GRAND RIVER BASIN WATER MANAGEMENT STUDY

GRAND RIVER STUDY TEAM

TECHNICAL REPORT SERIES

Report #4

CENTRAL GRAND RIVER BASIN

WASTE ASSIMILATION STUDY

PREPARED FOR THE GRAND RIVER IMPLEMENTATION COMMITTEE BY:

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Water Resources Branch
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Toronto, Ontario

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FOREWORD

This report is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken through the Grand River Study Team at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information and, in itself, does not necessarily constitute policy or management practices. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this one report but should be analyzed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Study Team, c/o J. G. Ralston, Water Resources Branch, Ministry of the Environment, 135 St. Clair Avenue West, Toronto.

CREDITS AND ACKNOWLEDGEMENTS

This report was prepared by Mr. D. G. Weatherbe and Dr. T. P. Halappa Gowda of the Water Modelling Section, Ministry of the Environment. The section on low flow analysis was prepared by Dr. J. Coward. Technical modelling support work was carried out by Messrs. D. Alleway, E. Smith and R.L. Van Biesbrouck. The field surveys and preliminary data analyses were carried out under the supervision of Mr. S. Irwin of the Planning and Co-ordination Section.

ABSTRACT

The objectives of this investigation were to develop relationships between waste input loads and streamflows for different levels of minimum dissolved oxygen concentrations in the stream for each of the following sewage treatment plants in the central portion of the Grand River basin:

Waterloo, Kitchener, Guelph and Galt, Preston and Hespeler in Cambridge

These relationships were based on the application of steady state dissolved oxygen models developed from intensive water quality survey data. Two cases of effluent quality were considered (a) low quality effluent produced by conventional activated sludge treatment (without nitrification); and (b) high quality effluent (conventional activated sludge treatment with nitrification). Results generally indicate a significant improvement in water quality when nitrification is incorporated in the treatment plants. An increase in the nitrified effluent loads did not significantly change the predicted minimum dissolved oxygen concentrations of the stream water. For each sewage treatment plant, the results are presented in graphical form relating the total oxygen demand loading rate to the streamflows and predicted minimum dissolved oxygen concentration levels. These relationships will be useful (1) to determine the allowable waste loadings at each treatment plant, (2) to determine the required flow augmentation (through appropriate reservoir operation policies) to maintain desirable dissolved oxygen levels in the stream and (3) to determine the quantity of water that can be withdrawn from any section of the stream without serious deterioration of the water quality in that section.

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1. INTRODUCTION

1.1 BACKGROUND

Growing residential and industrial development in the Grand River basin has resulted in the increased discharge of waste loads into the river system. These waste loads are derived from treated municipal sewage, untreated urban storm sewer effluent, and rural drainage. At present, treated municipal sewage is the only well defined controllable source. Studies are in progress to devise tools for the management of urban storm runoff and rural drainage; they are, however, not taken into consideration in this analysis.

The various waste sources have enriched the river water with nutrients, resulting in excessive growth of aquatic plant and algae throughout long reaches of the river system. The presence of this excessive biomass has emerged as one of the major factors affecting the dissolved oxygen (DO) regime of the river water and the general aesthetic values of the watercourse.

Mathematical relationships have been developed to take into account the effect of carbonaceous and nitrogeneous oxygen demanding materials discharged from the sewage treatment plants (STP) as well as the effects of photosynthesis and respiration of the biomass of aquatic flora present in the river system.

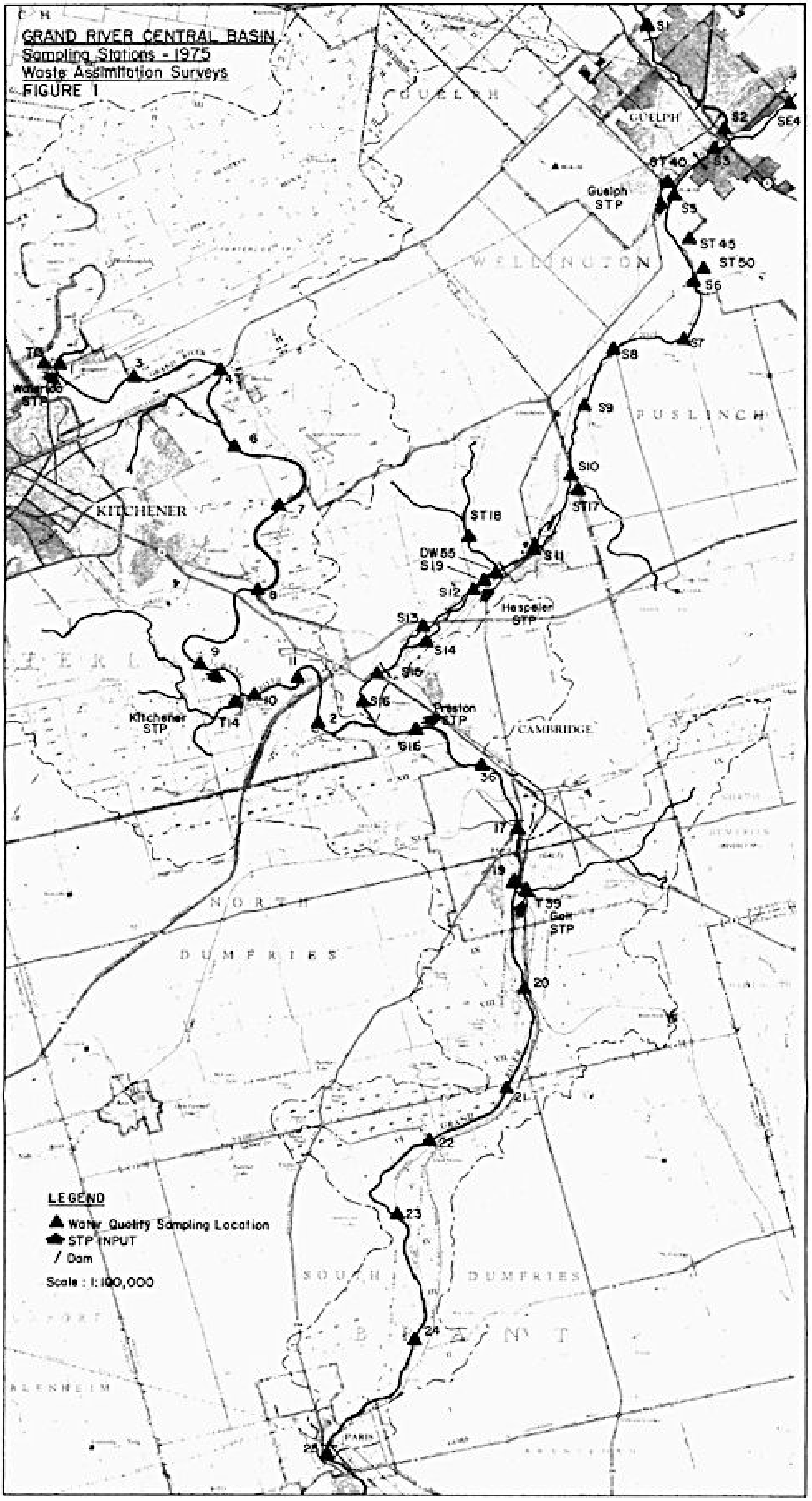
1.2 STUDY AREA

The 1975 investigations have been limited to the central basin of the Grand-Speed river system extending from Guelph to the Grand River confluence on the Speed River, and from Bridgeport to Paris on the main Grand River. Figure 1 shows a map of the study area. The locations of survey stations and other features such as waste input locations, tributaries and dams are shown on the map.

1.3 OBJECTIVES

The objective of this investigation was to develop relationships between waste input load and streamflow for different levels of minimum dissolved oxygen concentrations in the stream for each of the following sewage treatment plants: Guelph, Hespeler, Waterloo, Kitchener, Preston and Galt.

These relationships were based on steady state dissolved oxygen models developed from a 72 hour, intensive water quality survey for each section. The results derived are useful for the design of waste treatment and flow augmentation systems. Close attention should be paid to the assumptions and limitations of the techniques used, as discussed in subsequent sections.


GRAND RIVER CENTRAL BASIN
Sampling Stations - 1975
Waste Assimilation Surveys
FIGURE 1
LEGEND
Water Quality Sampling Location
STP INPUT
/ Dam
Scale : 1:100,000
GUELPH
Guelph STP
WELLINGTON
PUSLINCH
KITCHENER
Waterloo STP
Kitchener STP
Hespeler STP
Preston STP
CAMBRIDGE
Galt STP
NORTH DUMFRIES
SOUTH DUMFRIES
BRANT
PARIS
BLENHEIM

2. FIELD DATA

2.1 HYDRAULIC DATA

The streamflows in various reaches were calculated using data from the basin flow gauging stations. The flows for the survey conditions are given in Tables A1 to A3 (Appendix). The time of travel data, collected during several flow conditions, were used to establish relationships between the time of travel and flow for each reach. The variation of mean values of depth, width and velocity with the streamflow, were expressed by the equations given by Leopold and Maddock (Water Quality Engineering for Practicing Engineers, by W. W. Eckenfelder, p. 50).

2.2 ASSIMILATION SURVEY DATA

Two waste assimilation surveys were carried out in each of three sections of the central basin during summer 1975. The data of only one survey were used in the development and calibration of the model, summarized in the appended tables as follows:

Table A1: Bridgeport to Kitchener on Grand River: August 11-14, 1975

Table A2: Kitchener to Paris on Grand River: July 28-31, 1975

Table A3: Guelph to confluence (with Grand River) on Speed River: September 2-4, 1975

At each station, DO and temperature measurements were taken and samples were collected at 4-hour intervals (approx.); the samples were analyzed in the laboratory for conductivity, pH, BOD_5, free ammonia, total kjeldahl-, nitrite-, and nitrate nitrogens, and total and soluble reactive phosphorous.

The data collected during the second survey (June 9-11, 1975) in the Kitchener-Paris section were used to test the calibrated model output for this reach, as described in Section 3.3.

Semi-log plots of observed waste loads transported in the river vs. time of travel have been presented for each section in Figures A1 to A3 (Appendix). These plots indicate the changes in the various constituents of sewage which directly affect the dissolved oxygen regime in the river. For example, the nitrification reaction is indicated by the conversion of un-oxidized forms of nitrogen, free ammonia and total kjeldahl nitrogen (sum of organic and free ammonia), to the intermediate form, nitrite nitrogen, and the fully oxidized nitrate nitrogen downstream from the treatment plants.

3. STEADY STATE DISSOLVED OXYGEN MODELLING

3.1 MODEL AND ASSUMPTIONS

The mathematical model used describes the distribution of dissolved oxygen during a single 24 hour period for defined reaches in the river system by taking into account the effects of carbonaceous and nitrogeneous oxygen demands, sedimentation, benthic oxygen demand, atmospheric aeration, photosynthetic oxygen production and respiration of aquatic plants and algae. (The model used in this study has been utilized in other studies and is described in the report "Water Management Study-Thames River Basin", p. 78-79). The following basic assumptions were made in the development and application of the steady state model.

1. The flow regime in the river system is steady during the 24 hours for which the model is applied.

2. The sewage effluent is completely mixed with the river water instantaneously, and dispersion effects are negligible.

3. Under design conditions, the stream processes, such as sedimentation, deoxygenation, and re-aeration, are unchanged from survey conditions, except for flow and temperature effects. Assumptions are made to reflect the lowered reaction rate of the remaining nitrogenous oxygen demand in highly nitrified effluents.

4. The biomass of aquatic flora remains constant and consequently, daily average photosynthesis and respiration rates are constant (except as affected by temperature and flow).

5. Under design conditions, upstream water quality conditions remain constant and unchanged from survey conditions.

6. Mean temperature increases in the stream cause the following changes in the model:
   - increases in reaction rates satisfying carbonaceous and nitrogenous oxygen demand and increases in the algal respiration rate;
   - decreases in oxygen saturation values;
   - increases in atmospheric re-aeration rate.
   -

7. Flow increases in the stream cause the following
   - changes in the model:
   - increases in flow velocity, depth, and width according to relationships referred to in Section 2.1;
   - decrease in the re-aeration rate;
   - decreases in algal photosynthetic and respiration rates.

Estimates of model parameters for various reaches of each section were determined by analysis of the assimilation survey data. For each section, the model was calibrated by altering these parameters within acceptable ranges to produce dissolved oxygen output values which were very close to the observed values. The calibrated model was used to predict the dissolved oxygen output under various waste loading and streamflow conditions with model parameters adjusted to account for changes in the effects of flow and temperature.

3.2 LOW FLOW ANALYSIS

The seven-day low flows at the five sites above the major sewage treatment plants (Guelph, Hespeler, Waterloo, Kitchener and Galt) were estimated for a number of dam operation policies. (See Grand River Technical Reports 3 - Reservoir Yield Study, and 5 - Stream Flow Analysis at the Woolner Flats Induced Infiltration Site.)

The natural seven-day low flows were estimated by analyzing streamflow for periods prior to any major dam construction (before 1942) and adjusting these for the increase in STP flows to the present. These derived 'pristine flows' were also used to estimate local inflows between the streamflow gauges and the five sites in question, assuming uniform yield between stations. Seven-day low flows under present dam operating policies were determined by analyzing stream-flow records for the period 1960-1973.

Low flow values that could be maintained by the Shand, Conestogo and the proposed West Montrose dams, under improved dam operation policies, were determined by reservoir yield studies carried out by the Conservation Authorities Branch of the Ministry of Natural Resources (see Technical Report No. 3). The effect of the new Guelph Dam on the Speed River flows was estimated using a mass curve analysis to determine minimum flows. This analysis was carried out for two dam operation policies, taking evaporation into account. Using existing historic records of streamflow below the existing Shand and Conestogo dams, the minimum seven-day low flows were estimated to be approximately 0.75 of the minimum monthly flows determined by the reservoir analysis.

The seven-day low flow values for natural flow, present day dam operating, and improved dam operating conditions are shown in Table A4 (Appendix). It should be pointed out that these figures are subject to errors in measurement and other uncertainties. The data, particularly those for the long return periods, are subject to an estimated variation of up to ±50 per cent. In addition, the yields calculated from the dams for improved operating policies, represent the maximum theoretical yields, and may not be achievable in practice.

3.3 MODEL VERIFICATION

The steady state model for the Kitchener to Paris section of the Grand River, calibrated to the survey conditions of July 28-31, 1975, was used to predict dissolved oxygen concentrations for the conditions observed in the June 9-11, 1975, survey of the same section. Model parameters were altered to account for observed differences in flow and temperature conditions, and the observed quality was used to account for the boundary conditions (upstream quality, STP quality and Speed River quality). Flows were practically identical in the two surveys (July- 436 cfs vs June- 456 cfs), with the major difference being temperature (July-24.5°C vs June-19.8 °C). In addition, stop logs in the small dam at Galt were in place for the July survey and out for the June survey, but the effect on the hydraulic characteristics was not evaluated.

Figure A4 (Appendix) shows the predicted and observed range of dissolved oxygen concentrations with time of travel (distance) downstream in the reaches. From this, it can be seen that the difference between the predicted and observed minimum dissolved oxygen concentrations is less than 0.5 mg/L for four of the eight stations and is approximately 2 mg/L for the other four. The difference between predicted and observed maximum concentrations is less than 0.5 mg/L for three stations, is approximately 1 mg/L for three stations and is greater than 2 mg/L for two others. The model maintains the trend of the observed data except for the last two stations. The differences are attributed to a different algal biomass and thus a different photosynthetic and respiration rate than that estimated. This is confirmed by studies undertaken by the Limnology and Toxicity Section, which indicate a higher biomass (including decaying algae) in early June 1975, compared to late July 1975, in the reaches between Galt and Glen Morris (stations G20 to G22). The differences for stations G36 and G17 are attributed to the different hydraulic conditions, as these two stations are affected by the dam in Galt, referred to above. These results illustrate the limitations of the model in predicting dissolved oxygen for the whole summer, based on a single survey.

It is interesting to note that the minimum dissolved oxygen concentrations observed for the two surveys were, however, relatively close (4.0 mg/L for July vs 4.5 mg/L for June). This is because the expected (and model predicted) positive effect of reduced temperatures on dissolved oxygen in the June survey relative to the July survey, is counteracted by the negative effect of increased respiration from a larger floral biomass in the river in June compared to July. Consequently, the model based on the July survey alone would not introduce large errors.

4. MODELLING RESULTS

4.1 OPTIONS MODELLED

The calibrated model was used to develop general relationships for the response of dissolved oxygen to controllable variables for the sections downstream from the six sewage treatment plants. The controllable variables modelled consisted of: streamflow, sewage flow rate and waste treatment level.

The model was run for four streamflow cases in the range of flow conditions outlined in Section 3.2. Survey flows were one of the cases modelled in all model applications.

Sewage flow rate cases modelled consisted of 1, 2 and 3 times observed survey sewage flows. Some cases of flows less than existing and greater than three times existing were modelled, where required, to indicate the range of DO response.

Two treatment levels for each STP (except Preston and Hespeler) were modelled as follows:

- conventional or low quality effluent provided by secondary treatment without nitrification,
- high quality effluent provided by secondary treatment including nitrification.

Table A5 (Appendix) summarizes the quality and loading rates for both the treatment plants and the rivers at survey flows. For comparison purposes, average quality and loading rates for the period May to October 1975, are also included in this table. Survey waste loads are observed to be generally lower than the May to October average.

Mean daily water temperatures averaged over the survey period for the Bridgeport-Kitchener and Kitchener-Paris sections were assumed to represent typical summer conditions The temperature during the September survey for the Speed River was relatively low (19.8°C); consequently, parameters were adjusted for a mean temperature of 25°C. Since higher temperatures are possible and likely during low flow conditions (up to 30°C), the use of temperatures no greater than 25°C in the analysis represents a liberal assumption.

4.2 RESULTS FROM MODEL APPLICATION

The results of model runs of various options for each river section are presented graphically for each section, by plots of three variables - waste loading rate from the sewage treatment plant, streamflow and predicted minimum dissolved oxygen concentration. Waste loading rates are shown as "total oxygen demand load from given STP". Total oxygen demand is the sum of ultimate carbonaceous oxygen demand load (LO or CARBOD) and nitrogeneous oxygen demand (NOD) from the given STP. The total load in the river for each case can be calculated from the STP load (shown) and the background load in the section from upstream (from Table A5). The curves in figures 2 to 11 are derived using the specific treatment quality cases shown in Table A5; however, the curves may be used for other cases with different concentrations of effluent constituents (BOD_5 and TKN), as long as the appropriate curve for nitrified or non-nitrified effluent is used with the correct loading value.

Flow indicated is the flow in the stream immediately upstream from the sewage treatment plant input. Flow at a given location can be calculated as the sum of upstream flow, STP flow and tributary inflow.

Minimum dissolved oxygen indicated is the absolute minimum (in space and time) predicted from all reaches downstream from the STP in the section being modelled. Dissolved oxygen results can be interpreted in terms of the requirement for fish survival as indicated in "Guidelines and Criteria for Water Quality Management in Ontario". The dissolved oxygen criteria for warm water biota is stated as follows: "the dissolved oxygen concentration should be above 5 mg/L at all times, except that in certain situations, concentrations may range between 5 and 4 mg/L for short intervals within any 24-hour period provided that water quality is favourable in all other respects." Results are shown subsequently as families of curves of predicted minimum dissolved oxygen concentration at various upstream flows and total oxygen demand loading rates (figures 3,5,7,9,11). The predicted curve indicating a minimum dissolved oxygen of 5 mg/L is considered to be just meeting the above criteria, since factors not modelled such as low light energy, treatment plant quality and flow fluctuations, and high temperatures would cause the dissolved oxygen to fall below 5 mg/L with an unknown frequency and duration.

4.2.1 Waterloo STP-Model Results

Figure 2 shows graphically the relationship between minimum dissolved oxygen and STP waste load for the reaches downstream from Waterloo. It can be seen from this figure that the minimum DO is relatively unresponsive to waste load (shown by the shallow slope of the plot at a given upstream flow) and is highly responsive to upstream flow variations (shown by the large differences in DO concentrations for a change in upstream flow). These data are replotted in Figure 3, with upstream flow and STP load on the axes, indicating various predicted minimum DO levels. This figure indicates that for cases of flow and waste load that plot above or on the 5 mg/L line, a minimum dissolved oxygen level of 5 mg/L or better will be maintained. Evaluating presently attainable flows from Table A4, it can be seen that with the addition of the West Montrose Dam and the operation of all dams to improve low flows, waste load from the Waterloo STP can be increased without violating a 5 mg/L DO criteria in the stretch of the river down to the Kitchener sewage treatment plant.

Model runs indicate that not all waste load input by the Waterloo STP is oxidized (removed) in the river upstream from the Kitchener STP; consequently, an increase in waste load from Waterloo will increase the waste load in the river downstream from Kitchener. For this reason, the high quality effluent from the Waterloo STP observed during the survey should be maintained for the present treatment plant operation and for future expansions.

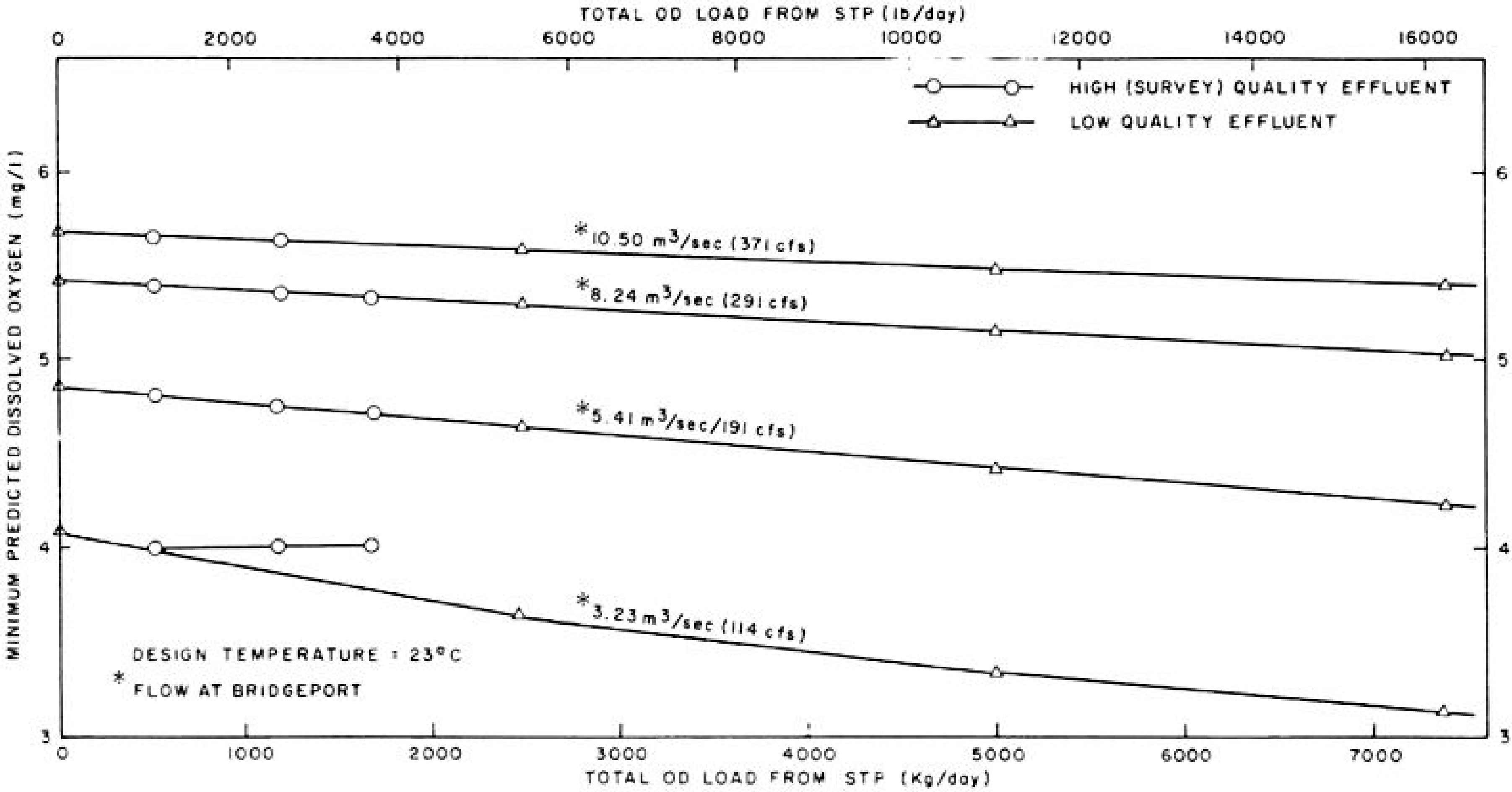


FIG. 2. Predicted Minimum Dissolved Oxygen Concentration vs. Total Oxygen Demand Loading Rate At Various Flow Conditions For Grand River Between Waterloo STP And Kitchener STP.

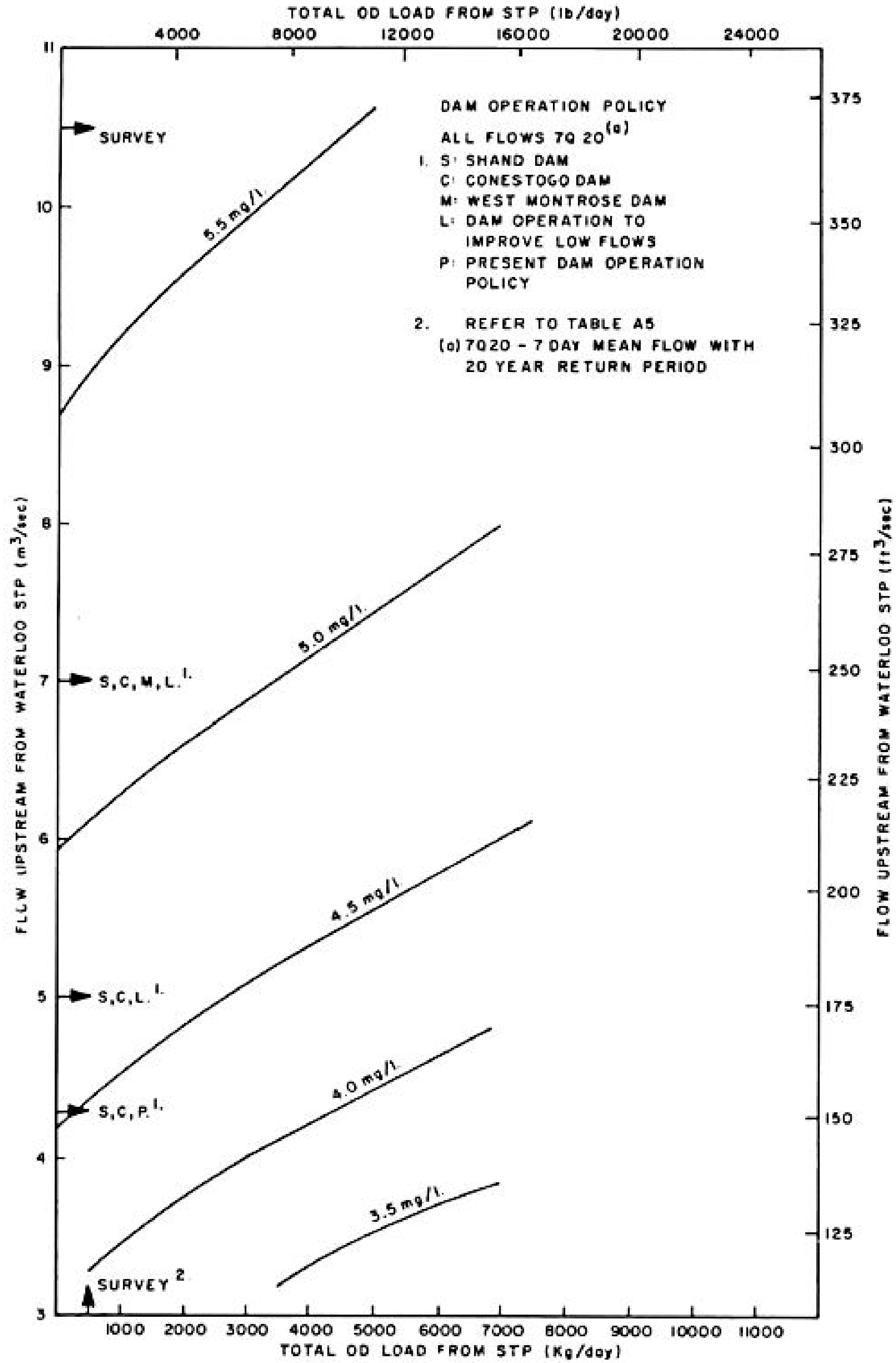


FIG. 3. Total Oxygen Demand Loading Rate From Waterloo STP vs. Upstream Flow For Various Predicted Minimum Dissolved Oxygen Levels.

4.2.2 Kitchener STP - Model Results

Figure 4 shows graphically the relationship between minimum dissolved oxygen and waste load from the Kitchener STP at various upstream flows. On this figure, the relatively large difference in DO output response for the two upstream flow rates of 12.35 and 12.64 m^3/sec is explained by the large difference in the Speed River flows input to the model - 2.12 and 4.59 m^3/sec, respectively. The latter case represents survey conditions; i.e. Figure 5. From this information and survey data, it can be seen that the present waste loading rate along with other conditions in the reach, such as low re-aeration, produced dissolved oxygen levels below the criteria level of 5 mg/L. Improvement of STP effluent to a high quality results in a marked improvement in DO quality, to such an extent that increases in load do not appear to decrease oxygen levels in the waste. However, at present low flows, the combination of background loads and conditions in the river cause DO to be less than 5 mg/L in model predictions. Figure 5 shows the same data replotted with upstream flow and STP Load on the axes. This plot compared with flows achievable with present and proposed dams, indicates that a 5 mg/L criteria is not achievable. A 4 mg/L level is achievable with the increased flows from the new West Montrose Dam and from a reduction in waste loads from the treatment plant. Expansion of the treatment plant at survey effluent quality would result in minimum DO's down to 3 mg/L at present low flows.

4.2.3 Preston STP - Model Results

The load from Preston STP was a negligible input to the dissolved oxygen model. Doubling of the survey loading caused an insignificant change in the dissolved oxygen level downstream. However, the load from Preston should be considered as part of the load from Kitchener, since the location of the STP outfall is close to the location where the minimum dissolved oxygen concentrations occur in the river in the sections between Kitchener and Galt. Consequently, a significant increase in waste load at this location would aggravate water quality conditions at the critical point. Accordingly, a high quality effluent as observed during the survey, should be maintained at this treatment plant.

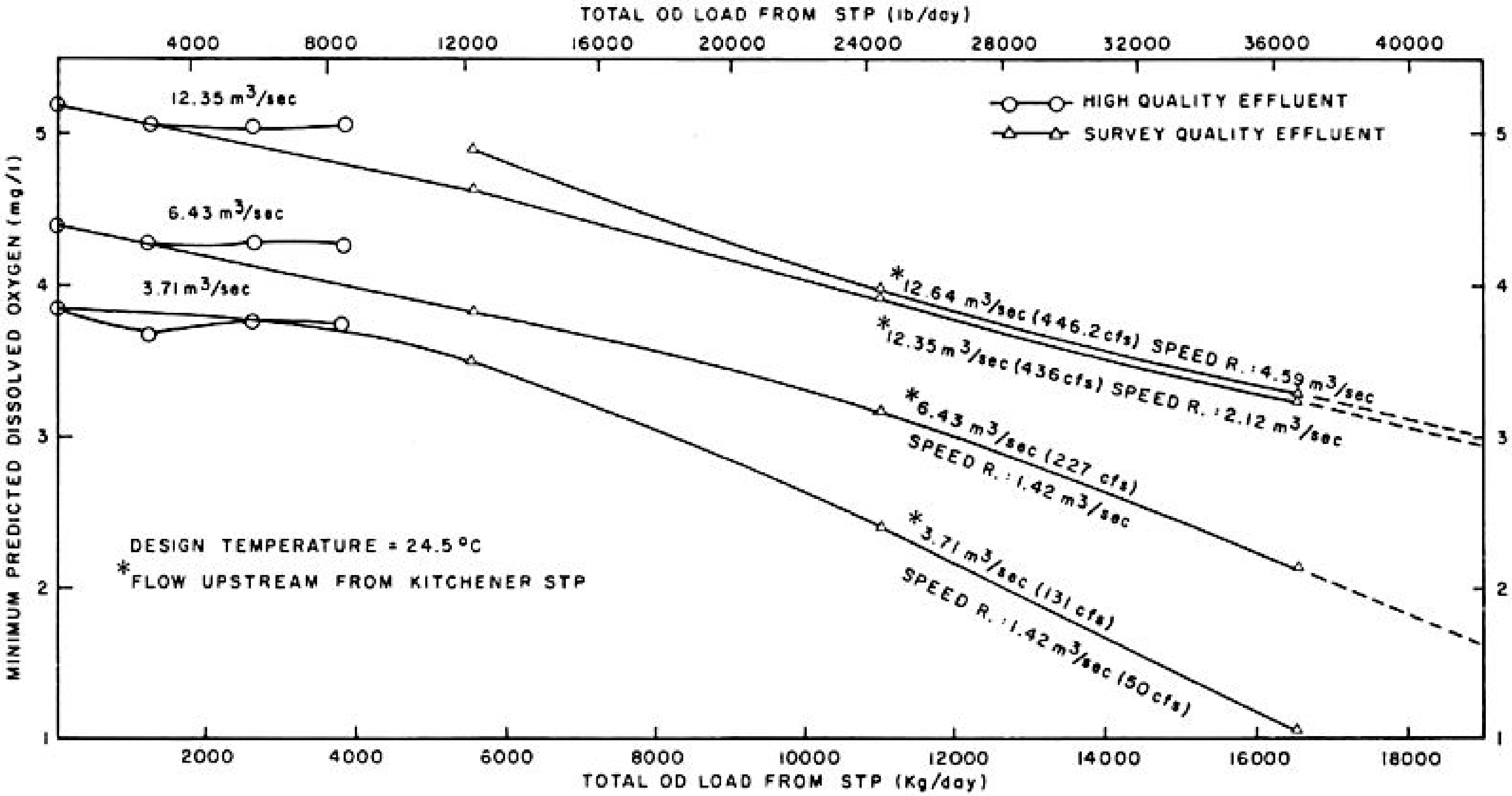


FIG. 4. Predicted Minimum Dissolved Oxygen Concentration Vs. Oxygen Demand Loading Rate At Various Flow Conditions For Grand River Between Kitchener STP and Galt STP.

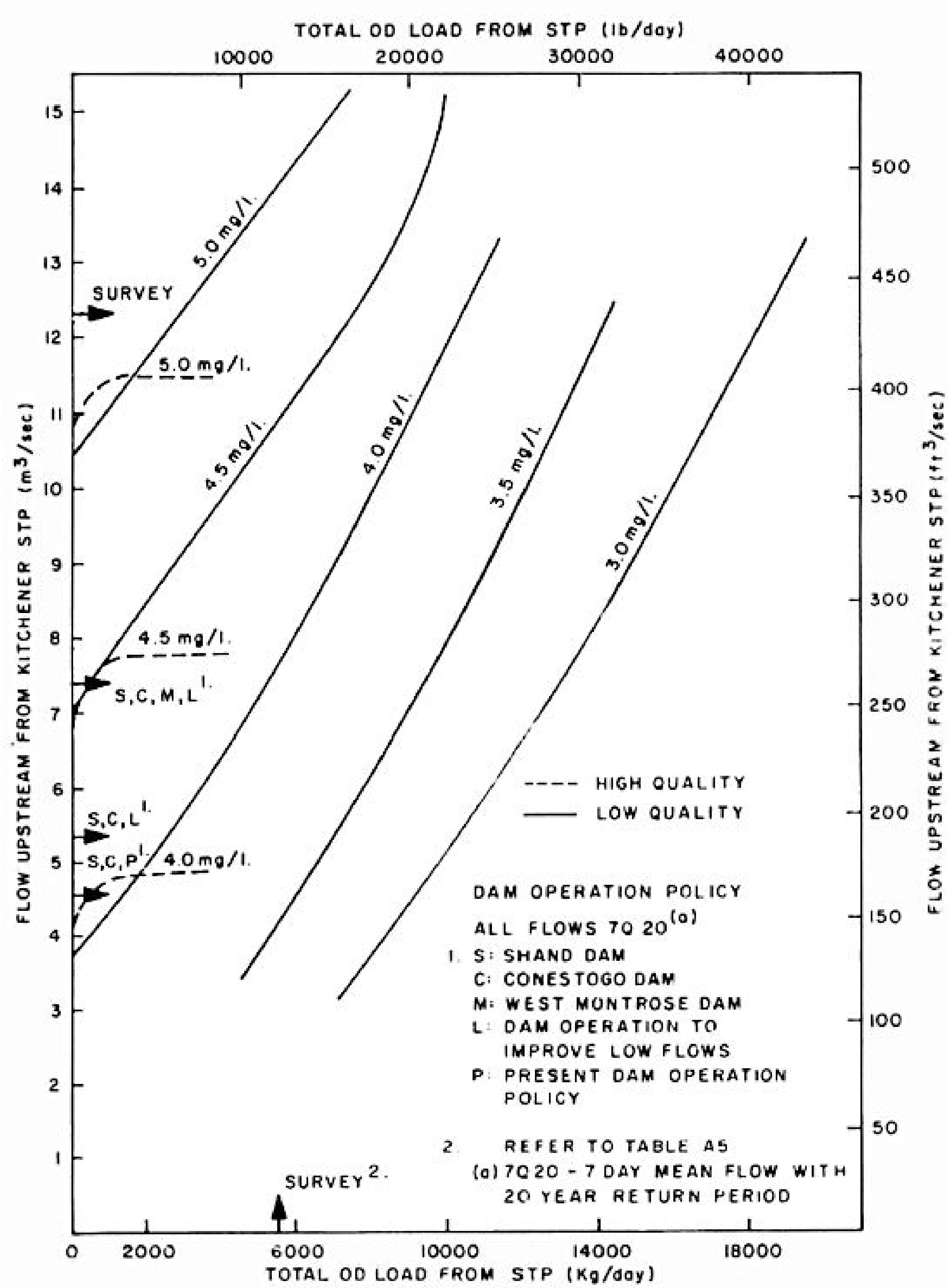


FIG. 5. Total Oxygen Demand Loading Rate From Kitchener STP vs. Upstream Flow For Various Predicted Minimum Dissolved Oxygen Levels.

4.2.4 Galt STP-Model Results

Figure 6 shows the relationship between minimum dissolved oxygen and waste load from the Galt STP at various upstream flows. The plot indicates that the DO output is relatively unresponsive to changes in waste load at survey quality (non-nitrified) and has an apparent beneficial response with high quality (nitrified) effluent. This response is due to the positive effect that the increased flow from the STP has on the modelled DO response, which counteracts the negative effect of the increased wasteload. Figure 7 shows the same output data replotted at various minimum DO's. From these figures it can be seen that a 5 mg/L DO criterion can be maintained at presently available lows and with increased loads from the treatment plant. However, the effect of possibly increased loads from expansion of upstream treatment plants should be evaluated when treatment levels for future expansions of the Galt STP are considered, since not all the waste load from upstream treatment plants is assimilated at the point of discharge of the Galt STP effluent.

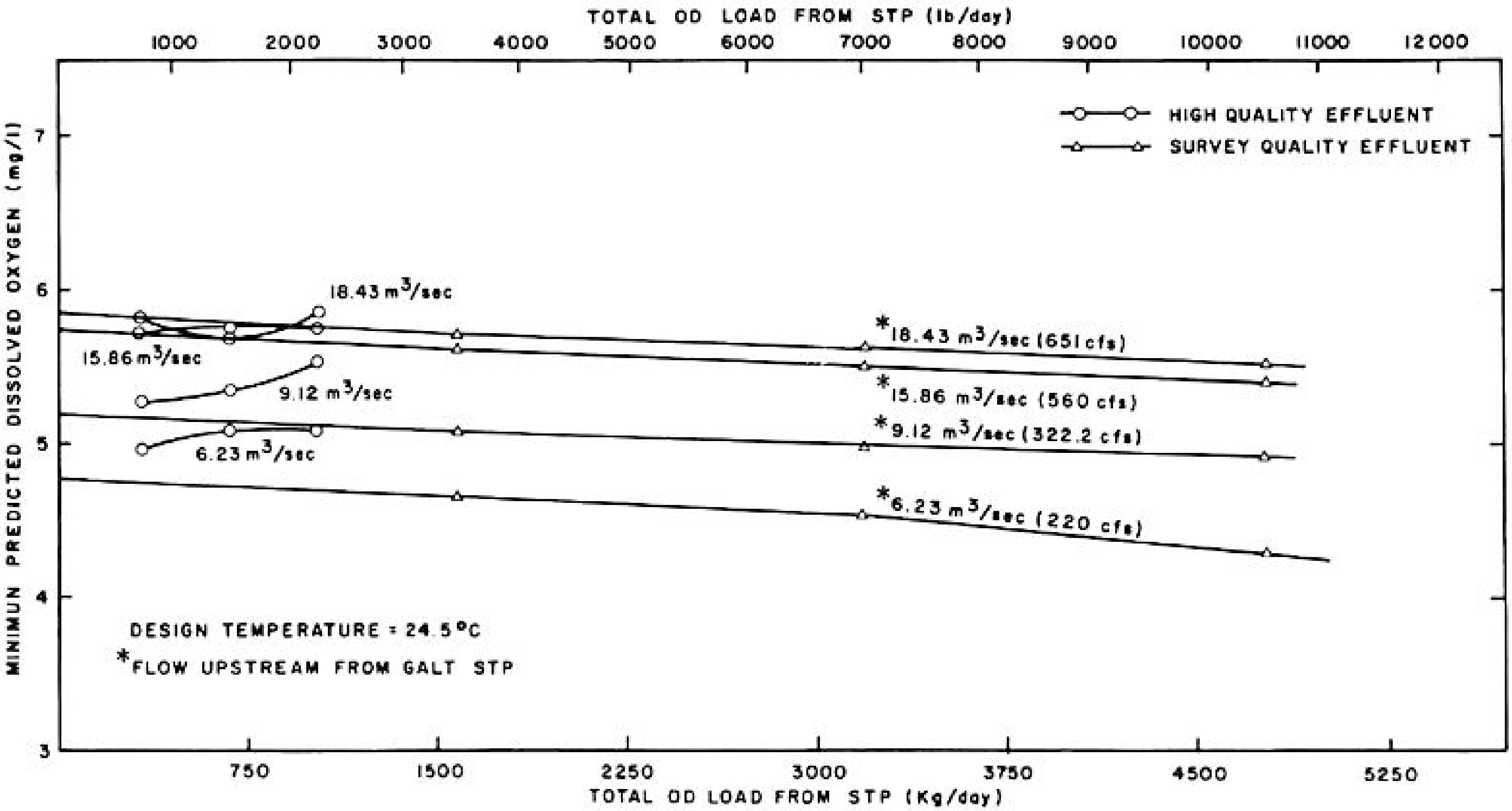


FIG. 6. Predicted Minimum Dissolved Oxygen Concentration vs Total Oxygen Demand Loading Rate At Various Flow Conditions For Grand River Between Galt STP And Paris STP.

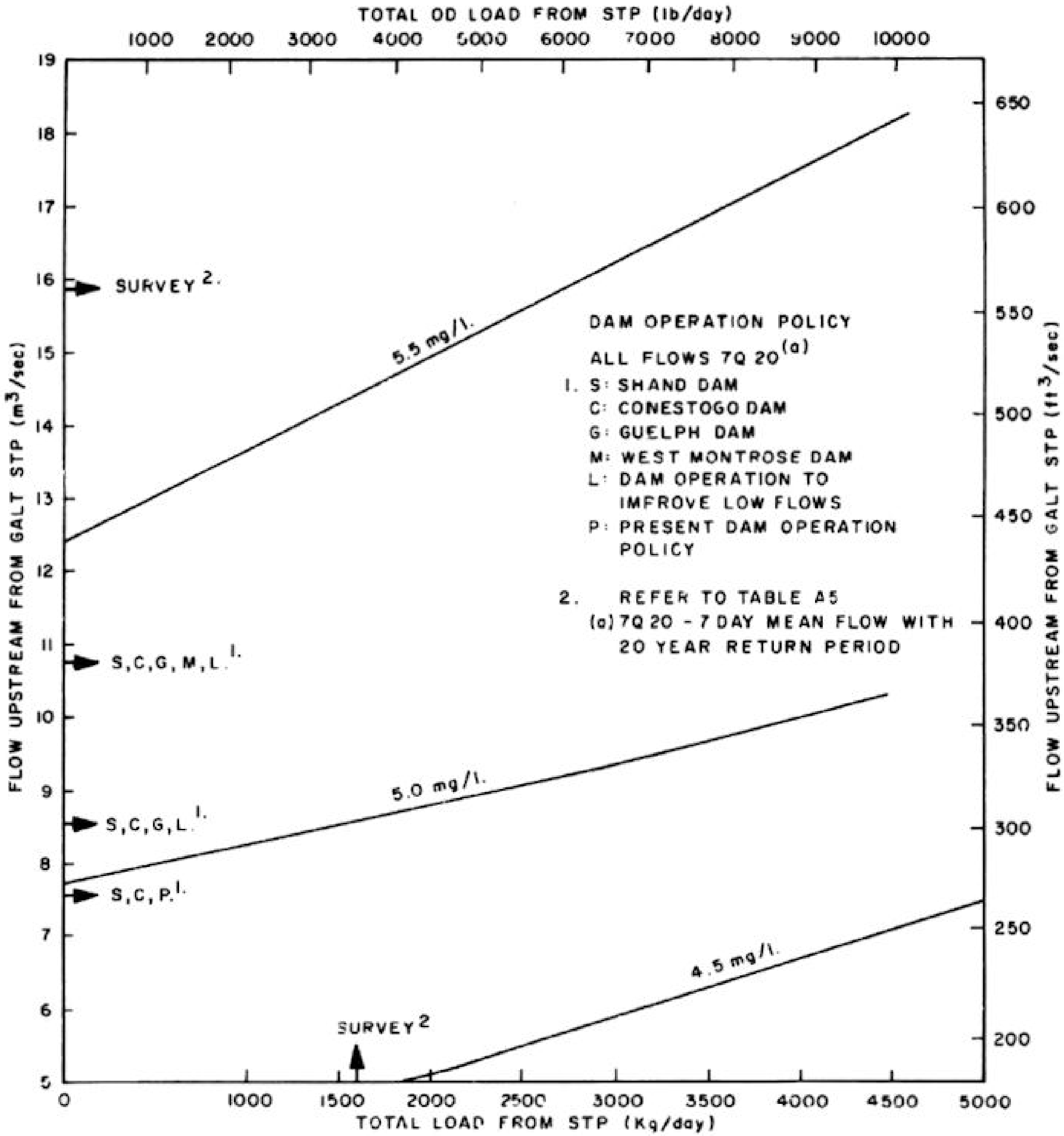


FIG. 7. Total Oxygen Demand Load From Galt STP vs. Upstream Flow For Various Predicted Minimum Dissolved Oxygen Levels.

4.2.5 Guelph STP-Model Results

Figure 8 shows the relationship between minimum dissolved oxygen and waste load from the Guelph STP at various upstream flows and Figure 9 shows the same data replotted for various minimum DO's. These figures indicate a good response to waste loading levels in the modelled DO output. High quality treatment has the effect of significantly improving minimum DO's in the Speed River. These figures, as well as Figure A3, clearly indicate the need for nitrification of the effluent, since NOD represents the largest proportion of waste load as can be seen by comparing the NOD concentration (68.6 mg/L) to carbonaceous OD concentration (22.5 mg/L) in the effluent. A minimum DO level of 5 mg/L appears to be unattainable even with the increased flow rate possible from the Guelph Dam, since a combination of upstream quality and conditions in the reach produce levels less than 5 mg/L, as predicted by the model.

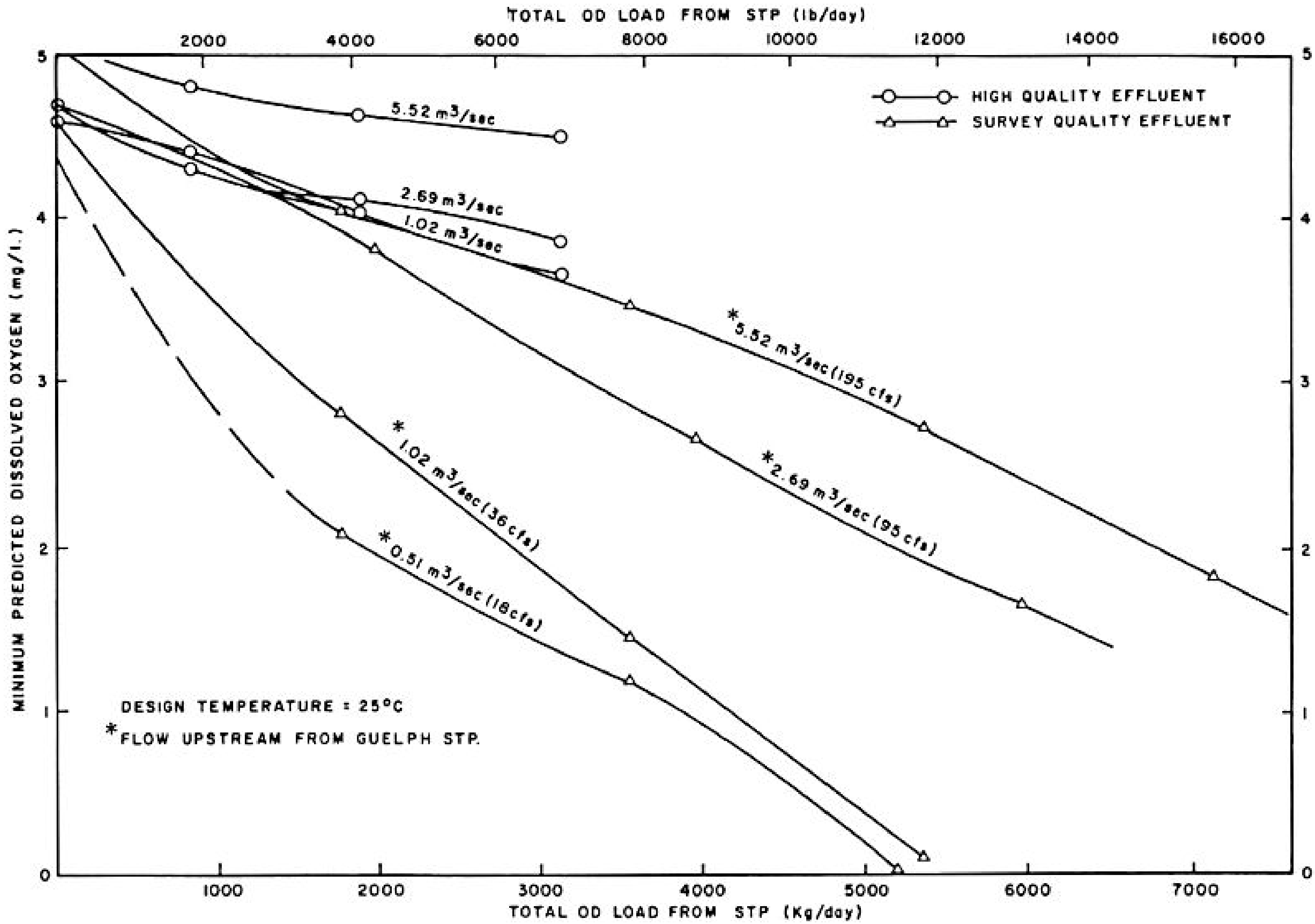


FIG. 8. Predicted Minimum Dissolved Oxygen Concentration vs. Total Oxygen Demand Loading Rate At Various Flow Conditions For Speed River Between Guelph STP And Hespeler STP.

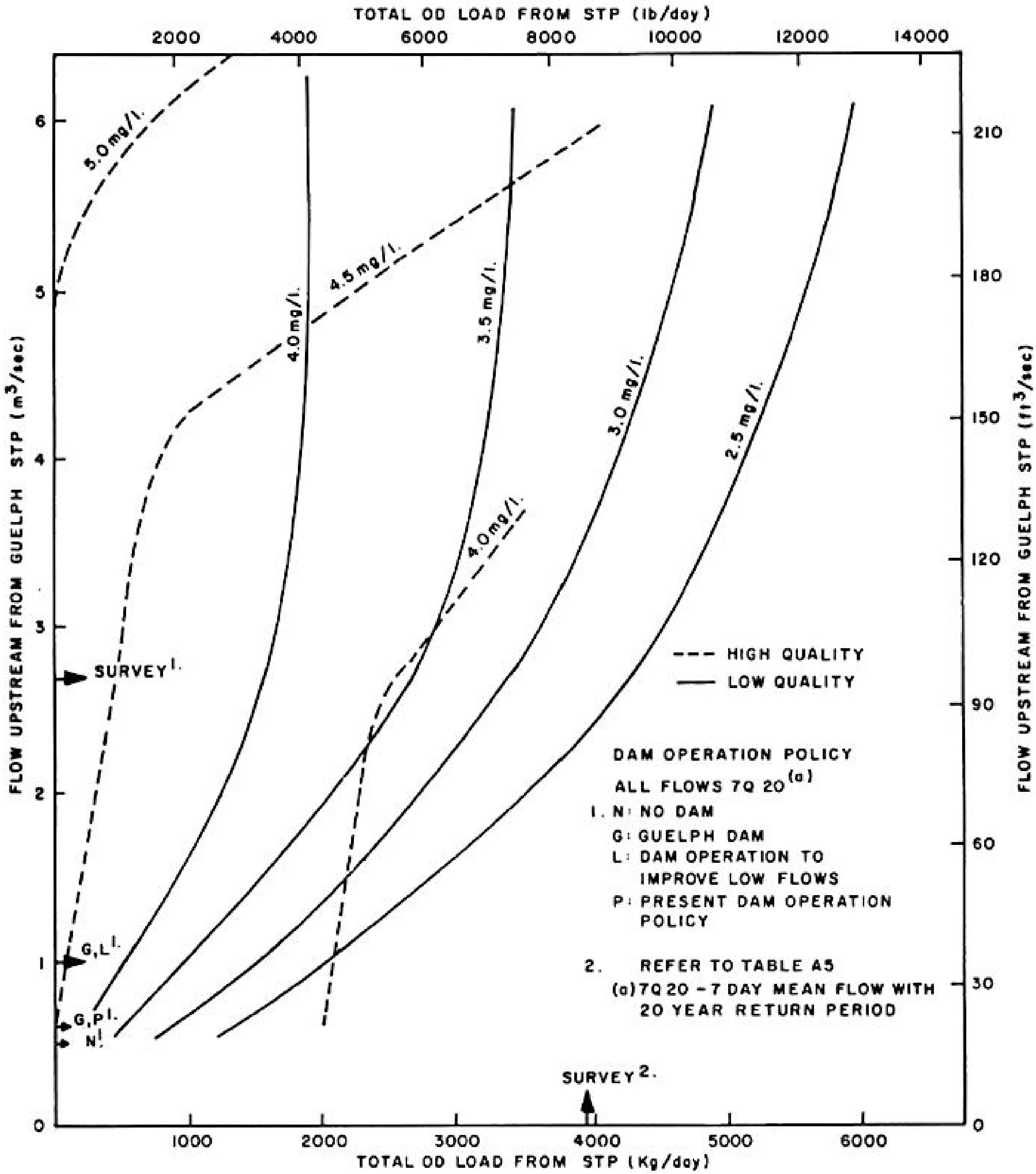


FIG.9. Total Oxygen Demand Load From Guelph STP vs. Upstream Flow For Various Predicted Minimum Dissolved Oxygen Levels.

4.2.6 Hespeler STP-Model Results

Figures 10 and 11 show dissolved oxygen relationships for the Speed River for the first reach downstream from Hespeler. From these figures it can be seen that at survey waste loads, minimum dissolved oxygen levels of 4.5 mg/L are likely at existing and future flow levels. The relatively high quality sewage effluent observed during the survey should be maintained since alteration of the treatment system to produce a non-nitrified effluent quality - similar to that observed at Kitchener - would approximately quadruple the waste loads and significantly reduce water quality.

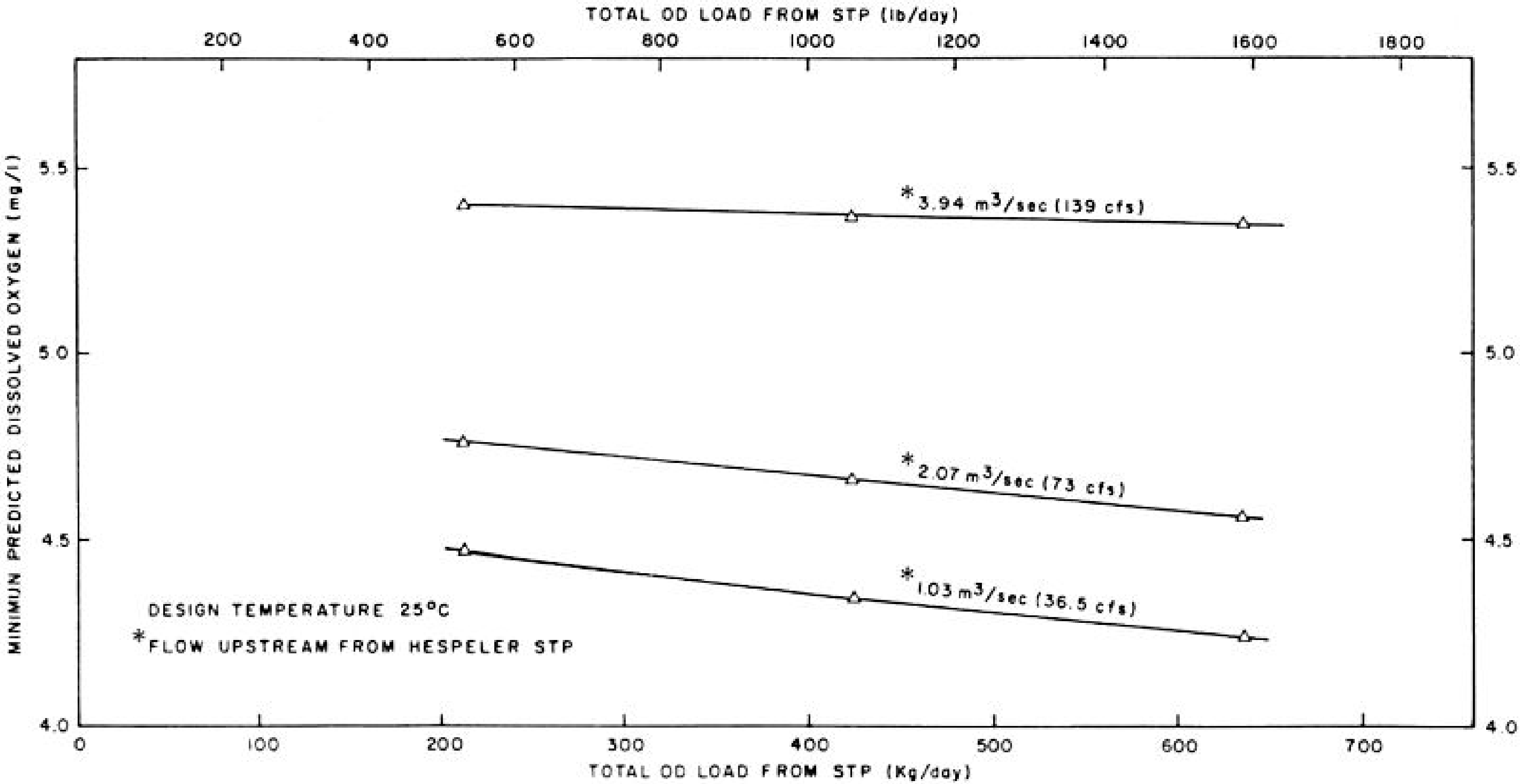


FIG. 10. Predicted Minimum Dissolved Oxygen Concentration vs. Total Oxygen Demand Loading Rate At Various Flow Conditions For Speed River Below Hespeler STP.

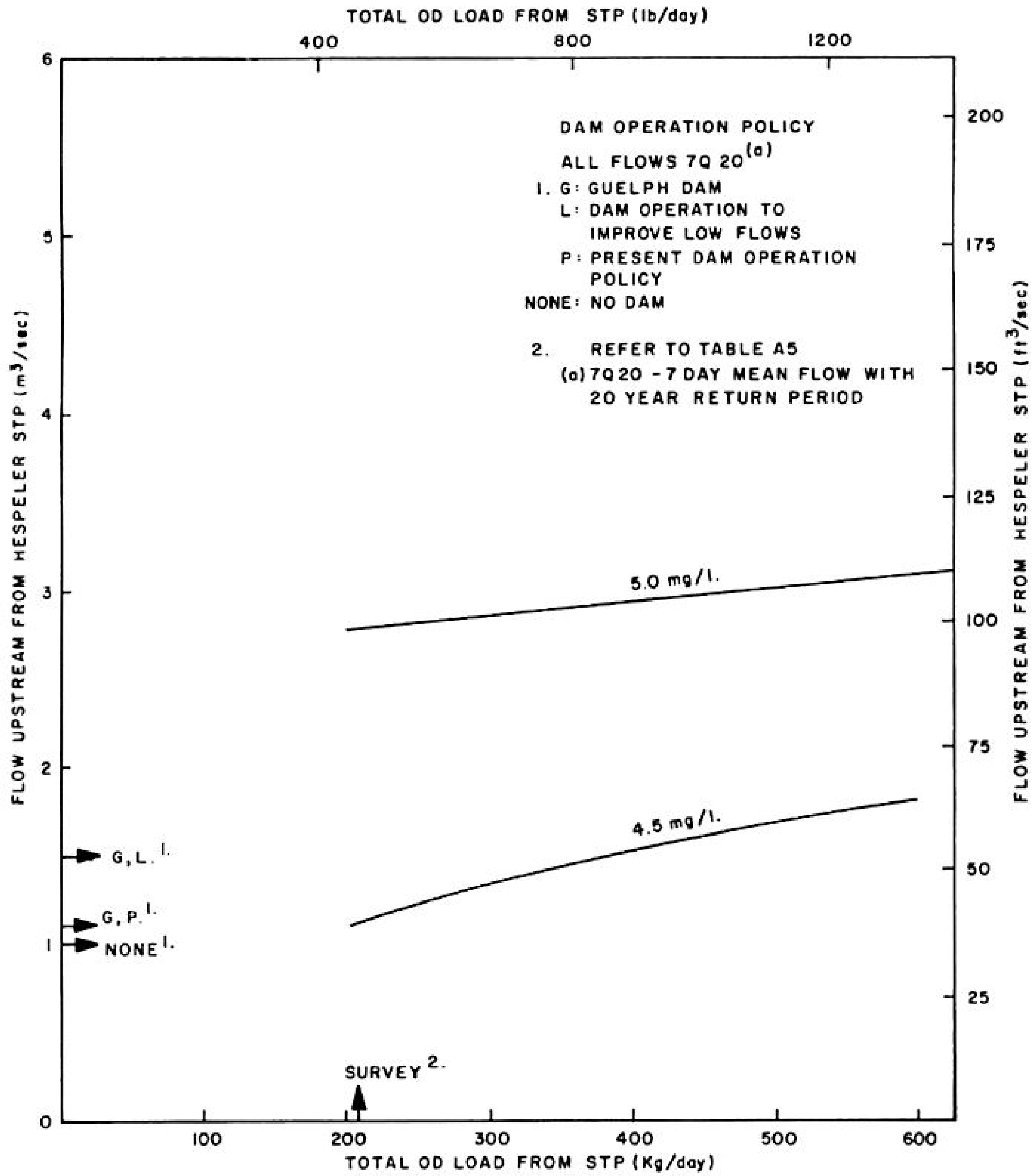


FIG. 11. Total Oxygen Demand Load From Hespeler STP vs. Upstream Flow For Various Predicted Minimum Dissolved Oxygen Levels.

4.3 DISCUSSION OF RESULTS

The modelling results presented in Section 4.2 are subject to several limitations; a few important ones are reviewed below.

As described in Section 1.1, the urban storm runoff and rural drainage sources affect the stream water quality in addition to the STP waste loads. To some extent, this is demonstrated in the lower DO values observed at the upstream boundaries of the river system. Because of this factor, the predicted minimum DO values are never higher than 6 mg/L (approx.), even under higher treatment options (see figures 2 to 11). The effect of increased loads from increased urbanization or altered rural land use could not be evaluated in this study.

From figures 2 to 11, it can be seen that the predicted response of DO concentrations to changes in the nitrified effluent loads were small (i.e. DO concentration values did not necessarily decrease with increased loads). Thus the small response of DO to nitrified effluent loads may permit the discharge of higher effluent flows without violating the DO criterion. However, in such cases, the effects of other factors such as toxicity of chlorine residuals and heavy metals may become significant as dilution ratios are reduced and should be evaluated.

The upstream waste loads in the stream considered for boundary conditions at any STP are the same as those observed during the surveys. However, these upstream loads may change depending on the change in waste loadings at an upstream STP. For example, if Waterloo STP were allowed to expand, then the background stream load upstream from Kitchener STP would be higher; the effects of such combinations have not been investigated. Such cases will have to be reviewed on an individual basis, and additional modelling is warranted in such situations.

Low flow, such as the seven-day low flow with an average twenty-year return period (7Q20), is only one of several extreme conditions, others being high temperature, low sunlight, waste load variations, etc. Different combinations of these are likely to produce different DO responses and were not investigated. High temperature effects were modelled for the Kitchener-Galt section and the results showed that the minimum DO value was 3.9 mg/L at 28°C compared to 6.0 mg/L at 24°C (survey temperature), all other conditions being identical. Since these extreme conditions were not investigated, the modelling results are somewhat liberal, i.e. represent an optimistic view of quality conditions. In addition, no reserve capacity was set aside as a safety factor to provide for possible occurrence of these extreme conditions. Consequently, management decisions regarding waste treatment or reservoir operation, based on results presented herein represent minimum acceptable courses of action to meet a given dissolved oxygen water quality requirement.

The foregoing discussion indicates that great care should be exercised in the interpretation and use of the modelling results to determine allowable waste loads from each STP.

Because of the limitations of the steady state model and the complexity of the river processes, it may be preferable to evaluate the stream response to various waste inputs and instream conditions by the use of more advanced modelling techniques such as the dynamic simulation model used in the Thames River Basin Water Management Study. Seasonal variations of plant and algal growth should be incorporated, when results of current biological studies in the Grand River basin become available. The data collected during the summer 1975 surveys, as well as during the previous years, would provide extremely useful basic information for the possible future application of dynamic models.

4.4 SUMMARY AND CONCLUSIONS

Steady state modelling techniques were applied to evaluate the waste assimilation capacity of the river sections below the major sewage treatment plants in the central portion of the Grand-Speed river system. The effects of nitrified, as well as non-nitrified effluents on predicted dissolved oxygen levels in the streams were evaluated. The relationships among STP waste loads, streamflows and DO, developed from modelling, have been presented in graphical form. The limitations of the results have been discussed.

The following general conclusions can be made from this study:

1. Nitrogenous waste loads (NOD) have significant effects on the stream DO regime, and consequently, reduction of NOD concentrations in sewage effluents would have significant beneficial effects on stream DO.

2. The results presented in graphical form are useful to determine the allowable waste loading rate at each treatment plant, to determine the required flow augmentation to maintain desirable dissolved oxygen levels in the stream and to evaluate the effects of withdrawal of river water on the dissolved oxygen levels in the stream.

APPENDIX

TABLE A1: Summary of August 11-14, 1975 Assimilation Survey Data for the Bridgeport-Kitchener Section along the Grand River.

Station	Temp °C	BOD_5	Dissolved Oxygen Avg.	Dissolved Oxygen Max.	Dissolved Oxygen Min.	Phosphorus Total	Phosphorus Soluble	Nitrogens F.A.	Nitrogens Kjel.	Nitrogens Nitrite	Nitrogens Nitrate	Flow m^3/sec	Flow cfs
T13	22.0	1.8	7.6	11.0	6.1	0.045	0.006	0.05	0.69	0.026	0.75	0.139	4.9
G1	22.9	1.0	7.7	10.6	5.8	0.053	0.004	0.02	0.65	0.007	0.61	10.477	370
Waterloo STP	22.1	6.1	2.6	4.0	1.2	0.490	0.230	0.95	2.50	0.31	1.3	0.263	9.3
G3L	22.97	1.4	7.4	15.4	4.2	0.084	0.013	0.07	0.76	0.029	0.84	10.817	382
G3C	23.22	1.2	7.6	10.7	5.9	0.057	0.004	0.03	0.66	0.013	0.60	10.817	382
G3R	23.2	1.0	7.6	10.2	5.8	0.050	0.002	0.01	0.57	0.006	0.56	10.817	382
G4L	23.1	1.2	7.4	10.7	5.4	0.072	0.007	0.04	0.64	0.014	0.64	10.845	383
G4C	23.0	1.1	7.5	10.7	5.8	0.060	0.004	0.02	0.61	0.010	0.61	10.845	383
G4R	23.0	1.0	7.6	11.0	5.8	0.052	0.002	0.02	0.61	0.008	0.59	10.845	383
T5	22.9	2.0	8.4	10.3	6.8	0.053	0.004	0.12	0.89	0.014	0.73	0.037	1.3
T38	21.1	1.2	7.2	8.4	6.6	0.025	0.003	0.04	0.49	0.015	2.50	0.017	0.60
G6	23.05	1.0	7.4	10.3	5.6	0.067	0.005	0.03	0.65	0.011	0.67	11.185	395
G7	23.3	1.1	7.6	12.0	5.7	0.066	0.003	0.03	0.67	0.010	0.63	11.242	397
G8	23.3	1.0	7.6	12.3	5.8	0.055	0.003	0.02	0.61	0.007	0.61	11.327	400
G9				Data Not Available								11.355	401

Note: All units mg/L except where specified;
All data are average values except where specified;
G refers to station on Grand River;
T refers to station on tributary;
L, C, and R refer in order, to sampling locations at left bank, centre and right bank (looking upstream) at the same location.

TABLE A2: Summary of July 28-31, 1975 Assimilation Survey Data for the Kitchener-Paris Section along the Grand River.

Station	Temp °C	BOD_5	Dissolved Oxygen Avg.	Dissolved Oxygen Max.	Dissolved Oxygen Min.	Phosphorus Total	Phosphorus Soluble	F.A.	Nitrogens Kjel.	Nitrogens Nitrite	Nitrogens Nitrate	Flow m^3/sec	Flow cfs
G9	24.3	1.3	8.9	13.6	5.4	0.052	0.006	0.02	0.73	0.008	0.65	12.346	436
Kitchener STP	21.5	9.6	4.6	5.4	3.7	0.450	0.108	13.0	18.0	0.037	0.07	0.668	23.6
G10	23.9	4.3	8.4	10.9	5.4	0.073	0.007	0.91	1.9	0.079	0.69	13.054	46.1
T14	22.6	1.5	8.9	11.5	5.9	0.031	0.003	0.04	0.59	0.011	0.38	0.144	5.1
G11	24.9	3.6	7.9	11.0	5.4	0.070	0.006	0.69	1.7	0.12	0.69	13.224	467
G12	24.7	2.3	7.3	10.5	4.1	0.063	0.006	0.30	1.02	0.17	0.73	13.224	467
Speed R.													
S16	24.6	2.9	9.9	13.4	6.0	0.170	0.022	0.02	0.97	0.026	1.22	2.124	75
G16L	24.3	2.0	8.0	12.0	4.6	0.062	0.006	0.18	1.0	0.17	0.89	15.461	546
G16C	-	1.9	-	-	-	0.069	0.006	0.14	0.90	0.158	0.80	15.461	546
G16R	24.8	2.4	9.2	12.8	6.0	0.13	0.020	0.05	0.96	0.067	0.88	15.461	546
Preston STP	21.0	8.9	5.8	6.9	2.1	1.70	0.92	0.33	3.4	0.21	12.0	0.074	2.6
G36L	24.8	1.8	8.6	12.6	3.9	0.056	0.009	0.10	0.80	0.136	0.92	15.574	550
G36C	24.8	1.9	8.7	13.2	4.0	0.057	0.010	0.09	0.77	0.128	0.85	15.574	550
G36R	24.8	1.9	9.1	13.8	4.1	0.073	0.012	0.07	0.83	0.12	1.01	15.574	550
G17	23.9	2.0	8.4	10.2	6.6	0.076	0.010	0.086	0.86	0.13	1.02	15.669	553
T37	20.9	1.0	9.0	11.4	7.2	0.014	0.002	0.01	0.39	0.005	0.11	0.127	4.5
T39	19.5	0.9	8.2	10.5	6.7	0.032	0.004	0.03	0.45	0.011	1.4	0.048	1.7
G19	23.8	1.9	8.4	9.3	7.4	0.077	0.084	0.05	0.91	0.096	0.95	15.801	558
Galt STP	19.6	9.2	3.2	5.5	1.7	0.58	0.16	7.70	11.8	0.39	3.5	0.227	8.0
G2OL	24.1	1.9	8.9	12.8	6.1	0.070	0.011	0.04	0.80	0.076	1.2	16.141	570
G2OR	24.0	2.2	8.3	10.6	6.0	0.083	0.011	0.10	0.89	0.10	1.2	16.141	570
G21	24.1	1.9	8.2	11.8	4.8	0.085	0.010	0.06	0.86	0.078	1.3	16.226	573
G22	22.8	1.9	8.9	12.6	5.3	0.075	0.009	0.03	0.75	0.054	1.0	16.254	574
G23*	-	3.2	-	-	-	0.048	0.003	<.01	0.70	0.037	0.91	16.339	577
G24*	-	2.3	-	-	-	0.053	0.004	<.01	0.77	0.036	1.3	16.395	579
G25	24.1	1.9	8.2	9.0	7.2	0.077	0.006	0.02	0.78	0.021	0.97	16.452	581

Note: Footnotes as in Table 1.

* Data subject to error; not used in modelling

TABLE A3: Summary of September 2-4, 1975 Assimilation Survey Data for the Guelph-Confluence Section along the Speed River.

Station	Temp °C	BOD_5	Dissolved Oxygen			Phosphorus			Nitrogens			Flow	
			Avg.	Max.	Min.	Total	Soluble	F.A.	Kjel.	Nitrite	Nitrate	m^3/sec	cfs
S5	17.4	0.9	9.2	11.5	8.0	0.040	0.003	0.02	0.75	0.010	0.65	2.577	91
ST40	16.0	0.7	8.7	9.2	8.2	0.010	0.002	0.02	0.42	0.008	0.85	0.057	2.0
Guelph STP	18.7	14.7	2.4	4.9	1.7	0.820	0.340	13	15	0.014	0.11	0.501	17.7
ST45	18.4	0.5	8.2	8.4	8.0	0.019	0.004	0.05	0.44	0.007	5.6	0.023	0.8
ST50	14.9	1.8	8.2	8.6	7.7	0.190	0.027	0.14	1.23	0.049	1.4	0.037	1.30
S6L	17.5	6.3	7.2	9.4	5.5	0.160	0.053	1.6	2.6	0.37	1.2	3.200	113
S6R	17.0	3.0	8.0	10.4	6.1	0.086	0.015	0.56	1.3	0.11	0.97	3.200	113
S7	17.3	5.4	6.9	8.5	5.6	0.130	0.026	0.76	1.7	0.24	1.2	3.370	119
S8	17.4	3.8	6.7	9.4	4.4	0.120	0.023	0.48	1.3	0.25	1.4	3.398	120
S9*	-	12.0	-	-	-	0.064	0.005	0.07	0.81	0.20	1.8	3.426	121
S10	17.5	2.4	7.1	9.3	5.2	0.107	0.023	0.21	0.96	0.22	1.7	3.483	123
ST17	16.2	0.9	8.5	8.9	8.1	0.038	0.011	0.08	0.76	0.018	0.61	0.108	3.8
S11	15.9	2.0	8.7	9.7	8.1	0.130	0.021	0.17	0.96	0.18	1.6	3.653	129
ST18	16.8	1.2	7.9	10.1	5.4	0.052	0.006	0.01	0.76	0.036	2.2	0.227	8.0
DW55	-	8.3	-	-	-	0.430	0.180	1.1	3.2	0.19	0.85	0.037	1.3
S19L	17.6	1.9	8.5	10.2	7.6	0.127	0.020	0.13	0.96	0.15	1.7	3.936	139
S19R	17.8	2.5	7.9	8.8	7.2	0.150	0.024	0.17	1.1	0.15	1.6	3.936	139
Hespeler STP	18.5	6.6	5.3	7.2	3.1	0.800	0.360	1.2	3.1	0.76	4.3	0.093	3.3
S12L	17.3	1.7	8.6	10.3	7.4	0.120	0.018	0.09	0.99	0.11	1.8	4.049	143
S12R	17.8	1.7	8.3	10.4	7.3	0.130	0.022	0.098	0.93	0.14	1.8	4.049	143
S13	17.3	1.4	8.7	12.6	6.8	0.120	0.020	0.04	0.78	0.11	1.8	4.078	144
S14	17.9	1.7	8.1	12.8	5.8	0.130	0.026	0.04	0.83	0.12	2.0	4.106	145
S15	17.7	1.6	8.4	10.7	7.0	0.120	0.022	0.03	0.78	0.09	1.9	4.106	145
S16	17.6	1.5	8.0	9.7	6.6	0.120	0.021	0.03	0.83	0.09	2.0	4.106	145

Note: All units mg/L except where specified
S refers to station on Speed River
L and R refer, (in order) to sampling locations at left and right banks (looking upstream) at the same station
DW refers to Dominion Woollens Plant

All data are average values except where specified
ST refers to station on tributary
*Data subject to error; not used in modelling.

TABLE A4: Low Flows for the Grand River.

Site	Dams Operating [a]	Operation of Dams [b]	Seven-Day Low Flow Values in m^3/sec (cfs) Return Period in Years			
			20	10	5	2
Speed above Guelph STP	None	-	0.50 (18)	0.62 (22)	0.76 (27)	0.98 (35)
Station S5	G	P	0.59 (21)	0.76 (27)	0.93 (33)	1.2 (42)
	G	L	0.96 (34)	1.1 (40)	1.4 (49)	1.6 (58)
Speed above Hespeler STP	None	-	1.0 (37)	1.2 (42)	1.4 (48)	1.6 (57)
Station S11	G	P	1.1 (40)	1.3 (47)	1.5 (54)	1.8 (64)
	G	L	1.5 (53)	1.7 (60)	2.0 (70)	2.3 (80)
Grand above Waterloo STP	None	-	0.39 (14)	0.59 (21)	0.93 (33)	1.5 (54)
Station G1	SC	P	4.3 (153)	5.0 (178)	5.7 (204)	7.2 (255)
	SC	L	5.0 (177)	6.1 (215)	7.0 (250)	8.3 (294)
	SCM	L	7.0 (249)	8.6 (306)	9.5 (336)	9.9 (352)
Grand above Kitchener STP	None	-	0.73 (26)	0.95 (34)	1.3 (45)	1.9 (68)
Station G9	SC	P	4.6 (165)	5.4 (190)	6.1 (217)	7.6 (270)
	SC	L	5.3 (189)	6.4 (227)	7.4 (263)	8.7 (309)
	SCM	L	7.4 (261)	9.0 (318)	9.8 (349)	10.3 (367)
Grand above Galt STP	None	-	2.3 (82)	2.6 (94)	3.1 (109)	4.0 (142)
Station G19	SC	P	7.6 (270)	8.5 (300)	9.6 (340)	12.4 (440)
	SCG	L	8.6 (306)	9.8 (348)	11.2 (398)	13.8 (490)
	SCGM	L	10.8 (381)	12.6 (445)	14.0 (494)	15.9 (560)

[a] Dams Operating:
- S - Shand Dam, built 1942
- C - Conestoga Dam, built 1958
- G - Guelph Dam, built 1975
- M - West Montrose Dam, proposed

[b] Operation of Dams:
- P - Present operating policy for Shand and Conestoga dams and proposed operating policy for Guelph dam, with 5-foot summer drawdown.
- L- Operation to improve low flows; based on data supplied by CAB of the Ministry of Natural Resources for the Shand, Conestoga and West Montrose dams, and by a mass curve analysis using full storage capacity for the Guelph dam.

TABLE A5: Summary of the Quality and Loading Rates for Boundary Conditions.

Location	BOD_5 mg/L	Lo [1] mg/L	TKN mg/L	NOD[2] mg/L	TOD[3] mg/L	Flow m^3/sec[5]	TOD[4] kg/day[6]	Remarks
Grand U/S Waterloo STP	1.0	1.79	0.65	2.97	4.76	10.5	4313	Survey Flow and Quality
Waterloo STP	6.1	10.92	2.5	11.43	22.35	0.26	508	Survey Flow and Quality
Waterloo STP	10.0	17.9	18.0	82.3	100.2	0.26	2276	Low Quality (non-nitrified) based on Kitchener STP quality
Waterloo STP	10.7	19.1	5.67	25.91	45.01	0.29	1128	May to October 1975 average
Grand U/S Kitchener STP	1.3	1.8	0.73	3.3	5.1	12.3	5452	Survey Flow and Quality
Kitchener STP	9.6	13.2	18.0	82.3	95.4	0.67	5500	Survey Flow and Quality
Kitchener STP	9.6	13.2	2.0	9.14	22.34	0.67	1293	High Quality (nitrified)
Kitchener STP	16.3	22.4	17.0	77.7	100.1	0.75	6507	May-October 1975 average
Speed River/confluence	2.9	4.0	1.0	4.4	8.4	2.12	1541	Survey Flow and Quality -
Preston STP	8.9	12.2	2.0	9.5	21.7	0.074	138	Survey Flow and Quality
Preston STP	10.2	13.94	5.04	23.03	36.97	0.078	249	May to October 1975 average
Grand U/S Galt STP	1.6	2.1	0.9	4.2	6.3	15.9	8655	Survey Flow and Quality
Gait STP	9.2	12.6	11.8	53.9	66.6	0.36	1593	Survey Flow and Quality
Galt STP	9.6	13.2	-	2.0	15.2	0.36	363	High Quality (nitrified)
Galt STP	7.7	10.5	14.33	65.5	76.0	0.27	1773	May to October 1975 average
Speed U/S Guelph STP	0.9	1.2	0.75	3.4	4.7	2.7	1083	Survey Flow and Quality
Guelph STP	15.0	22.5	15.0	68.6	91.1	0.50	3936	Survey Flow and Quality
Guelph STP	10.0	15.0	2.0	9.14	24.14	0.5	1043	High quality (nitrified)
Guelph STP	21.4	32.07	16.78	76.69	108.76	0.44	4135	May to October 1975 average
Speed U/S Hespeler STP	2.2	3.5	1.0	4.5	8.0	3.94	2150	Survey Flow and Quality
Hespeler STP	6.6	10.6	3.1	14.2	24.7	0.1	211	Survey Flow and Quality
Hespeler STP	25.3	40.68	7.5	34.28	74.96	0.09	583	May to October 1975 average

1. Lo = Carbonaceous oxygen demand (ultimate) = BOD5 x ratio (Lo/BOD_5)
2. NOD = Nitrogenous oxygen demand = 4.57 x TKN (Total Kjeldahl Nitrogen)
3. TOD = Total Oxygen Demand = Lo + NOD
4. TOD = Load (kg/day)TOD (mg/L) x Flow (m^3/sec) x 86.4. Other loading cases can be calculated from quality conditions above and given flow.
5. Flow (cfs) = Flow (m^3/sec) x 35.31
6. Load (lb/day) = Load (kg/day) x 2.203

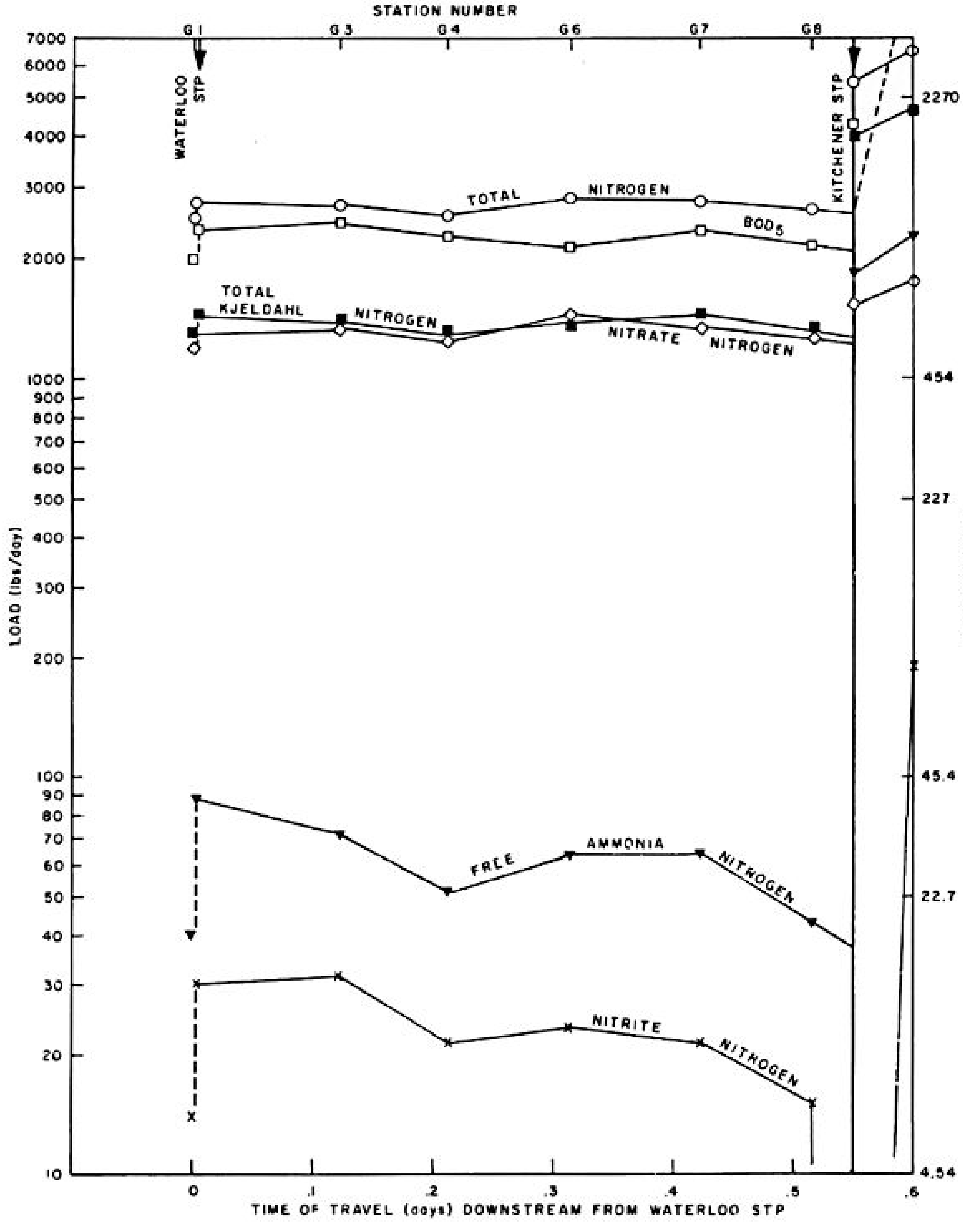


FIG. A1. Waste Load vs. Time Of Travel For Grand River Bridgeport - Kitchener Section.

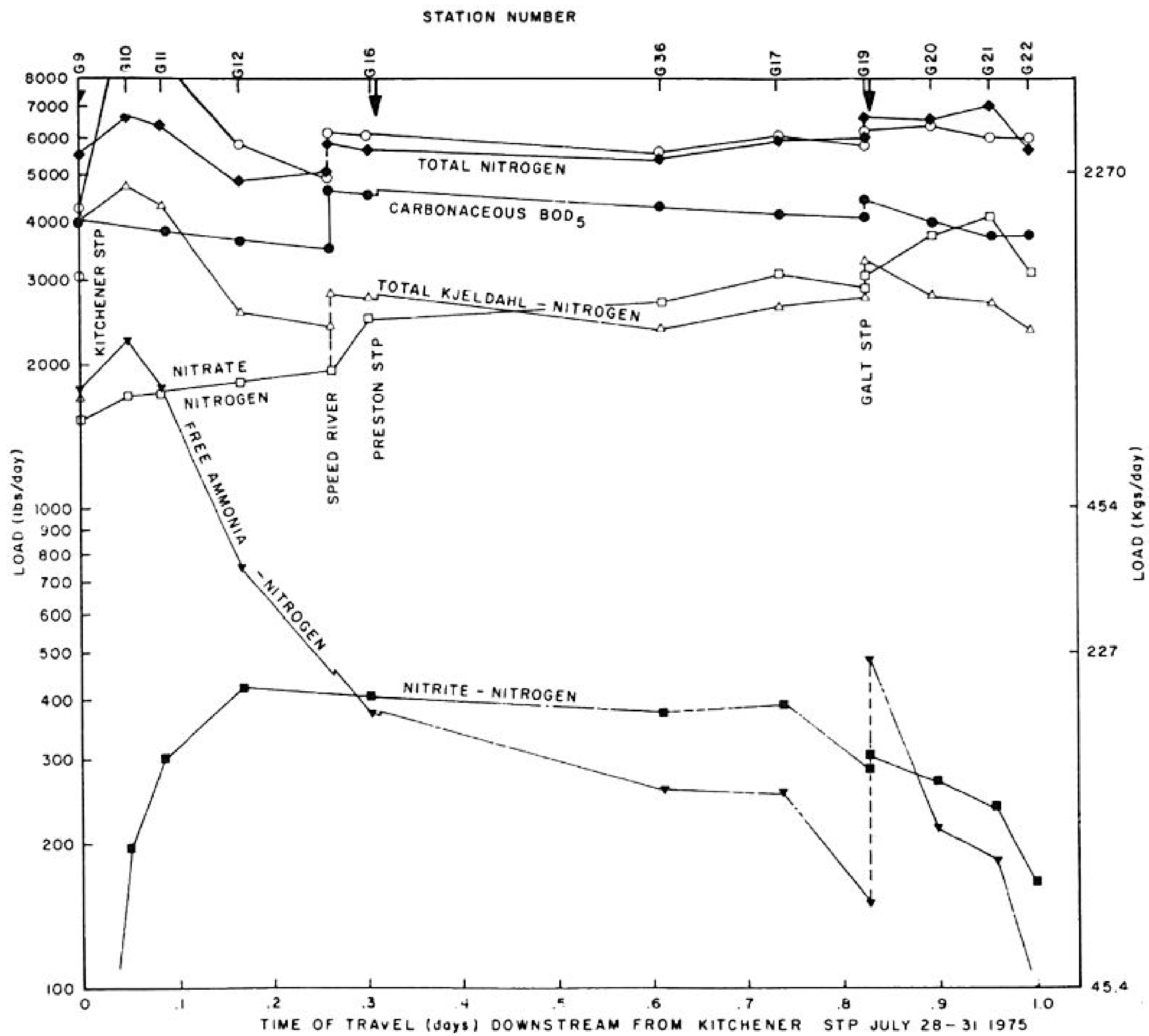


FIG. A2. Waste Load vs. Time Of Travel For Grand River Kitchener - Paris Section.

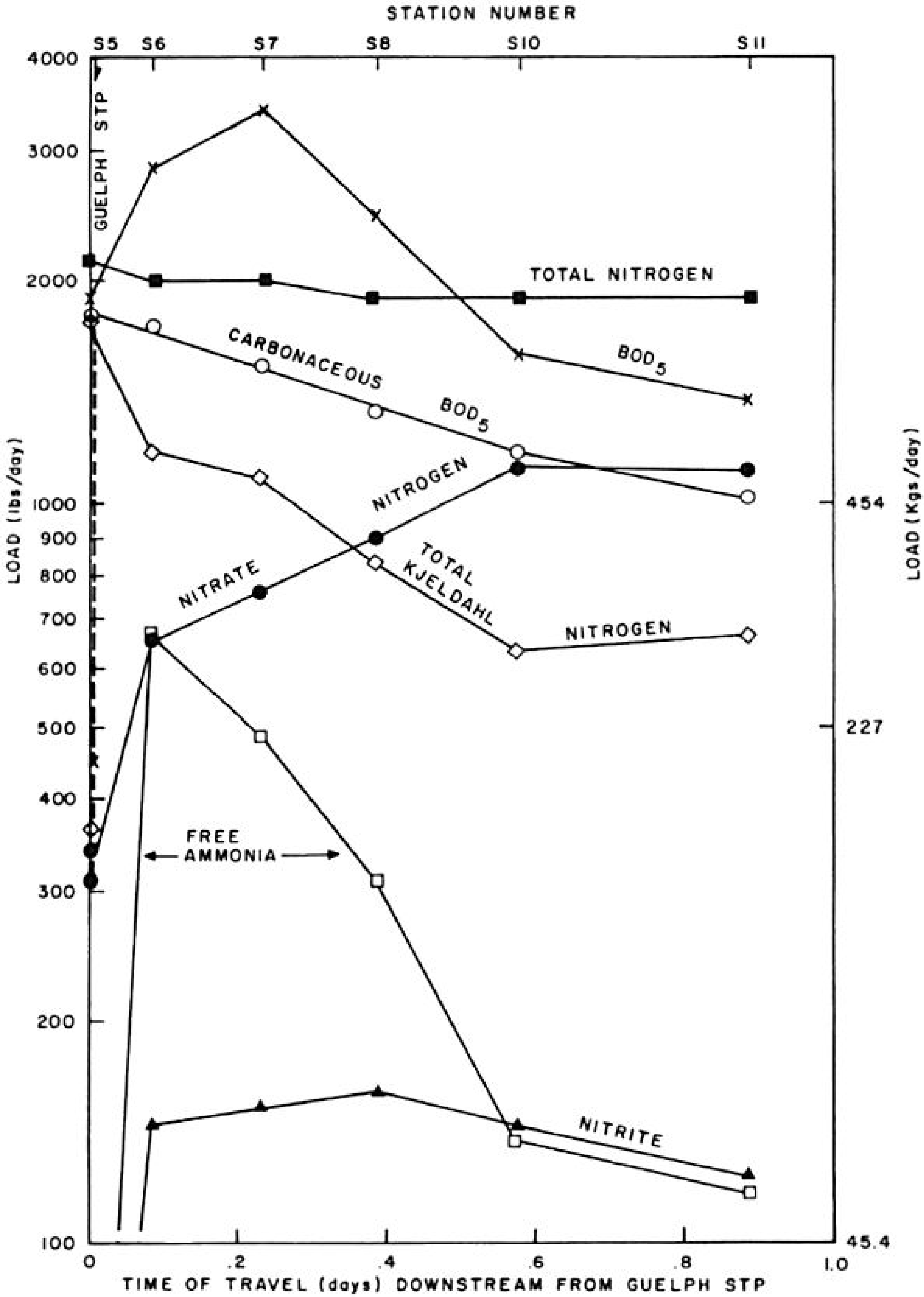


FIG. A3. Waste Load vs. Time Of Travel For Speed River Guelph - Confluence Section.

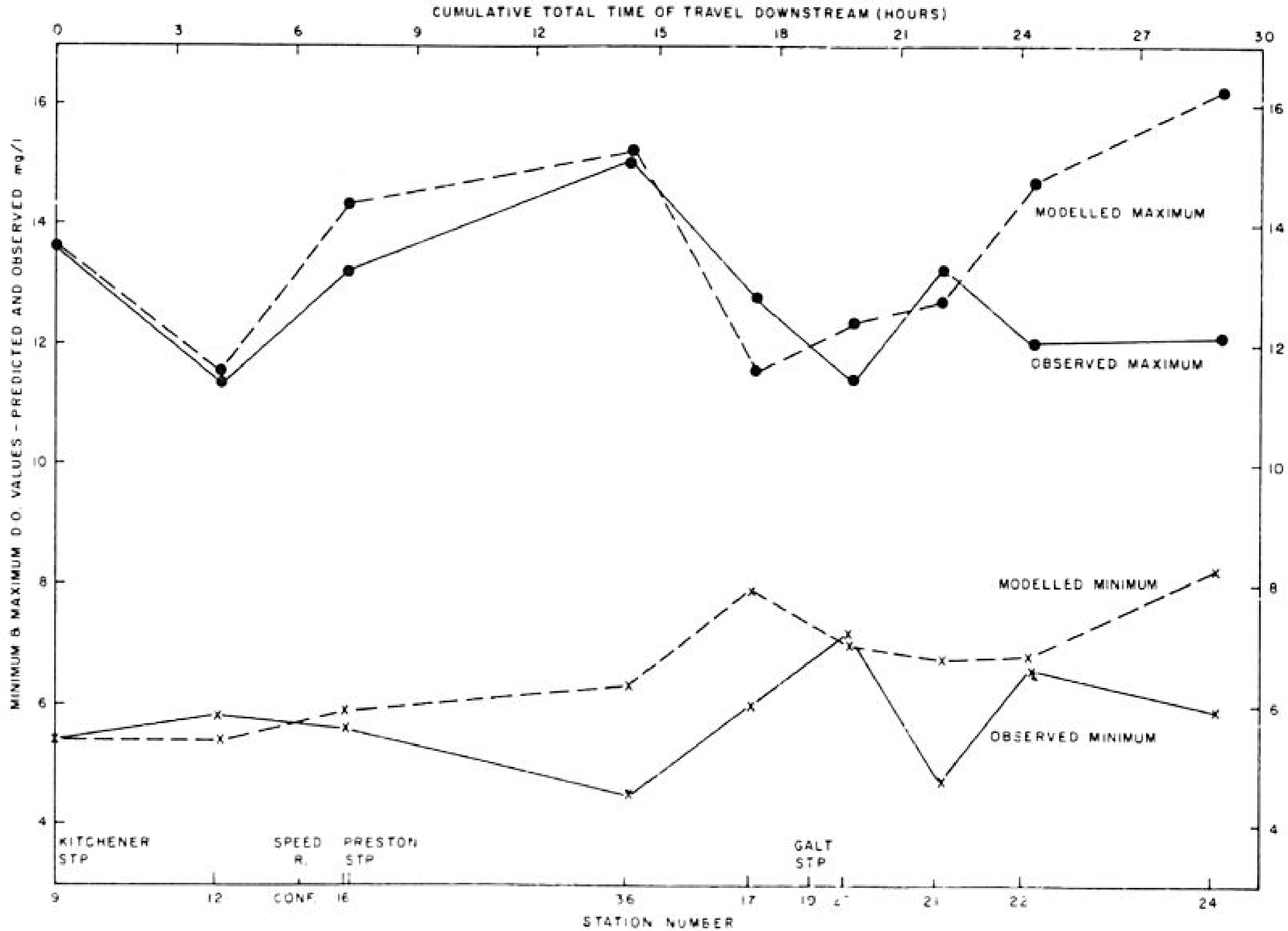


FIG. A4. Observed And Predicted Dissolved Oxygen Ranges (Maximum And Minimum) For The June 9-11, 1975 Survey On The Grand River (Predictions Based On Model Calibrated To Conditions Of Survey July 28-31, 1975).