FORT CHAMBLY

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

30" COLLECTOR

November 12 1965 Dilution Rate 1%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.05	12.2	8.70	5.05	12.2	8.70	8.70	1.00	
1	5.55	22.0	5.05	5.20	20.5	5.10	5.07	.582	363
2	5.35	22.0	4.85	4.80	21.8	4.40	4.62	.532	408
3	3.90	20.5	3.82	4.25	20.8	4.18	4.00	.460	470
4	4.20	20.5	4.10	3.80	20.5	3.73	3.91	.450	479
5	2.70	20.2	2.68	4.00	20.9	3.85	3.26	.375	544
6	3.05	20.8	2.92	2.60	20.9	2.58	2.75	.316	595
7	3.25	20.8	3.12	4.03	21.2	3.80	3.46	.398	524
8	3.00	20.9	2.88	2.60	20.3	2.57	2.72	.313	598
9	3.00	20.9	2.88	2.30	20.0	2.30	2.59	.298	611
10	2.90	20.3	2.77	2.40	20.6	2.33	2.55	.293	615

CHAMBLY

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

TWIN 24" COLLECTOR

October 25 1965 Dilution Rate 1.5%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.55	15.1	7.20	5.55	15.1	7.20	7.20		
1	4.65	19.5	4.90	4.60	19.0	5.00	4.95	0.688	150
2	4.40	19.0	4.80	4.20	19.5	4.42	4.61	0.644	172
3	4.10	19.5	4.30	4.10	19.7	4.26	4.28	0.595	195
4	3.90	19.3	4.20	3.50	19.1	3.80	4.00	0.555	213
5	3.70	19.0	4.02	3.45	19.0	3.75	3.88	0.540	221
6	3.40	19.6	3.54	2.80	19.0	3.05	3.30	0.458	260
7	3.40	20.0	3.40	3.45	20.1	3.45	3.42	0.475	251
8	3.10	19.6	3.22	3.05	19.4	3.22	3.22	0.448	266
9	2.05	19.5	2.16	2.35	19.6	2.45	2.30	0.320	327
10	2.60	20.2	2.58	2.60	21.0	2.48	2.53	0.350	312

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

36" COLLECTOR

October 26 1965 Dilution Rate 1%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.40	15.0	6.75	5.40	15.0	6.75	6.75		
1	4.70	19.6	4.90	4.60	19.8	4.75	4.82	.715	193
2	4.40	20.0	4.40	4.40	20.2	4.35	4.37	.650	238
3	4.15	20.1	4.15	4.10	20.2	4.05	4.10	.608	265
4	3.80	19.2	4.09	3.80	19.6	3.96	4.02	.593	273
5	3.60	19.3	3.88	3.55	19.4	3.74	3.81	.565	294
6	3.45	19.8	3.55	3.50	20.0	3.50	3.52	.522	323
7	3.40	21.5	3.18	3.35	20.6	3.25	3.21	.475	354
8	2.45	19.2	2.64	2.80	20.1	2.80	2.72	.403	403
9	3.00	20.0	3.00	2.80	19.8	2.88	2.94	.438	381
10	2.90	20.1	2.90	2.80	20.0	2.90	2.90	.430	385

ST BRUNO

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

ST BASILE COLLECTOR

October 19 1965 Dilution Rate 2%

Day	1st Comp Sample			2nd Comp Sample			Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr			
0	4.70	15.8	6.15	4.70	15.8	6.15	6.15		
1	4.70	20.6	4.65	4.75	20.6	4.40	4.52	0.735	81.5
2	4.45	19.2	4.78	4.50	19.1	4.90	4.84	0.790	65.5
3	4.25	20.5	4.16	4.35	20.6	4.20	4.18	0.680	98.5
4	4.30	20.2	4.25	4.25	20.3	4.20	4.22	0.685	96.5
5	4.30	20.6	4.18	4.20	20.3	4.15	4.16	0.678	99.5
6	4.20	20.5	4.10	4.20	20.3	4.15	4.12	0.670	101.5
7	4.10	20.6	3.96	4.00	20.5	3.92	3.94	0.640	110.5
8	4.10	20.5	4.00	4.05	20.4	3.97	3.98	0.648	103.5
9	3.90	20.4	3.82	4.20	20.6	4.17	3.99	0.650	108.0
10	2.20	20.3	2.18	4.10	20.6	3.98	3.08	0.500	153.5

McMASTERVILLE

DATA FOR COMPUTATION OF SEWAGE K VALUE

C.I.L. FIRST DISCHARGE POINT

October 19 1965 Dilution Rate [illegible]2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.40	16.5	5.50	4.40	16.5	5.50	5.50		
1	4.35	20.2	4.30	4.45	20.0	4.45	4.37	.795	56.50
2	4.20	20.3	4.15	4.25	20.4	4.20	4.17	.760	66.50
3	4.10	20.6	3.98	3.70	20.0	3.70	3.84	.700	83.00
4	3.80	19.9	3.92	4.00	20.1	4.00	3.96	.720	77.00
5	3.90	20.9	3.75	4.00	20.6	3.88	3.81	.692	84.50
6	3.00	19.6	3.12	3.40	19.7	3.55	3.34	.607	108.00
7	3.40	20.0	3.40	3.55	20.2	3.51	3.45	.629	102.50
8	2.10	20.2	2.00	1.40	20.0	1.40	1.70	.309	190.00
9	1.40	20.0	1.40	2.80	20.0	2.80	2.10	.382	170.00
10	1.90	20.5	1.86	1.50	20.5	1.47	1.66	.302	192.00

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

C.I.L. SECOND DISCHARGE POINT

October 19 1965 Dilution Rate 2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.55	16.5	5.68	4.55	16.3	5.68	5.68		
1	4.40	20.1	4.40	4.30	19.6	4.48	4.44	.782	62.00
2	4.20	20.2	4.15	4.20	20.1	4.20	4.17	.735	75.50
3	4.20	20.3	4.15	4.25	20.4	4.15	4.15	.732	76.50
4	4.20	20.0	4.20	3.10	20.0	3.10	3.65	.642	101.50
5	4.10	20.6	3.97	3.75	20.4	3.68	3.87	.682	90.50
6	3.40	19.9	3.50	3.90	20.3	3.85	3.67	.647	100.50
7	3.80	20.6	3.68	3.70	20.8	3.65	3.66	.645	101.00
8	3.35	20.2	3.31	1.00	20.0	1.00	2.15	.379	176.50
9	1.80	20.3	3.76	1.40	20.1	1.40	2.58	.453	155.00
10	1.40	20.2	1.38	1.00	20.5	.98	1.18	.208	220.00

McMASTERVILLE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

C.I.L. THIRD DISCHARGE POINT

October 19 1965 Dilution Rate 0.02%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.55	16.2	5.68	4.55	16.2	5.68	5.68		
1	4.50	20.6	4.36	4.60	20.8	4.42	4.39	.773	64.50
2	4.30	20.4	4.20	4.35	20.4	4.26	4.23	.745	72.50
3	4.25	20.5	4.16	4.25	20.4	4.17	4.16	.735	76.00
4	4.00	20.4	3.91	4.20	20.5	4.10	4.00	.705	84.00
5	4.00	20.9	3.84	4.20	20.9	4.05	3.94	.695	87.00
6	3.70	20.5	3.62	4.00	20.6	3.88	3.75	.660	96.50
7	3.80	20.8	3.66	3.90	20.8	3.75	3.70	.651	99.00
8	3.85	20.7	3.75	3.85	20.6	3.75	3.75	.660	96.50
9	3.75	20.3	3.70	3.85	20.4	3.77	3.73	.656	97.50
10	3.60	20.7	3.50	3.80	20.7	3.68	3.59	.632	104.50

DATA FOR COMPUTATION OF SEWAGE K VALUE

C.I.L. FOURTH DISCHARGE POINT

October 19 1965 Dilution Rate 0.2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.40	16.7	5.50	4.40	16.7	5.50	5.50		
1	4.40	20.2	4.35	4.20	20.2	4.15	4.25	.772	62.50
2	4.20	20.2	4.15	4.30	20.8	4.12	4.13	.750	68.50
3	4.15	20.3	4.10	4.20	20.4	4.10	4.10	.745	70.00
4	4.20	20.5	4.10	4.10	20.6	3.98	3.94	.715	78.00
5	4.20	20.4	4.10	4.10	20.3	4.05	4.07	.740	71.50
6	4.10	20.6	3.98	4.10	20.6	3.98	3.98	.725	76.00
7	4.05	20.4	3.95	4.10	21.0	3.90	3.92	.712	79.00
8	4.10	20.5	4.00	4.05	20.9	3.88	3.94	.715	78.00
9	4.10	20.7	3.98	3.70	20.6	3.60	3.79	.690	85.50
10	3.35	20.4	3.28	3.80	20.8	3.65	2.96	.540	127.00

McMASTERVILLE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

54" COLLECTOR

November 3 1965 Dilution Rate 2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	3.70	12.2	6.28	3.70	12.2	6.28	6.28	1.00	
1	4.35	20.8	4.20	4.40	20.8	4.22	4.21	0.62	103.5
2	4.30	21.0	4.10	4.30	21.0	4.10	4.10	0.655	109.0
3	4.15	21.0	3.95	4.15	21.0	3.95	3.95	0.630	116.5
4	4.00	20.9	3.85	3.95	20.9	3.80	3.82	0.610	123.0
5	3.20	20.6	3.10	3.85	20.8	3.70	3.40	0.542	144.0
6	3.65	20.1	3.65	3.40	20.5	3.33	3.49	0.558	139.5
7	3.40	21.0	3.27	3.35	21.0	3.20	3.23	0.515	152.5
8	3.20	21.0	3.05	3.20	21.0	3.05	3.05	0.490	161.5
9	3.15	21.8	2.90	3.20	21.8	2.94	2.92	0.465	168.0
10	3.00	20.7	2.90	3.10	20.5	3.05	2.97	0.470	165.5

BELOEIL

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

36" COLLECTOR

November 3 1965 — Dilution Rate 2%

	1st Comp	Sample		2nd Comp	Sample				
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	3.90	11.5	6.62	3.90	11.5	6.62	6.62		
1	4.45	20.6	4.31	4.35	20.4	4.25	4.28	.647	117
2	4.30	20.9	4.20	4.25	20.3	4.20	4.20	.625	121
3	3.75	20.2	3.70	3.40	20.0	3.40	3.55	.537	153
4	3.60	20.2	3.56	3.20	20.1	3.20	3.38	.510	162
5	3.40	20.5	3.33	2.55	20.1	2.55	2.94	.445	184
6	2.00	20.0	2.00	1.95	19.5	2.05	2.02	.305	230
7	2.00	20.8	1.92	2.50	20.5	2.63	2.27	.343	217
8	2.40	20.8	2.31	2.10	20.3	2.08	2.19	.331	221
9	1.90	20.6	1.85	1.85	20.5	1.81	1.83	.276	239
10	1.90	20.8	1.83	2.60	20.5	2.55	2.19	.331	221

MONT ST HILAIRE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

36" COLLECTOR

November 3 1965 Dilution Rate 2%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	3.80	12.0	6.55	3.80	12.0	6.55	6.55	1.00	
1	4.00	20.5	3.92	4.30	20.5	4.20	4.06	0.618	124.5
2	3.40	20.5	3.33	4.05	20.7	3.93	3.63	0.555	146.0
3	3.80	20.6	3.69	3.60	20.8	3.46	3.57	0.545	149.0
4	3.30	20.5	3.24	3.50	20.6	3.40	3.32	0.508	161.5
5	3.10	20.4	3.04	3.50	20.8	3.40	3.22	0.492	166.5
6	3.30	21.0	3.14	2.95	20.5	2.89	3.01	0.465	177.0
7	2.75	21.0	2.62	3.20	20.8	3.08	2.85	0.435	185.0
8	3.20	22.5	2.86	3.15	21.0	3.00	2.93	0.449	181.0
9	3.20	21.5	3.00	3.15	21.0	3.00	3.00	0.460	177.5
10	1.20	20.0	1.20	1.00	19.8	1.03	1.12	0.176	271.5

ST HILAIRE

DATA FOR THE COMPUTATION OF SEWAGE K VALUE

BEET SUGAR REFINERY

October 19 1965 Dilution Rate 0.5%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.65	16.0	5.80	4.65	16.0	5.80	5.80		
1	4.35	19.8	4.50	4.20	19.8	4.35	4.42	0.765	276.0
2	4.20	20.2	4.15	4.20	19.9	4.35	4.25	0.732	310.0
3	4.10	19.9	4.20	4.15	20.3	4.10	4.15	0.715	330.0
4	3.90	19.6	4.05	4.05	19.9	4.17	4.11	0.710	338.0
5	3.80	20.1	3.80	3.75	20.1	3.75	3.77	0.650	406.0
6	3.50	19.6	3.65	3.20	20.0	3.20	3.42	0.590	472.0
7	3.35	20.0	3.35	3.10	20.0	3.10	3.22	0.555	516.0
8	3.30	20.1	3.30	3.35	20.0	3.35	3.32	0.572	496.0
9	3.30	20.2	3.25	3.25	20.2	3.20	3.22	0.555	516.0
10	2.70	20.0	2.70	3.30	20.4	3.22	2.86	0.495	588.0

STATION 25

DATA FOR THE COMPUTATION OF RIVER WATER K VALUE

C.N.R. BRIDGE ST JEAN

August 2[illegible] 1965 Dilution Rate 100%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.00	24.2	4.15	5.00	24.2	4.15	4.15	1.00	0
1	3.75	19.0	4.07	3.75	19.2	4.04	4.05	0.980	.10
2	3.70	19.8	3.82	3.75	20.8	3.60	3.71	0.890	.44
3	3.70	19.6	3.86	3.60	20.0	3.60	3.73	0.900	.42
4	3.70	19.5	3.80	3.50	19.2	3.76	3.78	0.910	.37
5	3.70	19.9	3.90	3.40	19.0	3.70	3.80	0.915	.35
6	3.55	20.3	3.50	3.70	19.5	3.90	3.70	0.890	.45
7	3.70	20.3	3.66	3.70	20.3	3.66	3.66	0.880	.49
8	3.70	20.5	3.63	3.60	20.3	3.57	3.60	0.870	.55
9	3.70	20.8	3.56	3.60	20.6	3.50	3.53	0.850	.62
10	3.05	20.8	2.92	3.35	20.8	3.22	3.10	0.750	1.05

STATION 21

DATA FOR THE COMPUTATION OF RIVER WATER K VALUE

FRYERS ISLAND DAM

August 24 1965 Dilution Rate 100%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.60	23.2	3.98	4.60	23.2	3.96	3.98	1.00	.0
1	3.80	19.2	4.02	3.75	19.5	3.95	3.98	1.00	.0
2	3.80	19.8	3.92	3.70	19.8	3.82	3.87	0.975	.09
3	3.80	19.2	4.10	3.65	20.0	3.65	3.87	0.975	.09
4	3.65	19.2	3.82	3.70	19.0	4.00	3.91	0.990	.07
5	3.40	19.0	3.71	3.65	19.0	3.76	3.73	0.940	.25
6	3.35	20.5	3.28	3.65	20.2	3.61	3.44	0.880	.54
7	3.50	20.3	3.48	3.50	20.2	3.46	3.47	0.890	.51
8	3.50	20.1	3.50	3.30	20.1	3.30	3.40	0.690	.58
9	3.50	20.2	3.48	3.50	20.3	3.46	3.47	0.890	.51
10	3.55	20.8	3.38	3.30	20.8	3.17	3.27	0.840	.71

STATION 20

DATA FOR THE COMPUTATION OF RIVER WATER K VALUE

INLET CHAMBLY BASIN

August 24 1965 Dilution Rate 100%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	5.40	23.4	4.62	5.40	23.4	4.62	4.62	1.00	
1	3.80	19.5	4.00	3.70	19.5	3.90	3.95	0.858	.67
2	3.50	19.8	3.61	3.60	20.1	3.60	3.60	0.780	1.02
3	3.50	19.8	3.61	3.65	20.5	3.58	3.59	0.778	1.03
4	3.45	19.5	3.62	3.45	19.5	3.62	3.62	0.785	1.00
5	3.40	19.0	3.68	3.25	19.0	3.51	3.59	0.778	1.03
6	3.45	20.5	3.38	3.45	20.5	3.38	3.38	0.730	1.24
7	3.40	20.4	3.33	3.45	20.6	3.31	3.32	0.720	1.30
8	3.35	20.4	3.28	3.45	20.6	3.31	3.29	0.710	1.33
9	3.40	20.3	3.36	3.45	21.2	3.26	3.31	0.715	1.31
10	3.45	20.8	3.31	3.45	20.9	3.30	3.30	0.713	1.32

STATION 19

DATA FOR THE COMPUTATION OF RIVER WATER K VALUE

OUTLET CHAMBLY BASIN

August 24 1965 Dilution Rate 100%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.30	24.4	3.92	4.30	24.4	3.88	3.90	1.00	
1	3.60	19.2	3.88	3.70	19.6	3.85	3.86	.99	.04
2	3.60	19.9	3.72	3.65	20.5	3.58	3.65	.94	.25
3	3.25	19.5	3.42	3.30	19.5	3.44	3.43	.88	.47
4	3.10	19.5	3.26	3.15	19.4	3.32	3.29	.84	.61
5	3.00	19.2	3.23	3.00	19.1	3.27	3.25	.835	.65
6	3.05	20.2	3.02	3.10	20.2	3.06	3.04	.78	.86
7	3.00	20.1	3.00	3.15	20.6	3.06	3.03	.77	.87
8	3.00	20.2	2.96	3.10	20.4	2.89	2.92	.757	.98
9	3.10	20.6	3.00	2.90	21.2	2.74	2.86	.732	1.04
10	3.10	20.8	2.98	3.15	20.9	3.02	3.00	.76	.90

STATION 12

DATA FOR THE COMPUTATION OF RIVER WATER K VALUE

BELOEIL

August 24 1965 Dilution Rate 100%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.35	22.8	3.80	4.35	22.8	3.80	3.80	1.00	
1	3.40	20.0	3.40	3.60	19.7	3.75	3.57	0.940	.23
2	3.40	20.0	3.40	3.50	20.7	3.40	3.40	0.895	.40
3	3.45	19.8	3.55	3.40	20.0	3.40	3.47	0.915	.33
4	3.40	19.6	3.54	3.40	19.5	3.56	3.55	0.935	.25
5	3.40	19.5	3.58	3.40	19.3	3.65	3.61	0.950	.19
6	3.40	20.2	3.35	3.45	20.5	3.38	3.37	0.892	.43
7	3.45	20.5	3.38	3.45	20.5	3.38	3.38	0.890	.42
8	3.40	20.3	3.36	3.45	20.4	3.38	3.37	0.888	.43
9	3.20	21.2	3.02	3.15	21.5	2.94	2.98	0.785	.82
10	3.00	22.2	2.70	3.00	22.5	2.68	2.69	0.710	1.11

STATION 1

DATA FOR THE COMPUTATION OF RIVER WATER K VALUE

ST CHARLES

August 24 1965 Dilution Rate 100%

	1st Comp Sample			2nd Comp Sample					
Day	D.O.	T°C	D.O. Corr	D.O.	T°C	D.O. Corr	Avg. D.O.	$\frac{D_t}{D_o}$	B.O.D.
0	4.75	22.8	4.17	4.75	22.8	4.17	4.17	1.00	
1	3.85	20.1	3.85	3.80	20.0	3.85	3.85	0.925	.32
2	3.75	20.5	3.68	3.80	20.8	3.65	3.67	0.880	.50
3	3.75	19.8	3.85	3.80	20.2	3.75	3.80	0.912	.37
4	3.65	19.6	3.80	3.75	19.6	3.82	3.81	0.913	.36
5	3.60	19.4	3.80	3.70	19.4	3.90	3.85	0.925	.32
6	3.50	20.8	3.35	3.70	20.2	3.66	3.50	0.839	.67
7	3.40	21.0	3.23	3.50	20.6	3.40	3.34	0.800	.83
8	3.30	21.1	3.14	3.35	20.7	3.25	3.19	0.765	.98
9	3.20	21.6	2.94	3.15	21.5	2.94	2.94	0.705	1.23
10	3.00	21.8	2.75	2.95	21.8	2.70	2.72	0.652	1.45

APPENDIX C

COMPUTER PROGRAMS
1. OXYGEN SAG CURVE
2. Y DROP BY MULTILINEAR CORRELATION THEORY

```
FORTRAN     200         SOURCE LISTING AND DIAGNOSTICS                  PROGRAM:

              C       OXYGEN PROFILE                                    APR. 1,
              C       HEINZ O. WEBER                                     1966
001                   DIMENSION IDESC(7)
002                   REAL ID,IDPCT,K,L,MIXMIN,NETOXY,NEXTY
003               201 FORMAT(I4, 6X, 7A5)
004               202 FORMAT(8F9.0)
005               301 FORMAT(1H1, 9X, 18HOXYGEN PROFILE OF , 7A5)
006               302 FORMAT(20HONUMBER OF STATIONS , I4/)
007               303 FORMAT(43H NORMAL VALUE OF PERCENT OXYGEN SATURATION , F9.2)
010               304 FORMAT(26H INITIAL WASTE LOAD AT PO , F9.2)
011               305 FORMAT(23H BOD AMORTIZATION RATE , F9.2///)
012               306 FORMAT(51H2 NO. OF    MILEPOINT    PERCENT       TRUE PERCENT)
013               307 FORMAT(50H  ITER.                  SATURATION      SATURATION/)
014               308 FORMAT(1H , I6, 7X, F6.2, 8X, F6.2, 9X, F6.2)
015                77 READ (2,201) N,IDESC
016                   SUMREO=0.0
017                   SUMPAY=0.0
020                   READ (2,202) X,Y,K
021                   WRITE (3,301) IDESC
022                   WRITE (3,302) N
023                   WRITE (3,303) X
024                   WRITE (3,304) Y
025                   WRITE (3,305) K
026                   WRITE (3,306)
027                   WRITE (3,307)
030                   PCTSAT=X
031                   DO 11 J=1,N
032                   READ (2,202) P,T,V,D,Q,L,S,ID
033                   TIME=1.547*V/Q
034                   G=22.42*Q
035                   IF (T-20.) 12,13,13
036                12 SATOXY=G*(14.62+T*(.00565*(T-10.)-.019))
037                   GO TO 16
040                13 IF (T-30.) 14,14,15
041                14 SATOXY=G*(12.25-.154*T)
042                   GO TO 16
043                15 SATOXY=G*(10.6-.1*T)
044                16 SUMRUN=X*SATOXY/100.
045                   IF (3.-D) 17, 18, 18
046                17 MIXMIN=13.94*ALOG(D)-7.45
047                   GO TO 19
050                18 MIXMIN=.721*D+2.279
051                19 NEXTY=Y*EXP(-2.3026*K*TIME)
052                   SUMPAY=SUMPAY+Y-NEXTY+S+ID
053                   Y=NEXTY+L
054                   F=.486*SQRT(MIXMIN)*EXP(.0745*T-.7738)/D
055                   R=1.+.0896*MIXMIN*Q/(F*V)
056                   NETOXY=SUMRUN+SUMREO-SUMPAY
057                   REO=(SATOXY*(2.-.01*PCTSAT)-NETOXY-ID)/R
060                   PCTSAT=100.*(NETOXY+ID+REO)/SATOXY
061                   REO=REO+ID/R
062                   IF (ID) 21,20,21
063                20 IDPCT=PCTSAT
064                   GO TO 22
065                21 IDPCT=100.*(NETOXY+REO)/SATOXY
066                22 SUMREO=SUMREO+REO
```

```
067          11 WRITE (3,308) J,P,PCTSAT,IDPCT
070             PAUSE 1221
071             GO TO 77
072             STOP
073             END
```

```
FORTRAN     200        SOURCE LISTING AND DIAGNOSTICS                    PROGRAM:

            TITLERIVPO1
           C     CASE STUDY
           C     RIVER POLLUTION                                         APR. 5, 1
           C     HEINZ O. WEBER                                            1966
                 COMMON ICTR1,LCTR,IPAGE,IDESC(12),ISTN,IDATE1,IDATE2,X1,X2,X3,Y
                 COMMON A(3,4),SA(4,5),X1BAR,X2BAR,X3BAR,YBAR,SYSQ,AN
                 COMMON ITEMP1,ITEMP2,ITEMP3
             201 FORMAT(10X,12A3)
             202 FORMAT(I2,7X,2A3,4X,F5.1,5X,F5.1,5X,F5.2,5X,F5.1)
             301 FORMAT(1H1,29X,12A3,27X,5HPAGE ,I3/)
                 ICTR1=0
                 LCTR=0
                 IPAGE=1
                 SA(1,5)=1.
                 SA(2,5)=0.
                 SA(3,5)=0.
                 SA(4,5)=0.
                 READ (2,201) IDESC
                 WRITE (3,301) IDESC,IPAGE
                 IPAGE=2
               3 READ (2,202) ISTN,IDATE1,IDATE2,X1,X2,X3,Y
                 IF (ISTN-99) 1,2,2
               1 CALL CHAIN 2
               2 PAUSE 01
                 GO TO 3
```

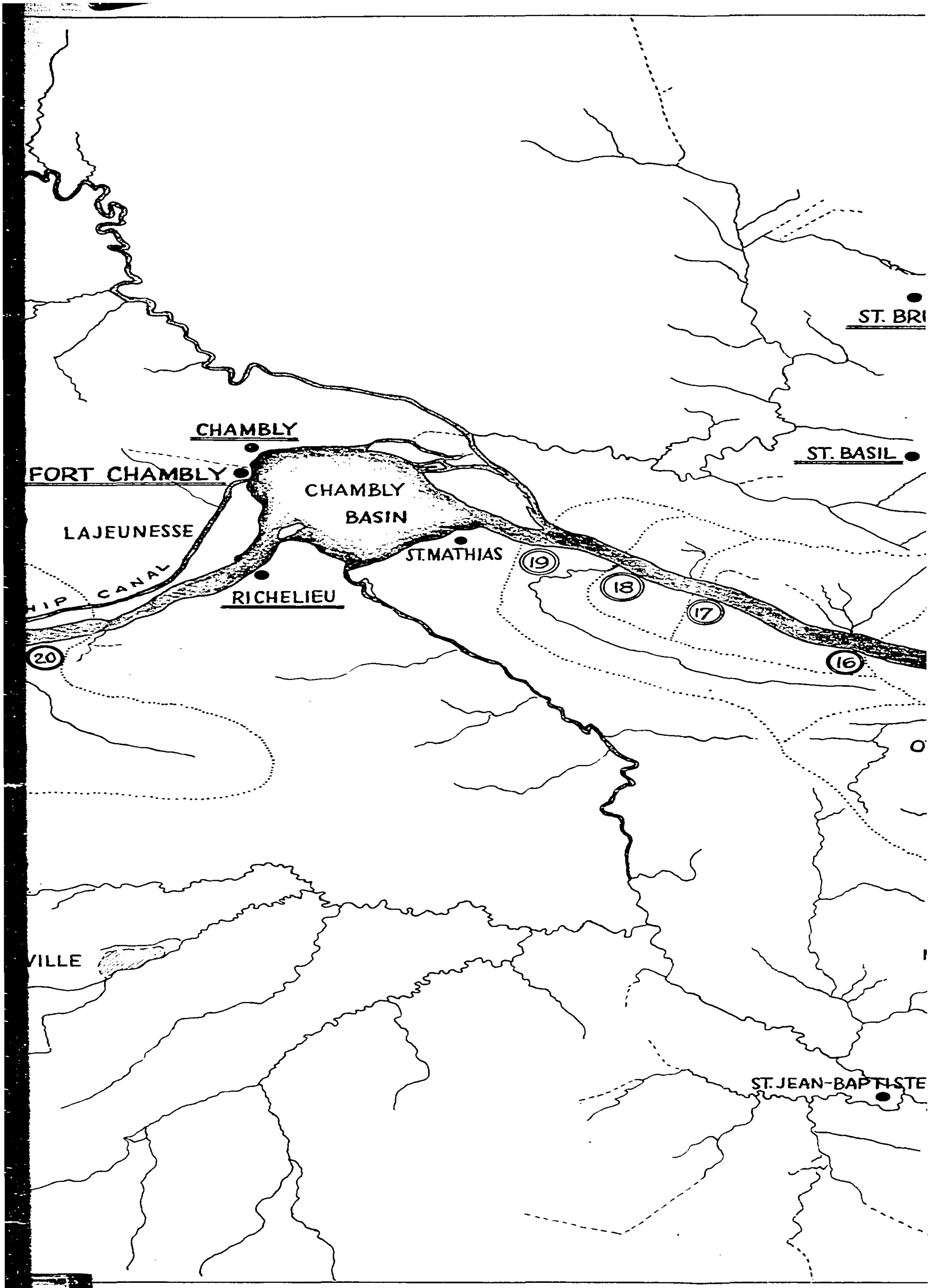
```
*CHAIN 2

 FORTRAN    200       SOURCE LISTING AND DIAGNOSTICS                     PROGRAM:

        TITLERIVPO2
 001          COMMON ICTR1,LCTR,IPAGE,IDESC(12),ISTN,IDATE1,IDATE2,X1,X2,X3,Y
 002          COMMON A(3,4),SA(4,5),X1BAR,X2BAR,X3BAR,YBAR,SYSQ,AN
 003          COMMON ITEMP1,ITEMP2,ITEMP3
 004      202 FORMAT(I2,7X,2A3,4X,F5.1,5X,F5.1,5X,F5.2,5X,F5.1)
 005      401 FORMAT(F4E12.6)
 006          AN=0.
 007          DO 2 J=1,4
 010          DO 2 I=1,4
 011          SA(I,J)=0.
 012        2 CONTINUE
 013          X1BAR=0.
 014          X2BAR=0.
 015          X3BAR=0.
 016          YBAR=0.
 017          SYSQ=0.
 020       17 AN=AN+1.
       C      CALCULATION OF CORRELATIONS
 021          A(1,1)=X1*X1
 022          A(2,1)=X1*X2
 023          A(3,1)=X1*X3
 024          A(1,2)=A(2,1)
 025          A(2,2)=X2*X2
 026          A(3,2)=X2*X3
 027          A(1,3)=A(3,1)
 030          A(2,3)=A(3,2)
 031          A(3,3)=X3*X3
 032          A(1,4)=Y*X1
 033          A(2,4)=Y*X2
 034          A(3,4)=Y*X3
 035          ITEMP1=ISTN
 036          ITEMP2=IDATE1
 037          ITEMP3=IDATE2
 040          X1BAR=X1BAR+X1
 041          X2BAR=X2BAR+X2
 042          X3BAR=X3BAR+X3
 043          YBAR=YBAR+Y
 044          SYSQ=SYSQ+(Y*Y)
 045          DO 11 J=1,4
 046          DO 11 I=1,3
 047          SA(I,J)=SA(I,J)+A(I,J)
 050       11 CONTINUE
 051          WRITE (4,401) X1,X2,X3,Y
 052          READ (2,202) ISTN,IDATE1,IDATE2,X1,X2,X3,Y
 053          IF (ISTN-99) 12,13,13
 054       12 IF (ISTN-ITEMP1) 15,14,15
 055       14 IF (IDATE1-ITEMP2) 15,16,15
 056       16 IF (IDATE2-ITEMP3) 15,17,15
 057       13 ICTR1=1
 060       15 END FILE 4
 061          REWIND 4
 062          CALL CHAIN 3
```

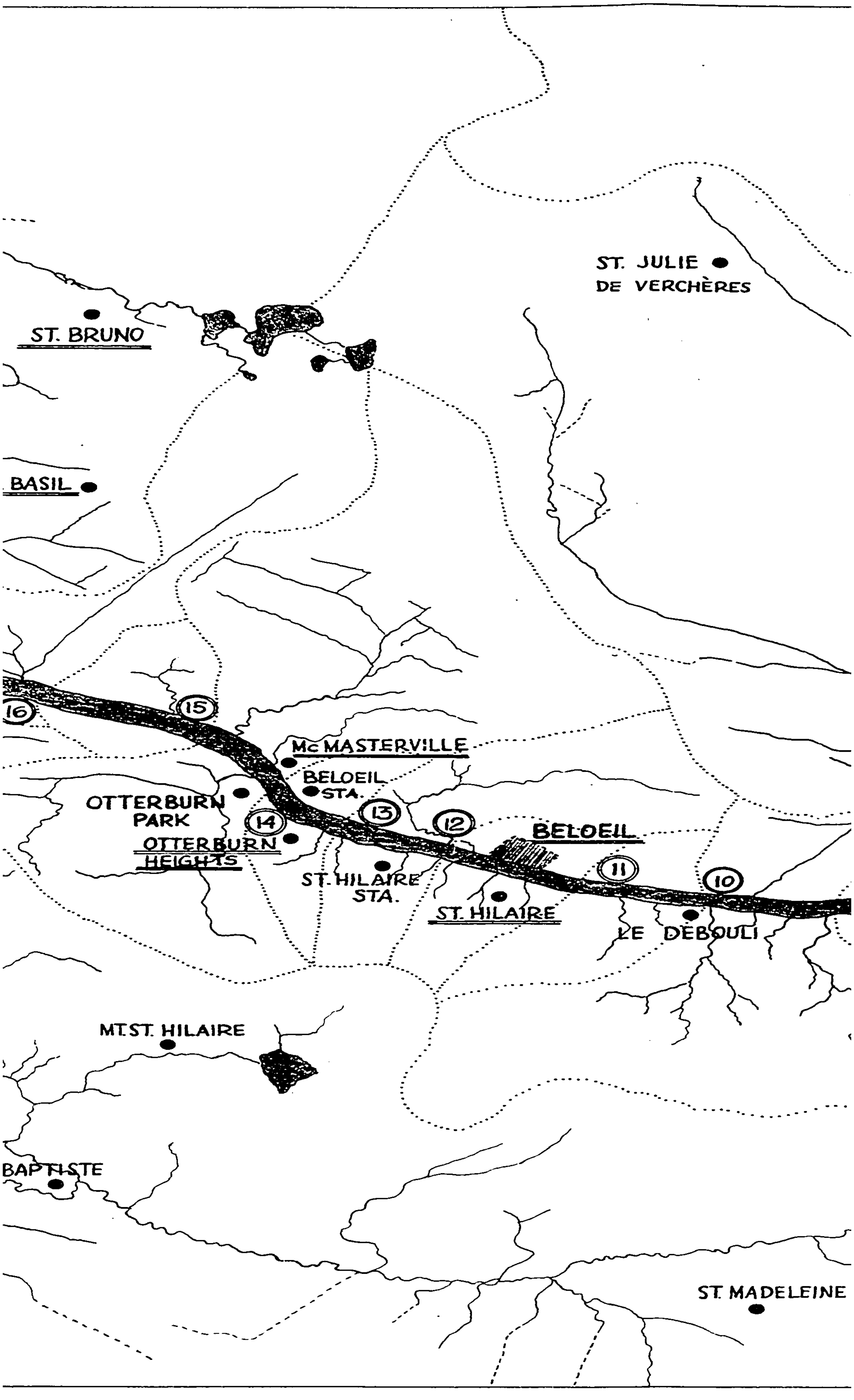
```
*CHAIN 3
 FORTRAN    200      SOURCE LISTING AND DIAGNOSTICS                 PROGRAM: RIV

          TITLERIVP03
                COMMON ICTR1,LCTR,IPAGE,IDESC(12),ISTN,IDATE1,IDATE2,X1,X2,X3,Y
                COMMON A(3,4),SA(4,5),X1BAR,X2BAR,X3BAR,YBAR,SYSQ,AN
                COMMON ITEMP1,ITEMP2,ITEMP3
                DIMENSION SAP(3)
            301 FORMAT(1H1,29X,12A3,27X,5HPAGE ,I3/)
            302 FORMAT(9H4STATION ,I3,3X5HDATE ,2A3,4X,5HB1 = ,F9.4,3X,5HB2 = ,
               1F9.4,3X,5HB3 = ,F9.4)
            303 FORMAT(1H ,29X,5HR =  ,F8.3,4X,5HA =  ,F8.3/)
            304 FORMAT(1H ,33X,2HX1,7X,2HX2,8X,2HX3,9X,1HY,9X,10HY COMPUTED/)
            305 FORMAT(1H ,30X,F5.1,5X,F5.1,5X,F6.2,4X,F5.1,8X,F8.4)
            401 FORMAT(F4E12.6)
          C     CALCULATING MEANS
                X1BAR=X1BAR/AN
                X2BAR=X2BAR/AN
                X3BAR=X3BAR/AN
                YBAR=YBAR/AN
                A(1,1)=AN*X1BAR*X1BAR
                A(2,1)=AN*X1BAR*X2BAR
                A(3,1)=AN*X1BAR*X3BAR
                A(1,2)=A(2,1)
                A(2,2)=AN*X2BAR*X2BAR
                A(3,2)=AN*X2BAR*X3BAR
                A(1,3)=A(3,1)
                A(2,3)=A(3,2)
                A(3,3)=AN*X3BAR*X3BAR
                A(1,4)=AN*YBAR*X1BAR
                A(2,4)=AN*YBAR*X2BAR
                A(3,4)=AN*YBAR*X3BAR
                DO 18 J=1,4
                DO 18 I=1,3
                SA(I,J)=SA(I,J)-A(I,J)
             18 CONTINUE
                SX1Y=SA(1,4)
                SX2Y=SA(2,4)
                SX3Y=SA(3,4)
          C     MATRIX INVERSION
                DO 21 M=1,3
                SAP(1)=SA(1,1)
                SAP(2)=SA(2,1)
                SAP(3)=SA(3,1)
                DO 22 J=1,4
                SA(4,J)=SA(1,J+1)/SAP(1)
                DO 22 I=1,3
                SA(I,J)=SA(I,J+1)-SAP(I)*SA(4,J)
             22 CONTINUE
                DO 23 I=1,3
                DO 23 J=1,4
                SA(I,J)=SA(I+1,J)
             23 CONTINUE
             21 CONTINUE
                R=SQRT((SA(1,1)*SX1Y+SA(2,1)*SX2Y+SA(3,1)*SX3Y)/(SYSQ-AN*YBAR*YBAR
               1))
                AA=YBAR-SA(1,1)*X1BAR-SA(2,1)*X2BAR-SA(3,1)*X3BAR
```

```
062             IF (LCTR-4) 25,24,24
063          24 WRITE (3,301) IDESC,IPAGE
064             LCTR=0
065             IPAGE=IPAGE+1
066          25 LCTR=LCTR+1
067             WRITE (3,302) ITEMP1,ITEMP2,ITEMP3,SA(1,1),SA(2,1),SA(3,1)
070             WRITE (3,303) R,AA
071             WRITE (3,304)
072             N=AN
073             DO 31 K=1,N
074             READ (4,401) X1P,X2P,X3P,YP
075             YSC=AA+SA(1,1)*X1P+SA(2,1)*X2P+SA(3,1)*X3P
076             WRITE (3,305) X1P,X2P,X3P,YP,YSC
077          31 CONTINUE
100             REWIND 4
101             IF (ICTR1-1) 1,32,32
102          32 PAUSE 02
103             CALL CHAIN 1
104           1 CALL CHAIN 2
105             END
```

APPENDIX D

MAP OF THE RICHELIEU RIVER SHOWING- 1. DRAINAGE BASINS
2. STATION LOCATIONS


CHAMBLY
FORT CHAMBLY
CHAMBLY BASIN
LAJEUNESSE
HIP CANAL
RICHELIEU
ST. MATHIAS
⑲
⑱
⑰
⑯
⑳
ST. BR
ST. BASIL
O
VILLE
ST. JEAN-BAPTISTE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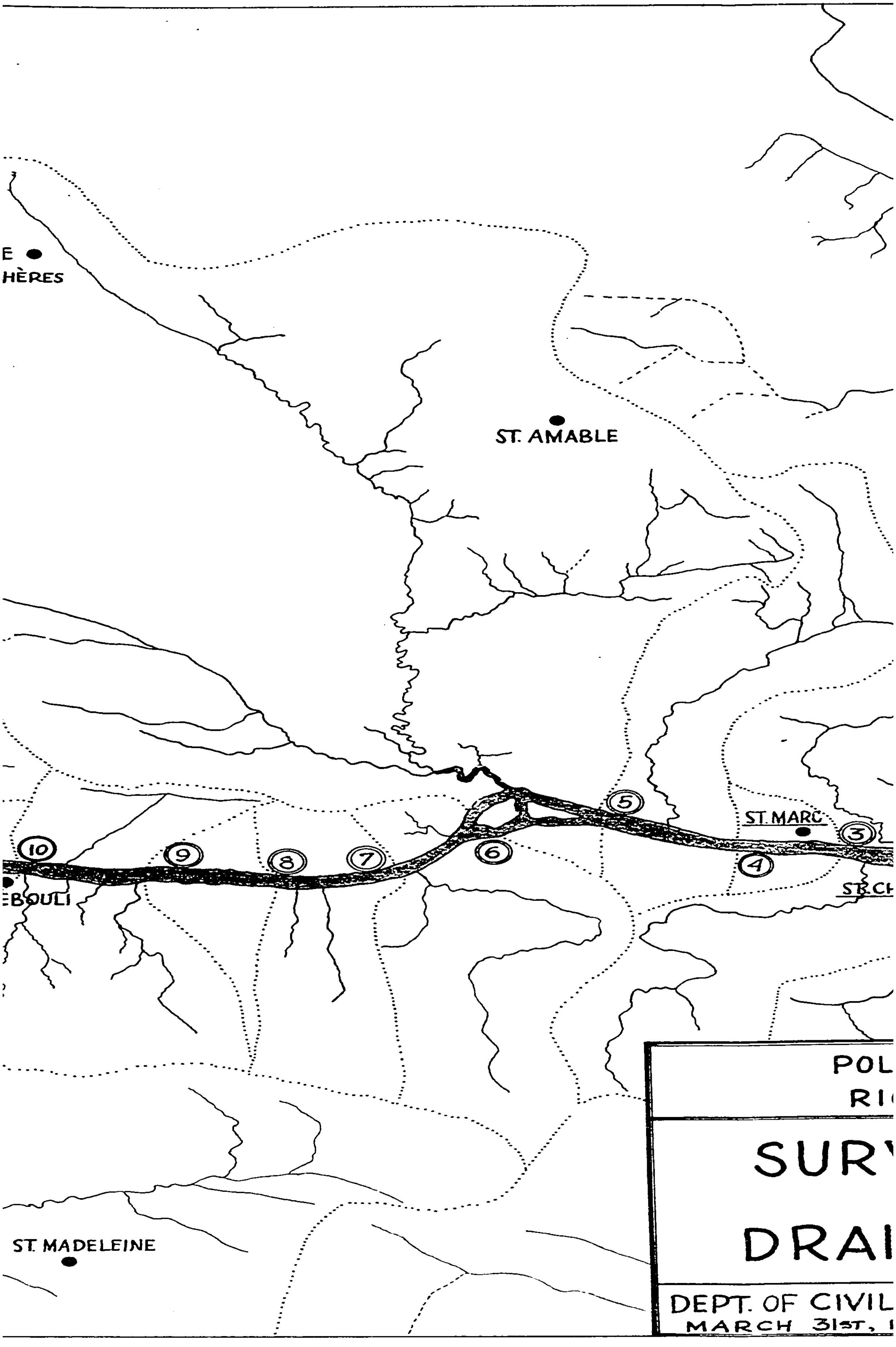
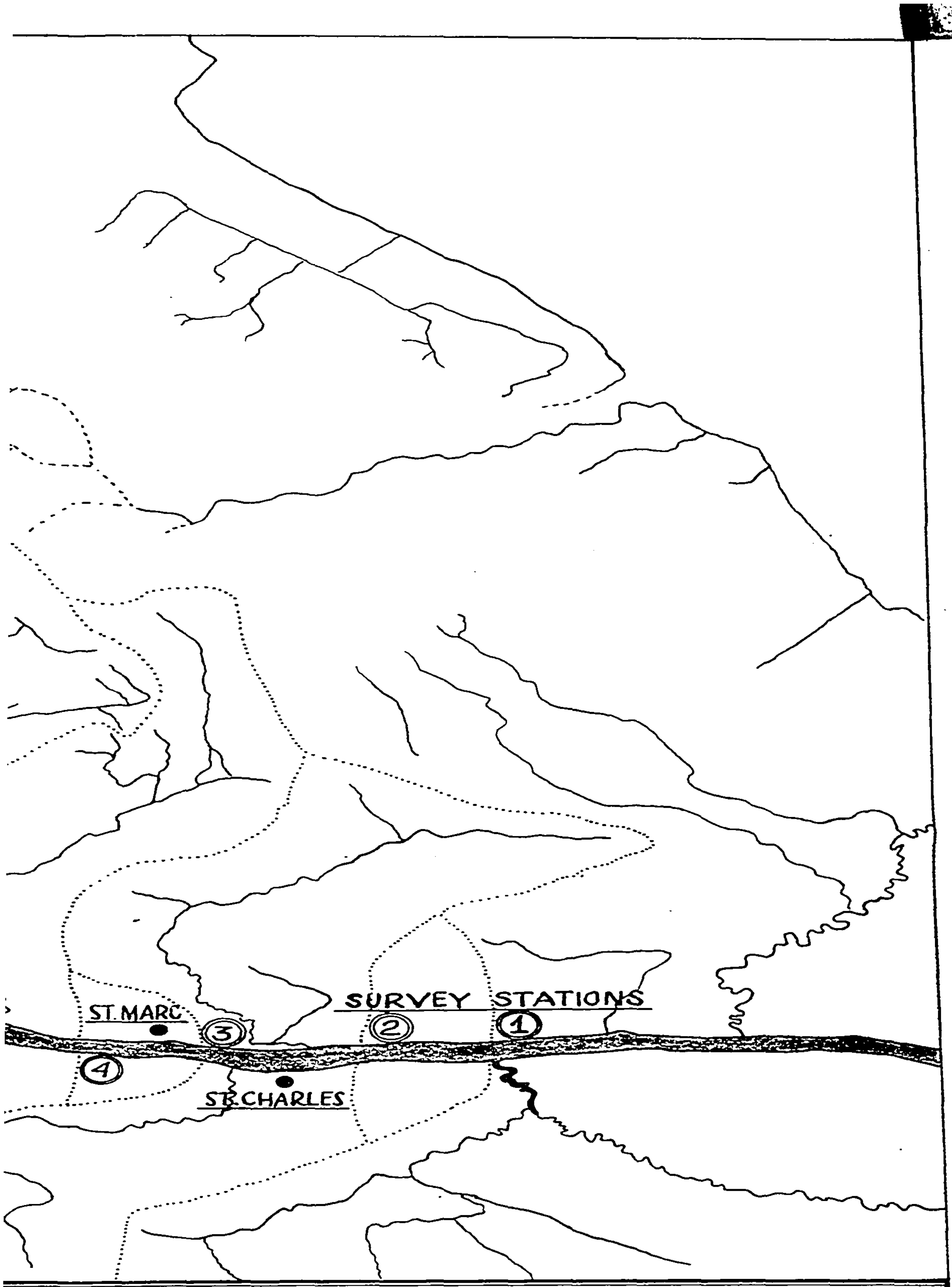
DE VERCHÈRES
ST. BRUNO
BASIL
16
15
McMASTERVILLE
BELOEIL
STA.
OTTERBURN
PARK
14
OTTERBURN
HEIGHTS
13
12
BELOEIL
ST. HILAIRE
STA.
ST. HILAIRE
11
10
LE DEBOULI
MT. ST. HILAIRE
BAPTISTE
ST. MADELEINE

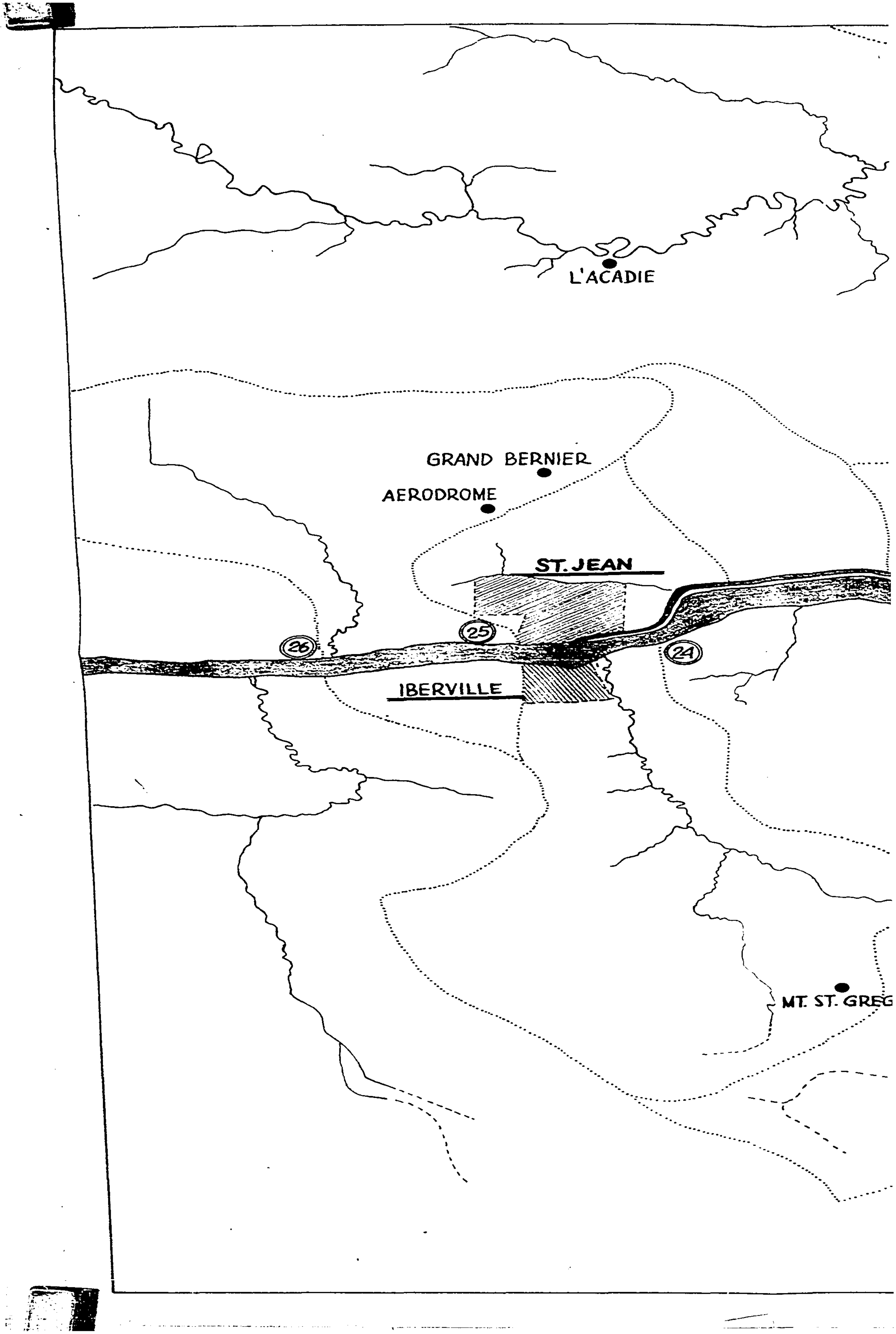

E
HÈRES
ST. AMABLE
10
9
8
7
6
5
4
3
EBOULI
ST. MARC
ST. CH
ST. MADELEINE
POL
RI
SURV
DRAI
DEPT. OF CIVIL
MARCH 31ST, 1



POLLUTION SURVEY OF
RICHELIEU RIVER, P.Q.

SURVEY STATIONS
AND
DRAINAGE BASINS

DEPT. OF CIVIL ENGRG., McGILL UNIVERSITY
MARCH 31ST, 1967. SCALE 1:50,000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GRAND BERNIER
AERODROME
ST. JEAN
25
26
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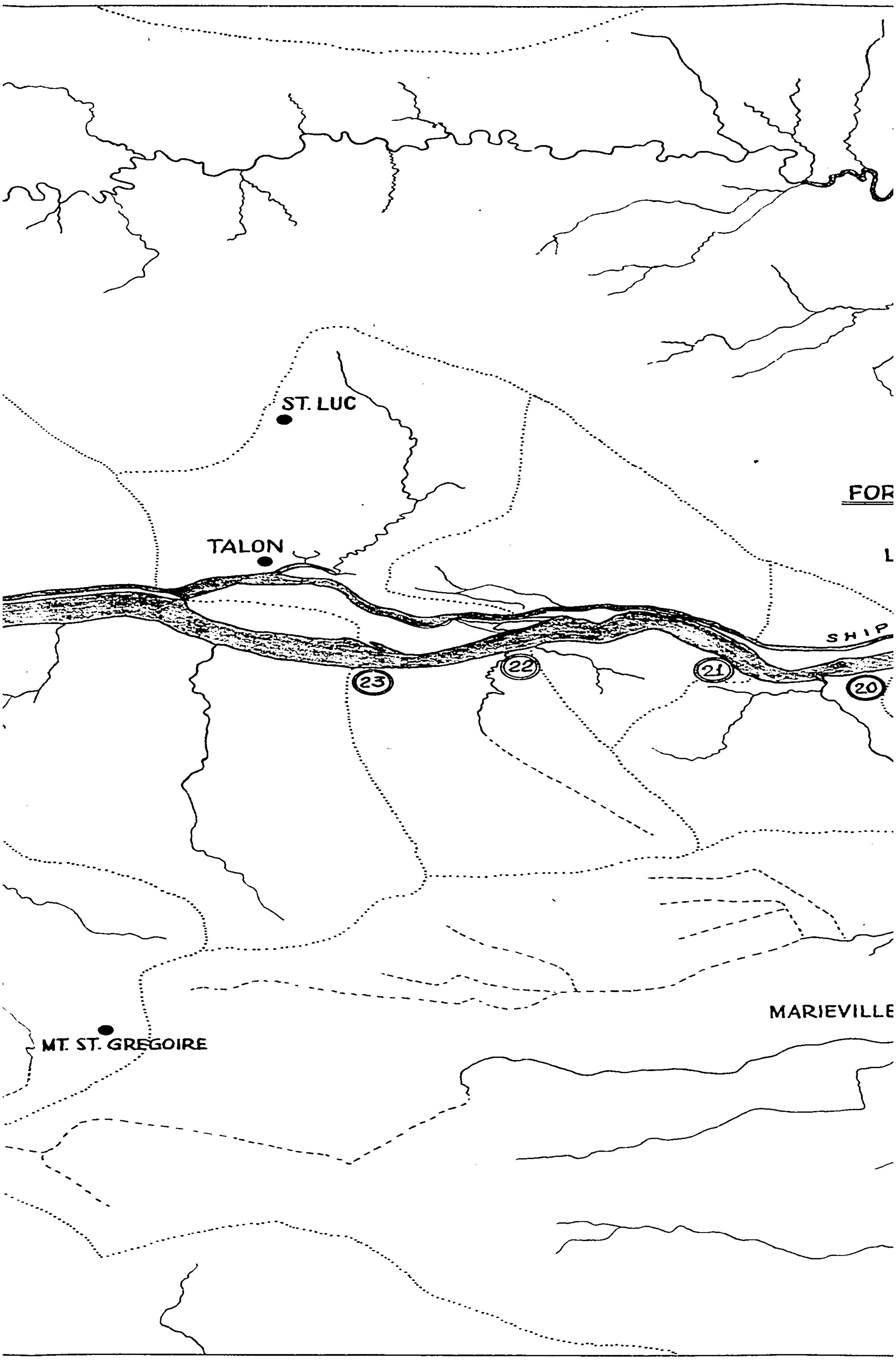
IBERVILLE
MT. ST. GREG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TALON
FOR
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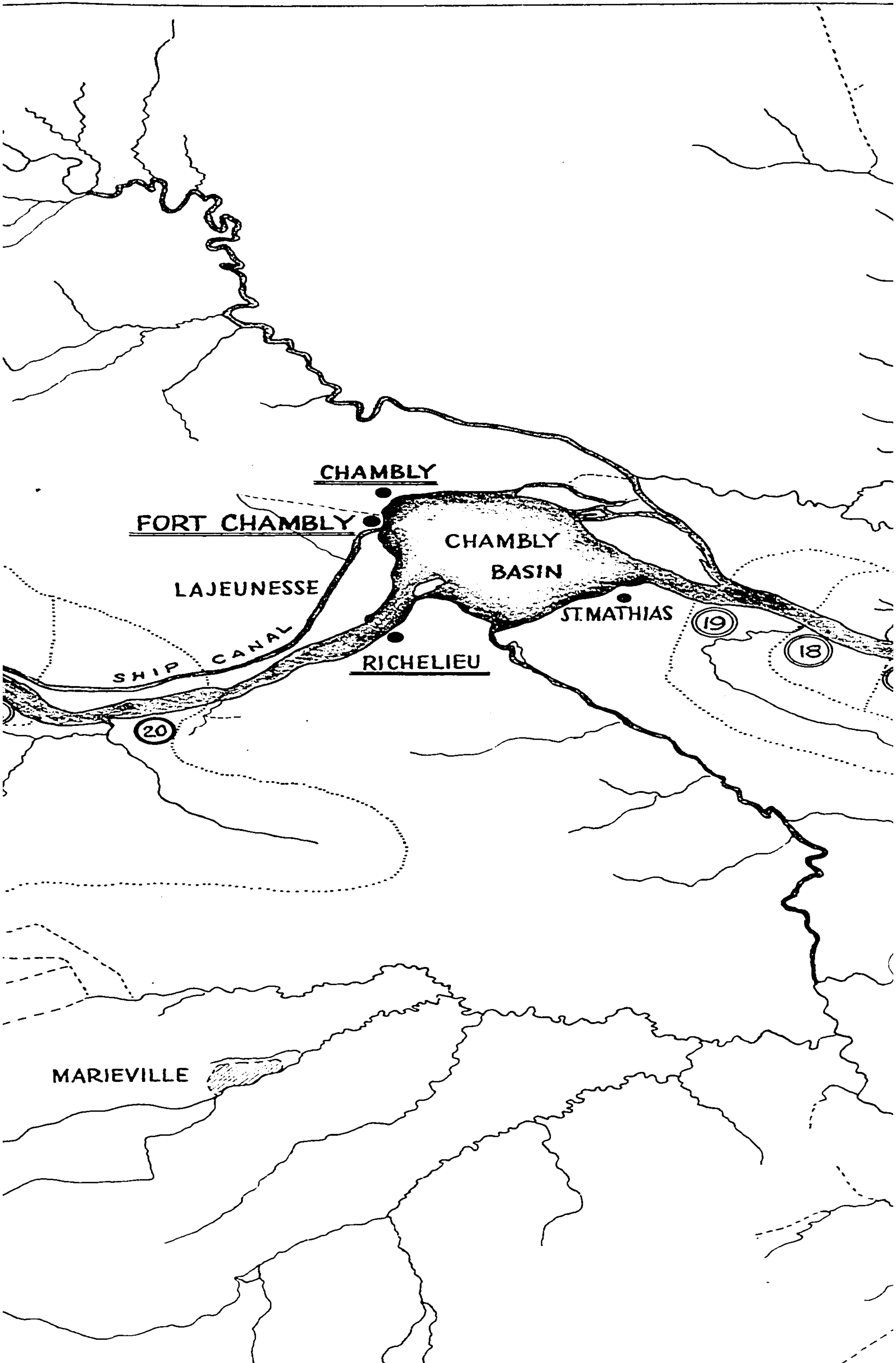
SHIP
23
22
21
20
MARIEVILLE
MT. ST. GREGOIRE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FORT CHAMBLY
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RICHELIEU
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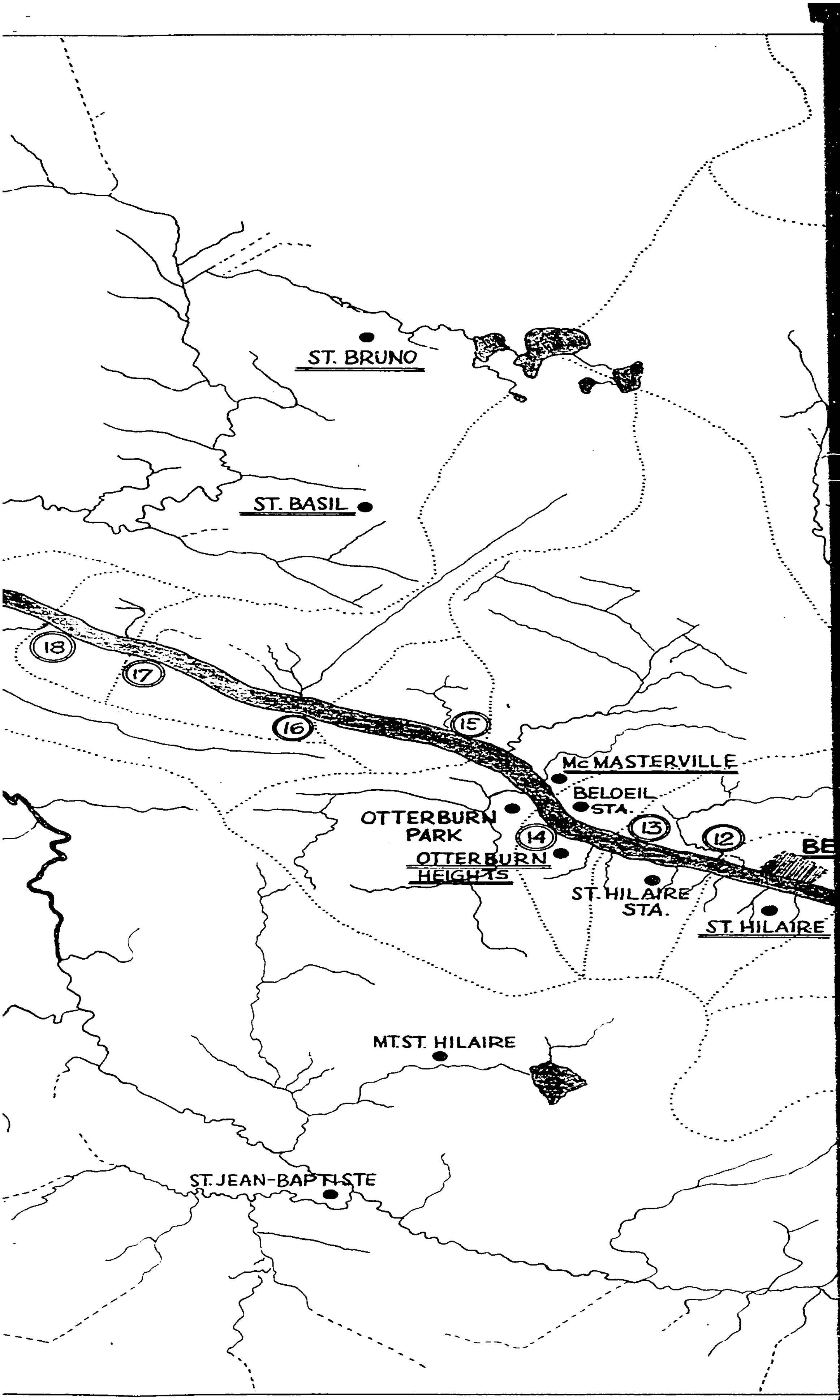
MARIEVILLE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BELOEIL STA.
OTTERBURN PARK
14
OTTERBURN HEIGHTS
13
12
BE
ST. HILAIRE STA.
ST. HILAIRE
MT. ST. HILAIRE
ST. JEAN-BAPTISTE