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Northern River Basins Study















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by
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NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 25

AN EVALUATION OF DISSOLVED OXYGEN MODELLING

OF THE ATHABASCA RIVER AND THE WAPITI-SMOKY RIVER SYSTEM

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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NORTHERN RIVER BASINS STUDY
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Whereas the above publication is the result of word conducted under the Northern River Basins Study and the terms of reference for the work are deemed to be fulfilled,

IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

F. J. Wrona | 30 NOV 93
(Dr. F. J. Wrona, Ph.D., Science Director) | (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",

IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.

SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

P. A. Larkin | Dec 14/93
(Dr. P. A. Larkin, Ph.D., Chair) | (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,

IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public.

Bev Burns | Dec-16, 1993
(Bev Burns, Co-chair) | (Date)

Lucille Partington | Dec-16, 1993
(Lucille Partington, Co-Chair) | (Date)

NRBS.005

AN EVALUATION OF DISSOLVED OXYGEN MODELLING OF THE ATHABASCA RIVER AND THE WAPITI-SMOKY RIVER SYSTEM

STUDY PERSPECTIVE

Two of the major objectives of the Northern River Basins Study are to determine the impacts of effluent discharges on the aquatic environment and to develop predictive tools to determine the cumulative effects of such discharges. A particular area of concern related to effluent discharges is the effect of nutrients on the aquatic environment. The development of reliable nutrient models is therefore important to understand the relationship between nutrients, and algal and invertebrate biomass, dissolved oxygen in sediments and the water column, and nutrient transport and fate in the aquatic environment, so that the consequences of controlling or not controlling nutrients can be assessed.

An important component of an overall nutrients model is the development of appropriate dissolved oxygen models for the northern river systems. Previous dissolved oxygen modelling has been carried out on the Athabasca and Peace/Wapiti/Smoky system using 1989-90 winter dissolved oxygen data. This project utilizes these previously calibrated models and winter dissolved oxygen data collected in subsequent years to assess the ability of the models to predict observed conditions and to identify field research needs for model refinement. The results of the assessment are presented in this report.

Related Study Questions

2) What is the current state of water quality in the Peace, Athabasca and Slave river basins, including the Peace-Athabasca Delta?

5) Are the substances added to the rivers by natural and man made discharges likely to cause deterioration of the water quality?

7) What concentrations of dissolved oxygen are required seasonally to protect the various life stages of fish, and what factors control dissolved oxygen in the rivers?

13a) What predictive tools are required to determine the cumulative effects of man made discharges on the water and aquatic environment?

13b) What are the cumulative effects of man made discharges on the water and aquatic environment?

14) What long-term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stakeholders have the opportunity for input.

EXECUTIVE SUMMARY

The dissolved oxygen model DOSTOC was calibrated in 1989 for the Athabasca River and in 1990 for the Wapiti/Smoky River system. The calibrated models were used to assist in the evaluation of pulp mill developments. Since 1989 new mills have been constructed on the Athabasca River system and intensive dissolved oxygen monitoring has occurred.

One of the objectives of this study was to test the model capabilities by predicting the dissolved oxygen conditions for 1991 and 1992 and comparing these predictions with what was actually measured. Model predictions approximated the longitudinal dissolved oxygen pattern within 0.5 mg/L on average, but over or under predicted concentrations in specific reaches by up to 1.0 mg/L. Predicted dissolved oxygen concentrations were typically under predicted in the Hinton to Whitecourt reach and over predicted in the Smith to Grand Rapids reach. In the Wapiti/Smoky Rivers the model continually under predicted dissolved oxygen.

Since the original model calibration new river time-of-travel information has been collected in the lower Athabasca River where information was previously wanting. The time-of travel measurements were compared to simulated travel times in DOSTOC. For a 155 km reach which includes Grand Rapids and Boiler rapids the DOSTOC hydraulics underestimates the measured travel times. In the remaining 308 km of the study reach measured and simulated travel times were comparable.

To determine how mill effluent BOD variability might influence variability in minimum dissolved oxygen levels the DOSTOC model was run using a 5000 iteration Monte Carlo technique. The effluent distributions were described by the actual 1990 to 1992 effluent flows and BOD concentrations for all mills except Alberta Pacific. The Alberta Pacific effluent distribution was estimated as the mill had not been

completed. This probabilistic assessment was used to simulate oxygen concentrations at 4 steady-state river flow conditions. Predicted dissolved oxygen concentrations at the two output locations varied by over 5.0 mg/L indicating the importance of effluent BOD in the model as calibrated.

A sensitivity analysis was conducted for the Athabasca River 1989 calibration by increasing and decreasing input variables by a constant percentage and recording the change in the dissolved oxygen concentration at downstream locations. It was determined that headwater DO, SOD rate, ice-cover reaeration rate, tributary DO concentration and velocity were the most sensitive input variables.

Recommendations are made with respect to how a model recalibration could proceed and potential improvements to the data collection. The evaluation of the model and modelling approach found nothing inherently wrong with the model itself but concluded that some of the assumptions made in the 1989 modelling approach are not supported by more recent data.

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1.0 INTRODUCTION

In 1989 the dissolved oxygen model DOSTOC (HydroQual and Gore & Storrie 1989) was successfully calibrated to measured conditions in the Athabasca River for the winters of 1988 and 1989. At that time there were only two pulp mills in operation, Weldwood at Hinton and Millar Western at Whitecourt. Information required for the modelling, such as BOD decay rates, BOD settling rates, BOD_5:BOD_U ratios and sediment oxygen demand, were based upon measurements made either below each of the mills or using effluent from the two mills. Once calibrated, the model was used to predict river DO concentrations likely to occur for various pulp mill development options. Macdonald and Hamilton (1989) document the model calibration and use of the model for scenario evaluations.

River and effluent monitoring continued in the winter of 1990 on the Athabasca River. BOD discharged from Millar Western in 1990 was significantly reduced from 1989 levels, and the 1990 river flows were considerably higher than in the winter of 1989; thus, the 1990 data set provided a good test for the predictive capabilities of the model. When the model was run using the 1989 calibration and the 1990 data, it adequately described the measured 1990 condition, although it did raise concerns regarding the relationship between BOD load and sediment oxygen demand, and differences between effluent BOD measured by the mills compared with measurements by Alberta Environment (Macdonald and Radermacher 1992)

Dissolved oxygen in the Wapiti/Smoky and Peace River systems was simulated in 1990 using DOSTOC and WASP (Ambrose et al. 1991) respectively, based upon measured conditions of the river and effluents in 1989 and 1990 (Macdonald and Taylor, 1990). The modelling focused on describing effects due to the pulp mill discharge at Grand Prairie (now Weyerhaeuser) and at the town of Peace River

(Daiashowa). To date, the calibrated models have not been used to predict oxygen conditions for development options.

The objective of this study was to evaluate the capabilities of the existing model calibrations using winter dissolved oxygen data collected subsequent to the calibration. Specifically, this study was intended to:

1. Simulate winter dissolved oxygen conditions in the Athabasca River and Wapiti/Smoky Rivers for the winters of 1991 and 1992, using the previously calibrated models, and to compare the results with measured concentrations;

2. Compare model predictions of constituent travel time with the 1992 dye measurements;

3. Conduct a sensitivity analysis of effects of model input data and rate coefficients on predicted dissolved oxygen;

4. Develop a histogram of predicted dissolved oxygen concentrations at Smith and at Grand Rapids based upon the observed distributions of effluent flows and BOD concentrations at the existing mills, and an assumed distribution for the Alberta Pacific mill, under a range of river flow conditions; and

5. Re-evaluate the use of the models based upon the results of this study.

2.0 MODEL VERIFICATION

The intent of a verification study is to simulate conditions that have not been used in the model calibration, but using the assumptions and structure of the calibrated model. All that should be changed in a verification are the flows and constituent concentrations in the headwaters, tributaries and effluents. Since one of the original assumptions of the model was that sediment oxygen demand changed proportionally with effluent BOD load, SOD should also be changed in the verification. The following sections describe the information used to set up the model simulations for each year and river system.

2.1 Athabasca River

The DOSTOC model was used with the same model configuration as reported in Macdonald and Hamilton (1989). This includes over 1200 km of river from Hinton to Embarras and all the significant tributaries and effluent discharges (Figure 2.1). The configuration includes simulation of the Lesser Slave River. Twenty unique hydraulic reaches were used to describe the hydraulic characteristics of the rivers.

2.1.1 Model Inputs

The following sections detail the information used as input to the model for 1991 and 1992. Information which has not been changed since the 1989 calibration is not included, but can be found in Macdonald and Hamilton (1989). Sources of information are cited as the information is presented; most information was derived from two sources, Alberta Environment (AE) and the four Athabasca River pulp mills: Weldwood, Alberta Newsprint, Millar Western and Slave Lake Pulp. Data from any of the pulp mills is referred to herein as "mill" data.

2.1.1.1 Hydrology

In 1991 and 1992 Alberta Environment undertook synoptic water quality sampling of the Athabasca River and its significant tributaries. River flows were measured during the surveys at several points along the Athabasca River and at the mouths of significant tributaries. Table 2.1 shows the "balanced" flows as derived by Alberta Environment for the 1991 survey. "Balanced" refers to the process of taking the raw measurements and balancing tributary inflows to match changes in mainstem flows. This is necessary for steady-state modelling to ensure a conservation of mass. Also in Table 2.1 are the actual flows used in the 1991 dissolved oxygen modelling. There are some differences in the flow values as further "balancing" was required to exactly match changes in mainstem flows. The discharge volumes for the effluents were compiled from the flow recorder at each effluent outfall on the day of the water quality sampling and are listed in Table 2.10.

Table 2.2 shows the river, tributary and effluent flows measured for 1992. They are similar to the 1991 information (Table 2.1), except that the Alberta Environment values are "estimated" values from the field measurements rather than "balanced" flows. The other column of flows are those adjusted for use in the modelling. Effluent flows are again as measured by the dischargers as shown in Table 2.10.

There are only small differences between the balanced and modelled flows for 1991, concerning only the flows near Smith and downstream of Athabasca. In 1992, however, there are some significant differences in flows which may be due to use of "estimated" flows rather than "balanced" flows from Alberta Environment. The differences are most noticeable between Obed and Windfall, and between Athabasca and Ft. McMurray (Table 2.2).

2.1.1.2 Headwater and Tributary Water Quality

Information on dissolved oxygen and biochemical oxygen demand (BOD) used in the modelling has been taken from Alberta Environment's synoptic surveys. Table 2.3 lists information that was used either as input to the model or as observed data to compare with the simulation results. Note that in some instances tributary quality was not available and water quality was therefore estimated, based upon values from previous years or similar tributaries. Measured values of BOD_5 were converted to BOD_u by multiplying by 6.4 (Macdonald and Hamilton, 1989).

2.1.1.3 Effluent Loading

The Athabasca River (or its tributaries) currently receives effluent discharged from four pulp mills, four sewage treatment facilities and one petroleum plant. During Alberta Environment's synoptic surveys, effluent samples were collected and analyzed for numerous parameters, but of note for this dissolved oxygen modelling are: dissolved oxygen, five-day BOD (BOD_5) and ultimate BOD (BOD_u). The largest sources of BOD, and indeed the primary reason for the oxygen modelling, are the pulp mill discharges. Consequently, there is also the greatest amount of information for these effluents in 1991 and 1992. The following discussion focuses as on these data.

Macdonald and Hamilton (1989) and Macdonald and Radermacher (1992) identified the need for BOD_u data in addition to conventional BOD_5 data for each of the mill effluents. BOD_u measurements provide a measure of the total BOD load, which is a state variable in the model. Without this direct measure the model would have to rely on an estimate of BOD_u based on a correction factor taken from the literature. In addition, the BOD_u measurements at least provide a relative measure of the rate at which each effluent exerts its oxygen demand, although the rate is from a test done under laboratory conditions and does not necessarily reflect true rates in the river.

Ultimate BOD measurements have been made by Alberta Environment, from samples collected during the synoptic surveys, and by each of the mills. Table 2.4 is a summary of the annual average results for each of the mill effluents as measured either by the mill or by Alberta Environment. Also listed in Table 2.4 are the average oxidation rates (K_1) from the long-term tests. None of the results reflect split samples collected on the same day, and some significant discrepancies between the two sources of information are apparent, especially at Alberta Newsprint, where the Alberta Environment results show BOD_u levels an order of magnitude higher than results from the mill. This discrepancy was noted when the chemical oxygen demand (COD), a measure of the total amount of oxidizable material, was consistently less than the BOD_u measurements made by Alberta Environment (Brian Steinback, Alberta Newsprint Company, personal communication), an impossible result. Further investigation revealed that for several of the Alberta Environment BOD_u measurements and one measurement done by Slave Lake Pulp in 1991, tests were done using dilution ratios of greater than 200; this means that for every one part effluent 200 parts of dilution water were used. At these dilution levels it is very difficult to accurately differentiate between oxygen demand from the dilution water and oxygen demand from the effluent. Therefore we have excluded all Alberta Environment data collect in 1991 and 1992 for Alberta Newsprint, Millar Western, and Slave Lake Pulp as well as the 1991 results for Slave Lake Pulp collected by that mill.

The probable reason that the high dilution ratios were used for the three CTMP mills was that the approximate in-river dilution ratio is also approximately 200:1. The analysis may have been designed to represent actual river conditions.

Tables 2.5 through 2.8 are lists of the BOD ultimate results for each of the mills which have been used for this modelling study. These only include measurements where the dilution ration was less than 200. A graphical presentation of the oxygen demand curves from each of these tests is included in Appendix A. Also shown on Tables 2.5 through 2.8 are the BOD_5 measurements from the mills, which have been used to calculate an average ratio between BOD_5 and BOD_u, and the oxidation rates (K_1).

The BOD_5 data collected by the mills has been used rather than data collected by Alberta Environment during the synoptic surveys, as there were again inexplicable differences between the two sources for split samples (Table 2.9). Given that the large majority of the available BOD_5 data are collected by the mills (daily testing) and that tests are done on site, these data have been used exclusively for determining mill effluent BOD_5 loading until the reasons for the differences with Alberta Environment data can be determined. Additional paired BOD_5 data are available and should be reviewed with respect to these apparent differences.

In summary, the 1991-1992 model verification used BOD_u:BOD_5 ratios based on screened measurements of BOD_u from the pulp mills and Alberta Environment, and BOD_5 measurements from the mills alone. The average BOD_u:BOD_5 ratio from each mill was used to convert the mill's estimated BOD_5 for the appropriate day of the synoptic water quality survey to BOD_u, and the latter value was used in the model (Table 2.10). Estimates of BOD_u for effluent sources other than pulp mills are taken as BOD_5, as measured by Alberta Environment, multiplied by 2.0 (Macdonald and Hamilton 1989).

2.1.1.4 Rate Coefficients

The majority of the rate coefficients were determined in the 1989 calibration (Macdonald and Hamilton, 1989) and since this report concerns model verification rather than re-calibration, these rate coefficients remain unchanged:

reaeration,
BOD settling,
background BOD decay,
Leopold-Maddock hydraulic exponents.

In the original calibration, two key assumptions were made regarding rate coefficients: (1) mill effluent decays (exerts an oxygen demand) at a rate equal to the rate measured in the long-term test; (2) sediment oxygen demand (SOD) below each mill discharge is linearly related to BOD loading (Macdonald and Hamilton, 1989). For this verification we have continued with these assumptions. The effluent BOD decay rate and SOD used in the 1991 and 1992 modelling are compared with the values used in 1989 in Table 2.11.

Sediment oxygen demand has been measured in several years since the original 1989 measurements (Casey and Noton, 1989), including data in Casey (1990) for winter 1990, Monenco (1992) for winter 1992 and Hardy-Agra (1993) for winter 1993. A summary of average results for each year at each of the study sites is shown in Table 2.12. The table is intended to show roughly how SOD, as measured, has changed over the years in comparison with how SOD as used in the modelling has changed. As such the values in the table should not be considered exact values, but representative values, as a comprehensive review of comparability between methods or sites has not been done.

There has been an approximate doubling of SOD below Weldwood from 1989 to 1992 compared with a 50 per cent increase assumed for the modelling (Table 2.12). Downstream from Alberta Newsprint and Millar Western, measured results indicate a small increase (10 per cent) from 1989 to 1992, while the assumed change for modelling was a decrease of 60 per cent. Further significant sediment oxygen demand has been measured at Athabasca (town site) and ALPAC (Alberta Pacific mill site) but all of the modelling to date has assumed background (zero) demand in this river reach (Table 2.12).

2.1.2 Verification Results

Using the information described in Section 2.1.1, two model verification simulations were made, one for 1991 (Figure 2.2) and one for 1992 (Figure 2.3). In both figures the measured river oxygen concentrations are from the Alberta Environment synoptic surveys and are shown as points, with the model simulation result shown as a continuous line.

The 1991 simulation is a reasonable approximation of the measured values. Between Hinton and Whitecourt the model consistently under-predicts the dissolved oxygen concentration by about 0.5 mg/L, but does simulate the shape of the oxygen decline. The observed data indicate a more rapid decline in dissolved oxygen immediately below Whitecourt, and a slower decline from about the Freeman River to the Pembina River, than predicted by the model. In the reach between Smith and Grand Rapids, the observed slow, steady decline in DO is reasonably well simulated, with the model perhaps slightly underestimating the rate of decline. Below Grand Rapids simulated and observed conditions are comparable.

Simulated oxygen concentrations for 1992 are considerably different from observed levels between Hinton and Smith. Most of this difference is due to difficulty simulating the observed pattern between Hinton and Windfall. At Windfall the simulated concentration > 1 mg/L below the observed concentration. This difference continues downstream until it is compensated by a discrepancy between measured dissolved oxygen concentrations upstream and downstream from the Pembina River confluence. In most winters the Pembina River has very low dissolved oxygen levels (2.5 mg/L in 1991, 4.1 mg/L in 1992) and when the Pembina River enters the Athabasca River, the result can be a drop in Athabasca River oxygen levels of almost 1 mg/L. The measured river data indicate a sharp drop in oxygen below Pembina confluence in 1992, but the measured flows and oxygen levels in the Pembina River were insufficient to cause so large a drop in the simulation. The opposing 1-mg/L errors offset one another, so the simulation and the observed data again match downstream from the Pembina River confluence. Below Smith the rate of oxygen decline appears to be slightly lower than measured, similar to results for 1991. The final reach of river downstream from Grand Rapids was reasonably well simulated by the model.

Statistics of fit were calculated for the 1991 and 1992 simulations over the entire length of the river. They were calculated as the average of each measured value minus the corresponding predicted value, and the mean and maximum of the absolute value of measured versus predicted. The average measured minus predicted for 1991 was -0.01 mg/L and 0.15 mg/L for 1992 indicating that overall the 1991 simulation neither over or underpredicted the measured values and that the 1992 simulation underpredicted by 0.15 mg/L on average. The average of the absolute value of measured minus predicted is an indicator of precision versus indicator of over or under prediction. In 1991 the average absolute value of measured minus predicted was 0.39 mg/L with a maximum difference of 0.93 mg/L compared with 1992 where the average was 0.51 mg/L with a maximum difference of 1.07 mg/L. The sample size for 1991 was 32 and the sample size for 1992 was 27.

Based on the 1991 and 1992 verification results it appears that the present model calibration is not adequate to predict year-to-year variability in minimum winter dissolved oxygen levels, particulary in the reach between Hinton and Windfall. Preliminary results for 1993 confirm this discrepancy. Review of the 1990 verification results (Macdonald and Radermacher, 1992) also shows some differences in the Hinton-to-Windfall reach, although they are smaller than these observed in the present exercise. The model also appears to underestimate the rate of oxygen consumption in the Smith-to-Grand Rapids reach. Based on these results, and the clear discrepancies between measured SOD levels and those assumed for modelling, a recalibration of the model is warranted.

2.1.3 Travel Time Verification

Since all the model rate processes are time dependent, river travel time can be an important model parameter. DOSTOC estimates time-of-travel based on empirical relationships between river discharge and depth, width and velocity (HydroQual and Gore & Storrie 1989). These relationships in turn were developed from a more complex hydraulic model that used cross-sections, channel slope and time-of-travel measurements (Thompson and Fitch 1989). In February 1992, The Alberta Research Council undertook a tracer-dye study to measure time-of-travel of the Athabasca River between the town of Athabasca and the confluence with the Ells River, a total distance of 463.8 km. Three distinct segments of river were used to reflect differences in hydraulic characteristics, and a separate dye injection was done in each of the segments. The segments were:

1. Ft. McMurray to Ells River;
2. Upper Wells to Ft. McMurray;
3. Athabasca to Upper Wells.

Hydraulic characteristics, river discharges and dye study results were reported for 12 subreaches covering the full study reach.

A comparison of travel times within the 12 subreaches defined by Alberta Environment with computed travel times from DOSTOC's empirical relationships for the same flows is shown in Table 2.13 and Figure 2.4. Hydraulic reaches defined for DOSTOC were somewhat different than those defined for the dye study. Figure 2.4 compares calculated travel times (DOSTOC) with measured travel times for the trailing edge of the dye cloud, the leading edge, the peak, and the centroid. The centroid is the centre of the dye cloud mass and is the most relevant point to compare with the computed travel time. There are three subreaches where the computed travel times are significantly less than the measured:

1. Algar R. to Ft. McMurray;
2. Brule Pt. to Algar River;
3. Boivin Cr. to Brule Pt.

These subreaches coincide with DOSTOC hydraulic reaches C, D1, E, D2 and F as well as a fraction of B (Table 2.13). This length of river has the steepest gradient and includes two significant rapids (Grand Rapids and Boiler Rapids) (Kellerhals 1972). At the time DOSTOC hydraulics were derived, this was also a section of river where hydraulic information was limited, so a discrepancy is not unexpected. The affected section of river represents 155 km of the 463 km studied.

For the remaining subsegments there is reasonable agreement between the measured and calculated results although there is a tendency for the computed results to overestimate travel times more often than underestimate them (6 times versus 2). Over the entire study reach, the centroid time-of-travel was 279 h compared with a calculated 233 h. If the three problem sections identified above are removed the figures are: 172 h (measured) versus 180 h (calculated).

2.2 Wapiti/Smoky Rivers

Dissolved oxygen modelling of the Wapiti/Smoky Rivers was originally undertaken in 1990 using the Alberta Environment synoptic survey data from March 1989 and February 1990 (Macdonald and Taylor 1990). The modelling was done using DOSTOC and the calibration followed a similar approach to that for the Athabasca River (Macdonald and Hamilton 1989); however, the modelling procedures were not defined explicitly for use in evaluating development scenarios. The model structure assumed that the river of interest was the Wapiti River to the confluence of the Smoky, and then the Smoky River to its mouth. Thus, the upstream Smoky River is actually modelled as a tributary of the Wapiti R. In total, over 225 km of river were simulated, from immediately upstream from Grand Prairie to the mouth of the Smoky River, including the effects of effluent from the sewage treatment plant (STP) at Grand Prairie and the Weyerhaeuser pulp mill. The objective of this section is to test the 1990 DOSTOC calibration for the Wapiti-Smoky Rivers using the 1991 and 1992 Alberta Environment synoptic survey data.

2.2.1 Model Inputs

The following sections detail the information used in the verification modelling that has changed from the calibration. Any information not explicitly discussed here should be assumed to be as reported for the calibration in Macdonald and Taylor (1990).

2.2.1.1 Hydrology

During the two synoptic surveys, mainstem (Wapiti and Smoky) river and significant tributary flows were measured by Alberta Environment. These flows are reported in Table 2.14 as either "balanced" (1991) or "estimated" (1992). The difference is that balanced flows have gone through a level of interpretation and adjustment by Alberta Environment, whereas the estimated flows can be considered raw data. The flows used in the DOSTOC model are listed alongside the measured flows in Table 2.14.

Only minor changes were required to use the 1991 balanced flows in the model, indicating that Alberta Environment information was reliable. In 1992 however, several assumptions were made to utilize the flow information. First, because flows in the Simonette and Little Smoky Rivers were not measured in 1992, measured flows from 1991 were assumed to apply in both years. Second, flows in the Smoky river were assumed to increase linearly with distance from 210 m^3/s at the Wapiti River inflow to 548 m^3/s at Watino. Both assumptions are simplifications. However, considering that in 1992 the rivers were running at levels indicative of spring runoff, little emphasis was placed on refining this data set, as it is not indicative of the normal winter conditions that the model was intended to simulate.

2.2.1.2 Water Quality

Concentrations of dissolved oxygen, BOD_5 and BOD_u were extracted from the Alberta Environment synoptic surveys of 1991 and 1992 (Tables 2.3 and 2.15). Where more than one measurement was taken the average was used. Headwater and tributary BOD_u values were derived by multiplying the five-day value by 6.4 (Macdonald and Taylor 1990). The BOD_u values for Weyerhaeuser are from two sources: in 1991, long-term tests were done by Alberta Environment; the 1992 value was derived by multiplying the measured BOD_5 (as reported by Alberta Environment) by 5.0 (Macdonald and Taylor 1990). All other effluent BOD concentrations were obtained by doubling the five-day measurement (Macdonald and Taylor 1990).

The 1992 effluent flow rates (Table 2.15) are the same as those used for 1991 because 1992 data were not reported by Alberta Environment. These flows could presumably be obtained from the effluent dischargers.

2.2.1.3 Rate Coefficients

All the rate coefficients used for the verification simulations, including sediment oxygen demand, reaeration, effluent BOD decay, background BOD decay and BOD settling, are unchanged from the calibration (Macdonald and Taylor 1990). Unlike the Athabasca River model, formal hypotheses were not developed for the Wapiti/Smoky River with respect to the relationship between SOD and effluent BOD; therefore the SOD rate used in the verification is unchanged from the calibration, despite changes in loading.

2.2.2 Verification Results

A model simulation run was made for each of 1991 and 1992 using the data described above. Simulated dissolved oxygen concentrations are compared with measured concentrations in Figures 2.6 (1991) and 2.7 (1992). The vertical bars on the 1991 dissolved oxygen data points represent minimum and maximum values. In both cases a reference line indicating a surface water quality objective of 5.0 mg/L has been included.

Measured dissolved oxygen levels at the upstream boundary of the simulation are at or near saturation (12-13 mg/L) in both years. Downstream from the effluent discharges oxygen levels begin to decline, until the confluence with the Smoky River, where oxygenated inflowing water increases oxygen levels by 0.5 to 1.0 mg/L. Below this point oxygen levels in 1991 gradually decline a further 2 mg/L by the mouth, but remain near saturation in 1992.

There are two significant differences in the dissolved oxygen patterns between 1991 and 1992. First the decline in the Wapiti River is clear but relatively small in 1991 (1 mg/L), but is almost unnoticeable in 1992, and second, between the Wapiti-Smoky confluence and the mouth of the Smoky River there is a decrease in oxygen of 2.0 mg/L in 1991 compared with a slight increase in 1992. These differences can probably be attributed to differences in river flows. Wapiti River flows in 1992 are twice the 1991 levels and the 1992 Smoky River flows are over seven times the 1991 levels. Elevated flows affect dissolved oxygen by increasing aeration and dilution of effluent BOD, and by increasing water velocity, and thereby spreading the oxygen consumption from BOD over a longer distance.

The longitudinal pattern of dissolved oxygen for the simulation results is generally similar to that for measured concentrations. However, in both 1991 and 1992 the simulation results continually underestimate dissolved oxygen levels by 0.5 to 1 mg/L. In the 1991 simulation, it appears that there is an increase in measured dissolved oxygen levels over the 5 to 10 km below the pulp mill discharge which is not adequately represented by the model (Figure 2.6). This observed increase could be due to reaeration in the open-water zone that is not adequately represented by the rates in the model. If this difference were corrected, it appears that the remainder of the simulation would exactly match the observed; that is, the simulated and observed data presently disagree by a constant amount along the entire simulated reach.

The extremely high flows observed in 1992 dominate the dynamics of dissolved oxygen in the river (Figure 2.7) as only slight changes took place in either the observed or simulated concentrations along the river length. Comparing the 1991 and 1992 simulations, the model did predict the appropriate level of change from the elevated flows. It does not, however, simulate the Smoky River dissolved oxygen regime adequately. There was probably a considerable length of open-water in the Smoky River in 1992, which has not been accounted for in the model; the model assumes winter conditions, but the 1992 flows in the Smoky River are more like spring conditions.

Statistics of fit were calculated over the entire length of river, as was done for the Athabasca River simulations (see Section 2.1.2). The average measured minus predicted for 1991 was 0.31 mg/L and 0.16 mg/L for 1992 indicating that overall both simulations under predicted the dissolved oxygen concentration. The average absolute value of measured minus predicted was 0.31 mg/L with a maximum difference of 0.89 mg/L compared with 1992 where the average was 0.29 mg/L with a maximum difference of 0.94 mg/L. The sample size for 1991 was 11 and the sample size for 1992 was 7.

Generally, the model adequately simulates dissolved oxygen kinetics for winter conditions. Any re-calibration should focus on changes in oxygen concentrations in the open-water zone below the Grand Prairie effluents.

3.0 PROBABILISTIC ASSESSMENT

All the dissolved oxygen modelling done to date for the Northern Rivers has been deterministic. That is, for a single set of input parameters (river flow, effluent load, SOD, etc.) the model will predict a single river concentration for each river mile. The conventional approach has been to use a design river flow with a known frequency of occurrence (such as the 7Q10) and a single effluent loading value for each discharge. The predicted river concentrations are then compared against a water quality objective. If the predicted river values remain in compliance with the objective at all locations then the development scenario may be deemed acceptable. While deterministic models may be appropriate for calibration and initial screening of possible scenarios, a complete analysis for informed decision-making requires that variability in model outcome be considered. In a probabilistic assessment it is possible to determine the probability that an objective will be exceeded at any point in the river for a given set of input parameters.

There are many input parameters used in the dissolved oxygen modelling, and any of these could be assigned a probability distribution function (PDF). The predicted result from a probabilistic model will also have a PDF for each river mile. In this assessment we have only assigned PDF's to effluent loading. The following sections describe the approach used for the probabilistic modelling and the results for four river flow conditions. The probability of river dissolved oxygen falling below 5.0 mg/L is then computed for each river flow.

3.1 Approach

DOSTOC was designed to enable probabilistic analysis easily by solving stochastic equations analytically instead of using Monte Carlo techniques (HydroQual and Gore & Storrie 1989). However, the PDF for any given input variable in DOSTOC must represent a normal distribution which can be adequately described by a mean and standard deviation. The input variable of interest here is effluent loading (flow and concentration) which is known to be non-normal, typically with a large skew to the left (USEPA, 1991). To circumvent this problem, DOSTOC was modified to run in a Monte Carlo mode by reading from a 5000 line file representing random samplings from the effluent PDF's. Predicted dissolved oxygen levels from each of the 5000 model runs are saved, with the end result being a PDF of dissolved oxygen described by 5000 points. The program takes approximately 20 minutes to run on a 386 personal computer.

Implicit in this approach is the assumption that all input parameters which are not dependent upon effluent loading (river flows, tributary flows, etc.) remain constant for each simulation. Thus, each of the 5000 DOSTOC simulations are exactly the same as in one deterministic run of the model, except for the stochastic variable. Sediment oxygen demand, as used in the modelling to date, has been assumed to change linearly with changes in effluent loading; this relationship has added into the code for the probabilistic assessment, as has the BOD_5:BOD_U ratio. All of the other modelling assumptions described in Section 2.1 were maintained in the probabilistic analysis. Four different river flow scenarios were evaluated with the probabilistic version of DOSTOC: 7Q10 flows at Athabasca, and measured winter flows in 1989, 1990 and 1992.

3.2 Data Sources

The 5000 line input file which is read by the DOSTOC model was created using the commercial software package @RISK. This program randomly samples a described PDF and creates an output file. The PDF can be described in numerous ways, the most accurate being an actual frequency distribution. PDF's for each mill effluent were created as described below.

The effluent data for each of the mills was extracted from the NORTHDAT data base compiled for the Northern Rivers Study (McCubbin 1993). It included the following period of record for each mill:

Weldwood	January 1, 1990 to January 31, 1991,
Alberta Newsprint Company	July 24, 1990 to February 29, 1992,
Millar Western	January 1, 1990 to February 29, 1992,
Slave Lake Pulp	December 4, 1990 to February 29, 1992.

These data were then used to compute 7-day running means of daily values which were then converted to BOD ultimate for the analysis using the ratios described in Section 2.1.1.3. Seven-day means were required to facilitate comparisons with statistical river flow information (7Q10) which is also calculated as a 7-day running mean. Table 3.1 lists the summary statistics for each the mills as daily means and as 7-day running means. These data are also shown graphically as time-series plots of BOD loading in Appendix B.

Effluent flows and BOD_5 concentrations were divided into equal-sized bins (0-5, 5-10, 10-15 mg/L etc.) for each effluent. The number of samples from the period of record which had values within these bin ranges was then calculated and this information was used to describe the PDF for the @RISK program. Figures 3.1 through 3.4 show the results from the 5000-iteration @RISK simulation as frequency histograms for effluent BOD_5 and effluent flows for Weldwood, Alberta Newsprint, Millar Western and Slave Lake Pulp. Because this analysis is intended to look at future conditions, the Alberta Pacific mill, which is not yet on line, has been included with an assumed effluent quality defined by Ian Mackenzie, Standards and Approval Division. The frequency histograms resulting from @RISK are shown for the Alberta Pacific mill in Figure 3.5. These data distributions were used directly in the probabilistic modelling.

3.3 Results

Dissolved oxygen concentrations at two key river locations (Smith and upstream Grand Rapids) were predicted using the probabilistic model, with the effluent data described in Section 3.2, for the four flow scenarios (Figure 3.6). Generally, the 7Q10 flows are lowest, followed by 1989, 1990 and then 1992 flows. This ordering holds true for the upper basin (Hinton to Smith) but below Smith the 1990 flows are greater than the 1992 flows due to differences in the contributions from the Lesser Slave River, where flows were low in 1992.

Figures 3.7 through 3.10 are the predicted dissolved oxygen frequency distributions for the four river flow scenarios. Kilometre 448.9 in Figures 3.7 through 3.10 corresponds to Smith and kilometre 810.8 corresponds to upstream Grand Rapids. The horizontal axis is divided into 0.5 mg/L bins, so the bar immediately above the 5 mg/L marker represents the frequency at which dissolved oxygen was between 5.0 and 5.5 mg/L. The vertical axis shows the number of simulation results in each bin as a percent of the total number of simulations (5000). The right-skewed shape of the dissolved oxygen distribution at Smith and at Grand Rapids is the result of the left-skewed distribution of the effluent loadings and the inverse relationship between effluent loading and river dissolved oxygen.

Probabilistic modelling results are summarized in Table 3.2. At Smith the probability that river oxygen would fall below 5 mg/L was slightly greater under the 1989 flow scenario (0.017) than under the 7Q10 flow (0.014) and reached zero under the 1990 and 1992 scenarios. At Grand Rapids, dissolved oxygen is most likely to fall below 5.0 mg/L under the 7Q10 flow (0.034), and an order of magnitude less likely with 1989 flows (0.0034). Similar to the Smith results, none of the 5000 model runs for Grand Rapids at 1990 or 1992 flows resulted in oxygen levels less than 5.0 mg/L (Table 3.2). Again, these results are based upon measured mill performance over the last few years (or estimated in the case of ALPAC) and are based upon the 1989 DOSTOC calibration.

Also listed in Table 3.2 are the probabilities that river flows would be less than or equal to the four flows used in the model scenarios. There are four Water Survey of Canada gauging stations on the Athabasca River, so a flow probability distribution could be determined for each location. The probabilities of encountering a flow lower than those used in the model scenarios ranged from a low of 0.006 for 7Q10 Athabasca flows at Athabasca to 0.386 for 1992 flows at Hinton. These statistics are useful when comparing dissolved oxygen modelling results from different years and different locations.

4.0 SENSITIVITY ANALYSIS

A sensitivity analysis is a means of discovering the sensitivity of model predictions to changes in input variables. The premise is that if we know which variables are the most sensitive (that is, cause the greatest change in model output) then greatest effort can be focussed on defining these variables. Naturally, the effort required to measure input variables to any given level of precision must also be considered. The model may be very sensitive to one variable, such as BOD settling rate, that is difficult or impossible to measure precisely without a prohibitive level of effort. In that case it may be more practical to concentrate on another variable, to which the model is somewhat less sensitive, but for which precise measurements are more readily obtained.

4.1 Approach

The approach we used for the sensitivity analysis was to take a set model configuration (the 1989 Survey 3 calibration) and, through the systematic alteration of input variables, generate a matrix of predicted dissolved oxygen concentrations at key river locations. The 1989 calibration was selected because it produced the best fit to observed data and therefore the most reliable predictions, and because it was based on the lowest river flow conditions for which dissolved oxygen data were available. All sensitivity analysis has been based upon this calibration.

Selection of output locations is critical in a sensitivity analysis because changes in input variables do not always result in equal changes in the dissolved oxygen concentration at different locations along the river length. The following locations were selected for reviewing results of the sensitivity analysis:

- upstream Berland (km 104.4)

- upstream Whitecourt (km 214.4)
- upstream Smith (km 448.9)
- upstream Athabasca (km 609.0)
- upstream Grand Rapids (km 810.8)
- upstream Ft. McMurray (km 950.2)
- end of modelled system (Embarras) (km 1144.5)

Sites were chosen to represent a range of distances down the river, to include local effects (e.g., Berland), and to include the anticipated minimum dissolved oxygen locations (Smith and upstream Grand Rapids).

The sensitivity analysis was conducted by first increasing, then decreasing, the value of each variable. All variables except ice cover were individually perturbed by 20% of the calibration values. The selection of 20% was arbitrary. The variables which were perturbed are:

- headwater and tributary flows
- Weldwood BOD and SOD
- Millar Western BOD and SOD
- Mill BOD and SOD (both mills)
- Mill BOD (both mills)
- Mill DO (both mills)
- other effluent BOD
- other effluent DO
- tributary BOD
- tributary DO
- headwater BOD
- headwater DO
- velocity

- BOD settling rate
- BOD decay rate (background BOD)
- BOD decay rate (effluent)
- reaeration rate (ice-cover)
- reaeration rate (open-water)
- SOD rate

Ice-cover reaeration rates were set essentially equal to zero in the calibration for all ice-cover reaches (Macdonald and Hamilton, 1989), consequently a 20% increase (or decrease) is meaningless. To determine some level of sensitivity for this parameter, the model was run with reaeration set at 0.02 in all ice-cover reaches versus the original 0.001 day^{-1}. Effluent BOD was manipulated in two ways: first it was treated as a stand-alone parameter and perturbed by 20%; then BOD and SOD were both perturbed by 20%, since the modelling approach assumed a direct linkage. The analysis for mill discharge related parameters was done for each mill separately as well as for both mills combined. SOD rates were increased and decreased by 20% in reaches where SOD was assumed to be present (Macdonald and Hamilton, 1989). In reaches where SOD was assumed to be zero the rate was set to 0.02 mg/L/day as per the reaeration rate. After each run of the model the predicted dissolved oxygen concentration, effluent BOD concentration, and background BOD concentration were recorded for each of the seven river locations.

4.2 Results

Results for each site are shown (Table 3.3) as average percent change in dissolved oxygen (neglecting sign); input variables are listed in descending order of sensitivity. Mean percent change ranged from as high as 19.6% to as low as 0.0%. More detailed results are included in Appendix D.

Predicted dissolved oxygen concentrations at Berland are most sensitive to headwater DO concentrations (15.8%), followed by Weldwood BOD and SOD (2.7%) and water velocity (2.4%). It is not surprising that headwater DO is the most sensitive parameter since Berland is so close to the headwaters. The model is much less sensitive to Weldwood BOD and SOD because these variables are both a function of time and therefore the model will tend to show increasing sensitivity to these variables with increasing distance downstream. This is particularly true for velocity.

At the upstream Whitecourt site, headwater DO is still the most sensitive parameter (11.9%) followed by tributary DO (6.1%) and ice-cover reaeration rate (2.9%). (Recall that reaeration was a special case as the magnitude of the perturbation was different.) At this location the model was sensitive to tributary dissolved oxygen levels because the river has almost doubled in volume since Hinton, all due to tributary inflows. The model remains as sensitive to velocity as at Berland, but Weldwood BOD and SOD drop slightly in significance.

The Smith location had the minimum dissolved oxygen concentration of any place along the river in 1989. While headwater DO is still a significant variable at this site (17.2%) it falls behind the SOD rate (19.3%) and ice cover reaeration (18.0 %). Reaeration and SOD are significant at this site because the water has now travelled over 400 km, and over that distance even a small change in a time-dependent variable can result in a significant change in the predicted dissolved oxygen concentration. Other time-dependent variables such as velocity (10.4%) and mill BOD/SOD loadings (10.7%) (Weldwood 3.8%, Millar 6.9%) have a greater influence on the model compared with upstream sites. A similar pattern exists at Athabasca, however SOD and headwater DO switch rankings.

The second river location where dissolved oxygen levels tend to sag is upstream of Grand Rapids. At this location headwater DO and reaeration are still the most significant input variables (19.6 and 19.4 % respectively) followed closely by the SOD rate (12.8%), then tributary DO (6.6%), velocity (6.4%) and combined mill BOD/SOD (6.1%).

No sites were evaluated below Grand Rapids because DOSTOC was not set up to easily simulate downstream conditions. Macdonald and Hamilton (1989) recognized that DOSTOC could not adequately simulate oxygenation through the rapids and so simply inserted a flow-specific diffuse term to bring the river to saturation.

In summary, headwater DO loading is consistently the most sensitive input variable for prediction of river dissolved oxygen, accounting for almost 100% of change at some locations. SOD, ice-cover reaeration, tributary DO concentrations, combined mill BOD/SOD and velocity were consistently the next most sensitive variables, and all were more or less equally important, although ranks changed at each site. SOD and ice-cover reaeration rates increase in significance downstream. However, because the value of these variables were not increased by the same amount as the other input variables (zero values were set to 0.02), their relative sensitivity is difficult to determine. Consistently the least important input variables are mill DO and other effluent DO and BOD, which always produce a change in predicted dissolved oxygen concentrations of less than 0.4%.

5.0 RECOMMENDATIONS

The following recommendations are based upon the work presented here as well as experience gained from the model calibration, scenario evaluations, the Dissolved Oxygen and Nutrients Modelling Workshop in Saskatoon and some preliminary 1993 model verification testing and data review.

First, it is important to differentiate between the simulation model and the modelling approach. Although these two things are often thought of interchangeably, they are in fact very different components of a modelling exercise. DOSTOC is a model. It is a set of equations described in a computer code which enables us to predict dissolved oxygen levels based upon a number of input variables. Little if any of the code is geographically specific, so the model can be applied to most river basins or effluent loading situations simply by changing the modelling approach. The modelling approach is the theoretical framework used to describe the site-specific problem. It is defined by the user in the input file and includes such things as:

reach configurations;
SOD being linearly related to effluent BOD;
SOD decreasing to background some distance below each mill;
reaeration being zero under ice;
effluent BOD consuming oxygen at a different rate than background BOD;
BOD settling below each mill to become SOD.

At the Saskatoon workshop it was repeatedly stated that because the model was not successful at predicting 1991, 1992 and particularly 1993 dissolved oxygen levels, the model should be rejected and a new one sought. It is not the model that does not fit the measured data, but the modelling approach. And in fact, given that we no longer accept some of the 1989 assumptions used in the modelling, it does a remarkable job of predicting oxygen levels over five very different years.

The following specific recommendations pertain to how the existing model (DOSTOC) should be recalibrated using a refined modelling approach that is not limited by a 1989 knowledge base, but utilizes all of our knowledge to date.

1. The use of "balanced", "estimated" or "measured" river and tributary flows should be standardized and perhaps a formal numerical relationships should be derived for determining tributary flows on ungauged systems based upon measurements at continuous gauge locations on other rivers. To date, modelling has focused on modelling synoptic surveys (when flows are usually measured) or statistical flows (7Q10). Future modelling efforts, including contaminant fate modelling, and any recalibration, would benefit from these flow relationships.

2. This study has only reviewed the 1991 and 1992 data directly relevant to verifying dissolved oxygen predictions and has not reviewed any of the other valuable information which would assist in redefining the modelling approach nor any of the 1993 data. During any recalibration effort it is imperative that all of the available information (industry and government) be considered, including: COD, DOC, TOC, and BOD_u and continuous recording datasonds.

3. Differences between BOD_5 and BOD_u measurements by the mills compared with those from Alberta Environment must be resolved by standardizing laboratory practices (including any numerical interpretation) and conducting relevant split sampling, and through the use of reference laboratories.

4. All the SOD data collected to date should be reviewed with respect to compatibility of data, relationships with river flow and effluent BOD load, etc. Supplemental information is needed to determine extent of channel width to which SOD rates apply, the composition of biofilms (bacterial versus algal), the extent of SOD downstream from Smith, and to test the hypothesis that the SOD is removed each spring and therefore does not accumulate over the years.

5. During the recalibration, the approach to simulating the open water zones, particularly at Hinton and Grand Prairie, should be reviewed.

6. The oxygen consumption rate between Smith and Grand Rapids should be increased in the model by perhaps either increasing the amount of mill BOD which exerts its demand in this reach or increasing SOD based upon the field measurements.

7. Based upon results of recommendation 4. above, the assumption that SOD is linearly related to effluent BOD, which we now know to be false, should be removed.

8. The hydraulic coefficients in the model for the Grand Rapids and Boiler Rapids areas should be adjusted to more accurately reflect travel time measurements made in 1992.

9. The sensitivity analysis revealed the importance of headwater and tributary dissolved oxygen concentrations for prediction of minimum dissolved oxygen levels. This conclusion is supported by the 1993 continuous oxygen measurements at Hinton, which vary by up to 2.0 mg/L during winter ice-cover. A statistical analysis should be conducted to determine if a predictive

relationship can be developed between air temperature, river flow and headwater oxygen levels that can be used as input to the model.

10. The oxygen model recalibration should proceed immediately for the Athabasca River so that preparations can be made for 1994 modelling requirements and so that any data deficiencies can be addressed. The model should not be recalibrated for the less critical Wapiti/Smoky system until the approach for the Athabasca River has been confirmed.

11. A revised modelling approach should be subjected to an external peer review which includes an evaluation of the ability of alternative approaches to reproduce 1988 to 1993 measured dissolved oxygen levels in the Athabasca River.

This evaluation has found nothing inherently wrong with the model itself. However, forthcoming model use requirements appear to exceed the capabilities of the model. For example, the probabilistic assessment reported here required code changes; any further probabilistic analysis should also allow for variable headwater and tributary flows which would require additional code changes. Another example is the need to predict, in January, the probability that river DO levels are going to fall below a given level in March. Presently there is no capability to do this kind of modelling and if it is deemed necessary, then alternative models should be considered. Similarly, if the modelling approach decided upon during the model recalibration exceeds the practical capabilities of DOSTOC, then a new model will be needed. If the model use does not change and recalibration is successful, then there is little reason to discard what has been an efficient analytical tool.

6.0 REFERENCES

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TABLE 2.1

ATHABASCA RIVER BASIN FLOWS (FEB 6 - MARCH 12, 1991) (ALL VALUES m^3/s)

SITE	BALANCED ATHABASCA FLOWS	BALANCED TRIBUTARY FLOWS	MODELLED ATHABASCA FLOWS	MODELLED TRIBUTARY FLOWS
u/s Hinton	51.7		51.7	
At Obed	51.9		51.7	
Oldman Cr.		-		0.2
Berland R.		12.2		12.2
Marsh Head Cr.		0.323		0.323
Pine Creek		-		0.577
At Windfall	65.0		65.0	
Sakwatamau R.		0.934		0.934
Mcleod R.		10.3		10.3
Freeman R.		0.0		3.586
At Ft. Assiniboine	79.2		79.82	
Pembina R.		5.78		6.88
u/s Smith	86.7		86.7	
Lesser Slave R.		17.5		18.3
At Athabasca	105.0		105.0	
Labiche R.		1.89		2.56
Calling R.		0.03		0.04
Pelican R.		0.295		0.40
u/s House R.	108.0		108.0	
House R.		1.14		1.18
u/s Horse R.	110.0		109.18	
Clearwater R.		41.2		42.82
d/s Ft. McMurray	152.0		152.0	
Muskeg R.		0.262		0.262
Ells R.		Trace		0.005
Firebag R.		9.81		9 .81
At Old Fort	163.0		162.1	

TABLE 2.2

ATHABASCA RIVER BASIN FLOWS (JAN 30 - MARCH 10, 1992)
(ALL VALUES m^3/s)

SITE	ESTIMATED ATHABASCA FLOWS	ESTIMATED TRIBUTARY FLOWS	MODELLED ATHABASCA FLOWS	MODELLED TRIBUTARY FLOWS
u/s Hinton	47.2		47.2	
At Obed	49.1		47.2	
Oldman Cr.				3.2
Spring				3.3
Berland R.		12.3		12.3
Marsh Head Cr.		0.359		0.359
At Windfall	70.8		66.4	
Sakwatamau R.		1.22		1.22
Mcleod R.		11.0		11.0
Freeman R.		-		0.0
At Ft. Assiniboine	83.3		78.4	
Pembina R.		4.96		4.96
u/s Smith	77.6		83.3	
Lesser Slave R.		15.1		15.6
At Athabasca	87.5		98.9	
Labiche R.		1.26		1.26
Calling R.		0.047		0.047
u/s Pelican R.	71.0		100.3	
Pelican R.		0.45		0.45
u/s House R	81.1		100.7	
House R.		1.43		1.43
u/s Ft. McMurray	86.2			
Clearwater R.		48.8		48.8
Muskeg R.		0.489		0.489
Ells R.		1.75		1.75
Firebag R.		9.89		9.89
At Old Fort	195.0		163.1	

TABLE 2.3

ALBERTA ENVIRONMENT SYNOPTIC SURVEY DATA FOR THE ATHABASCA, WAPITI AND SMOKY RIVERS FOR 1991 AND 1992

SITE	NAQUADAT CODE	DAY	MONTH	YEAR	DISCHARGE (m3/s)	METER D.O. (mg O2/L)	WINKLER D.O. (mg O2/L)	BOD5 (mg/L)
1991 ATHABASCA MAINSTEM DATA								
u/s Hinton	00AL07AD1085	7	2	91			12.02	-0.1
u/s Hinton	00AL07AD1085	7	2	91		12.3	11.98	0.5
u/s Hinton	00AL07AD1085	7	2	91			11.98	-0.1
d/s Hinton	00AL07AD1180	7	2	91	53.9	12.4	11.7	1
d/s Hinton	00AL07AD1180	7	2	91			11.75	
d/s Center Cr.	00AL07AD1220	7	2	91		12.4	11.8	0.6
d/s Center Cr.	00AL07AD1200	7	2	91		12.7	12.08	
d/s Trail Cr.	00AL07AD1280	7	2	91		12.6	12.03	
d/s Trail Cr.	00AL07AD1280	7	2	91		12.5	11.84	0.6
Obed Br.	00AL07AD1380	7	2	91			11.58	
Obed Br.	00AL07AD1380	7	2	91		12.2	11.48	1.2
Obed Ferry	00AL07AD1565	8	2	91		11.3	11.61	0.8
Obed Ferry	00AL07AD1565	8	2	91			11.83	
Haul Rd. Br.	00AL07AD1680	7	2	91	50.7			
Haul Rd. Br.	00AL07AD1680	7	2	91	53.8			
6.2 km d/s Oldman Cr.	00AL07AD1765	8	2	91		11.7	11.97	0.8
6.2 km d/s Oldman Cr.	00AL07AD1765	8	2	91			11.74	
u/s Berland R.	00AL07AD2060	8	2	91			11.27	
u/s Berland R.	00AL07AD2060	8	2	91		11.25	11.09	0.6
d/s Berland R.	00AL07AE0800	8	2	91	65			
d/s Two Cr.	00AL07AE1260	12	2	91			11.18	
d/s Two Cr.	00AL07AE1260	12	2	91			11.15	1
Windfall Br.	00AL07AE1285	12	2	91	65		11.1	0.9
Windfall Br.	00AL07AE1285	12	2	91			11.04	0.9
Windfall Br.	00AL07AE1285	12	2	91			11.1	
5 km u/s Highway 43 Br. - south	00AL07AE1370	12	2	91			11.2	0.7
5 km u/s Highway 43 Br. - south	00AL07AE1370	12	2	91			11.26	
5 km u/s Highway 43 Br. - north	00AL07AE1380	12	2	91			11.02	1
5 km u/s Highway 43 Br. - north	00AL07AE1380	12	2	91			10.98	
Highway 43	00AL07AE1495	12	2	91			11	
Highway 43	00AL07AE1495	12	2	91		11.4	10.98	0.7
3 km d/s McLeod R.	00AL07AH0660	13	2	91		11.1	10.96	0.2
3 km d/s McLeod R.	00AL07AH0660	13	2	91			10.7	
10 km d/s McLeod R.	00AL07AH1044	13	2	91			10.84	
10 km d/s McLeod R.	00AL07AH1044	13	2	91			10.68	-0.1
Blueridge Br.	00AL07AH1085	13	2	91			10.56	
Blueridge Br.	00AL07AH1085	13	2	91		10.2	10.61	0.2
5 km d/s 5 Mile Is.	00AL07AH1150	13	2	91			9.89	
5 km d/s 5 Mile Is.	00AL07AH1150	13	2	91		10	10.16	-0.1
Near Ft. Assiniboine	00AL07AH1310	13	2	91			10.01	
Near Ft. Assiniboine	00AL07AH1310	13	2	91		9.9	10.09	-0.1
u/s Pembina R.	00AL07BD0500	19	2	91			10.04	
u/s Pembina R.	00AL07BD0500	19	2	91		10.3	9.96	0.4
Highway 2 Br.	00AL07BD1000	21	2	91		9.6	9.07	0.2
Highway 2 Br.	00AL07BD1000	21	2	91			9.1	
Highway 2 Br.	00AL07BD1000	21	2	91			9.08	
d/s Lesser Slave R.	00AL07BE0400	20	2	91	105			
45 km u/s Athabasca	00AL07BE2200	23	2	91		9.42	9.2	0.5
45 km u/s Athabasca	00AL07BE2200	23	2	91			9.3	
1 km u/s Highway 813 Br.	00AL07BE2320	23	2	91	105	9.22	9	0.7
1 km u/s Highway 813 Br.	00AL07BE2320	23	2	91	105		9.02	1.4
1 km u/s Highway 813 Br.	00AL07BE2320	23	2	91			9.1	0.6
0.5 km u/s LaBiche R.	00AL07CB2410	26	2	91		9.6	8.97	0.4
0.5 km u/s LaBiche R.	00AL07CB2410	26	2	91			8.93	
11.7 km d/s Duncan Cr.	00AL07CB3300	26	2	91			8.64	
11.7 km d/s Duncan Cr.	00AL07CB3300	26	2	91		9.1	8.63	0.5

TABLE 2.3 CONTINUED

SITE	NAQUADAT CODE	DAY	MONTH	YEAR	DISCHARGE (m3/s)	METER D.O. (mg O2/L)	WINKLER D.O. (mg O2/L)	BOD5 (mg/L)
1991 ATHABASCA MAINSTEM DATA CONT								
1.7 km u/s Pelican R.	00AL07CB3800	26	2	91			8.41	
1.7 km u/s Pelican R.	00AL07CB3800	26	2	91		8.8	8.38	0.4
u/s House R.	00AL07CB4150	5	3	91	87.8	9.66	9.16	0.9
u/s Grande Rapids	00AL07CC2050	5	3	91			8.72	
u/s Grande Rapids	00AL07CC2050	5	3	91			8.67	
u/s Grande Rapids	00AL07CC2050	5	3	91		9.41	8.69	0.7
u/s Buffalo Cr.	00AL07CC3050	5	3	91			12.1	
u/s Buffalo Cr.	00AL07CC3050	5	3	91		13.32	12.41	0.6
u/s Boiler Rapids	00AL07CC4050	5	3	91		13.03	12.25	0.6
u/s Boiler Rapids	00AL07CC4050	5	3	91			12.19	
0.1 km u/s Horse R.	00AL07CC0600	7	3	91	78.6	11.21	12.41	3
u/s Suncor	00AL07DA0985	7	3	91		12.6	12.23	1.3
u/s Suncor	00AL07DA0985	7	3	91			12.21	
5 km d/s Bitumont	00AL07DA4250	7	3	91			11.91	
5 km d/s Bitumont	00AL07DA4250	7	3	91		12.29	11.95	0.9
u/s Firebag R.	00AL07DA5050	14	3	91		12.2	11.84	0.6
u/s Firebag R.	00AL07DA5050	14	3	91			11.65	
Old Fort	00AL07DD0900	14	3	91		11.22	10.72	0.4
Old Fort	00AL07DD0900	14	3	91			10.72	0.9
Old Fort	00AL07DD0900	14	3	91			10.83	1.1
u/s Fletcher Ch.	00AL07DD1125	14	3	91	158			
Big Point Ch.	00AL07DD1800	14	3	91		10.63	10.14	1.5
Big Point Ch.	00AL07DD1800	14	3	91			10.2	
1991 ATHABASCA TRIBUTARY DATA								
Berland R.	00AL07AC1000	8	2	91			11.22	
Berland R.	00AL07AC1000	8	2	91	12.2	10.8	10.88	0.4
Marsh Head Cr.	00AL07AE0900	12	2	91			12.3	
Marsh Head Cr.	00AL07AE0900	12	2	91	0.323	12.61	12.3	0.9
McLeod R. at Highway 43 Br.	00AL07AG2060	12	2	91			8.95	
McLeod R. at Highway 43 Br.	00AL07AG2060	12	2	91	10.3	9.1	9.23	0.9
Sakwatamau R.	00AL07AH0350	12	2	91			8.95	
Sakwatamau R.	00AL07AH0350	12	2	91	0.934	9.3	9.2	0.6
Freeman R.	00AL07AH1990	13	2	91			10.22	
Freeman R.	00AL07AH1990	13	2	91	0.015	9.4	10.05	-0.1
Pembina R.	00AL07BC0990	19	2	91			2.44	
Pembina R.	00AL07BC0990	19	2	91	5.82	2.6	2.56	-0.1
Lesser Slave R. near lake	00AL07BK2100	19	2	91	17.7	13.9	13.24	0.5
Lesser Slave R. near lake	00AL07BK2100	19	2	91			13.27	
Lesser Slave R. at Mitsue	00AL07BK2110	19	2	91			12.9	
Lesser Slave R. at Mitsue	00AL07BK2110	19	2	91		13.49	12.98	0.5
Lesser Slave R. u/s Otauwa R.	00AL07BK2120	21	2	91		13.14	12.95	0.8
Lesser Slave R. u/s Otauwa R.	00AL07BK2120	21	2	91			12.89	
Lesser Slave R. 0.5 km u/s Driftwood R.	00AL07BK2130	21	2	91			12.43	
Lesser Slave R. 0.5 km u/s Driftwood R.	00AL07BK2130	21	2	91		12.9	12.48	1
Lesser Slave R. at mouth	00AL07BK2150	21	2	91			11.86	
Lesser Slave R. at mouth	00AL07BK2150	21	2	91	17.5	12.4	11.75	1
Lac La Biche R.	00AL07CA1500	26	2	91			2.72	
Lac La Biche R.	00AL07CA1500	26	2	91	1.89		2.76	0.8
Calling R.	00AL07CB2500	28	2	91	0.034			0.7
Pelican R.	00AL07CB3900	26	2	91			12.72	
Pelican R.	00AL07CB3900	26	2	91	0.295	13.4	12.91	1.3
House R.	00AL07CB4500	5	3	91	1.14	9.84	9.83	0.9
House R.	00AL07CB4500	5	3	91			9.92	
Clearwater R.	00AL07CD1200	6	3	91			13.03	

TABLE 2.3 CONTINUED

SITE	NAQUADAT CODE	DAY	MONTH	YEAR	DISCHARGE (m3/s)	METER D.O (mg O2/L)	WINKLER D.O. (mg O2/L)	BOD5 (mg/L)
1991 ATHABASCA TRIBUTARY DATA CONT								
Clearwater R.	00AL07CD1200	6	3	91	41.2	13.12	13.37	0.5
Clearwater R.	00AL07CD1200	6	3	91			12.69	0.7
Muskeg R.	00AL07DA2650	7	3	91	0.262	6.47	5.71	1.5
Muskeg R.	00AL07DA2650	7	3	91			5.62	
Ells R.	00AL07DA3350	7	3	91			8.34	
Ells R.	00AL07DA3350	7	3	91		8.77	8.31	1.2
Firebag R.	00AL07DC0900	26	3	91	9.81	5.9	6.15	1.1
Firebag R.	00AL07DC0900	26	3	91			6.08	
Richardson R.	00AL07DD1140	14	3	91			6.22	
Richardson R.	00AL07DD1140	14	3	91	14.5	6.53	6.21	1.1
Riveire Des Rochers	00AL07NA0700	27	3	91	742	12.4	11.95	0.4
Riveire Des Rochers	00AL07NA0700	27	3	91			11.85	
Slave R.	00AL07NA3000	27	3	91			12.14	
Slave R.	00AL07NA3000	27	3	91		12.3	12.18	0.4
Slave R.	00AL07NA3050	27	3	91		12.4	12.12	0.3
Slave R.	00AL07NA3050	27	3	91			12.15	
1992 ATHABASCA MAINSTEM DATA								
u/s Hinton	00AL07AD1085	30	1	92		12.4	12.43	0.8
u/s Hinton	00AL07AD1085	30	1	92			12.43	0.7
u/s Hinton	00AL07AD1085	30	1	92	47.2		12.55	0.6
d/s Center Cr.	00AL07AD1225	30	1	92		12.3	12.22	1.6
d/s Center Cr.	00AL07AD1225	30	1	92			12.54	1.6
Obed Br.	00AL07AD1380	30	1	92		12.1	12.22	1.7
Obed Br.	00AL07AD1380	30	1	92			12.06	1.6
Haul Rd. Br.	00AL07AD1680	31	1	92		12.4	11.89	1.2
Haul Rd. Br.	00AL07AD1680	31	1	92			11.68	
u/s Berland R.	00AL07AD2060	31	1	92		12.1	11.86	1.1
u/s Berland R.	00AL07AD2060	31	1	92	53.7		11.89	
d/s Two Cr.	00AL07AE1260	4	2	92		12.3	11.78	0.2
d/s Two Cr.	00AL07AE1260	4	2	92			11.88	
Windfall Br.	00AL07AE1285	4	2	92	70.8	12.1	11.69	0.4
Windfall Br.	00AL07AE1285	4	2	92			11.66	0.3
Highway 43	00AL07AE1495	4	2	92		12.1	11.9	0.5
10 km d/s McLeod R.	00AL07AH1044	5	2	92		11.9	11.57	0.5
10 km d/s McLeod R.	00AL07AH1044	5	2	92			11.45	
Blueridge Br.	00AL07AH1085	5	2	92		11.8	11.47	0.4
Blueridge Br.	00AL07AH1085	5	2	92			11.54	
5 km d/s 5 Mile Is.	00AL07AH1150	6	2	92		11.7	11.52	0.6
5 km d/s 5 Mile Is.	00AL07AH1150	6	2	92			11.53	
Near Ft. Assiniboine	00AL07AH1310	6	2	92		11.3	11.35	0.6
Near Ft. Assiniboine	00AL07AH1310	6	2	92			11.27	
u/s Pembina R.	00AL07BD0500	11	2	92		11.9	11.15	0.2
u/s Pembina R.	00AL07BD0500	11	2	92			11.03	
Highway 2 Br.	00AL07BD1000	12	2	92		10	10.07	0.3
Highway 2 Br.	00AL07BD1000	12	2	92			10.42	
d/s Lesser Slave R.	00AL07BE0400	12	2	92	92.7			
45 km u/s Athabasca	00AL07BE2200	14	2	92		10.2	10.48	0.6
45 km u/s Athabasca	00AL07BE2200	14	2	92			10.41	
1 km u/s Highway 813 Br.	00AL07BE2320	14	2	92	87.5	10	10.3	0.4
1 km u/s Highway 813 Br.	00AL07BE2320	14	2	92			10.34	0.4
1 km u/s Highway 813 Br.	00AL07BE2320	14	2	92			10.26	0.5
0.5 km u/s LaBiche R.	00AL07CB2410	20	2	92		9.8	9.64	0.6
0.5 km u/s LaBiche R.	00AL07CB2410	20	2	92			9.72	
11.7 km d/s Duncan Cr.	00AL07CB3300	20	2	92		9.7	9.79	0.5
11.7 km d/s Duncan Cr.	00AL07CB3300	20	2	92			9.67	

TABLE 2.3 CONTINUED

SITE	NAQUADAT CODE	DAY	MONTH	YEAR	DISCHARGE (m3/s)	METER D.O (mg O2/L)	WINKLER D.O. (mg O2/L)	BOD5 (mg/L)
1992 MAINSTEM DATA CONT								
1.7 km u/s Pelican R.	00AL07CB3800	24	2	92		9.4	9.33	0.2
1.7 km u/s Pelican R.	00AL07CB3800	24	2	92			9.29	
u/s House R.	00AL07CB4150	24	2	92	71.7	9.2	9.22	0.3
u/s House R.	00AL07CB4150	24	2	92			9.19	
u/s Grande Rapids	00AL07CC2050	24	2	92		9.5	9.42	0.4
u/s Grande Rapids	00AL07CC2050	24	2	92			9.47	
u/s Buffalo Cr.	00AL07CC3050	24	2	92		13	12.89	0.3
u/s Buffalo Cr.	00AL07CC3050	24	2	92			12.56	
u/s Boiler Rapids	00AL07CC4050	24	2	92		12.7	12.72	0.3
u/s Boiler Rapids	00AL07CC4050	24	2	92			12.04	
0.1 km u/s Horse R.	00AL07CC0600	25	2	92	81.1	13.4	13.26	0.2
0.1 km u/s Horse R.	00AL07CC0600	25	2	92			13.34	
u/s Suncor	00AL07DA0985	26	2	92		13.4	12.96	1.1
u/s Suncor	00AL07DA0985	26	2	92			13.03	
5 km d/s Bitumont	00AL07DA4250	26	2	92		12.9	12.69	0.3
5 km d/s Bitumont	00AL07DA4250	26	2	92			12.73	
u/s Firebag R.	00AL07DA5050	10	3	92		13.1	12.79	0.8
u/s Firebag R.	00AL07DA5050	10	3	92			12.58	
Old Fort	00AL07DD0900	10	3	92		12	11.37	0.7
Old Fort	00AL07DD0900	10	3	92			11.43	0.7
Old Fort	00AL07DD0900	10	3	92				0.6
u/s Fletcher Ch.	00AL07DD1125	9	3	92	185			
Big Point Ch.	00AL07DD1800	10	3	92		11.2	10.71	0.6
Big Point Ch.	00AL07DD1800	10	3	92			10.97	
1992 ATHABASCA TRIBUTARY DATA								
Berland R.	00AL07AC1000	31	1	92	12.3	11.1	11	0.7
Berland R.	00AL07AC1000	31	1	92			11.06	
Marsh Head Cr.	00AL07AE0900	4	2	92	0.359	13.1	12.63	0.4
Marsh Head Cr.	00AL07AE0900	4	2	92			12.59	
McLeod R. at Highway 43 Br.	00AL07AG2060	4	2	92	11	9.4	9.39	0.4
Sakwatamau R.	00AL07AH0350	4	2	92	1.22	11.3	11.23	0.7
Sakwatamau R.	00AL07AH0350	4	2	92			11.06	
Pembina R.	00AL07BC0990	11	2	92	4.96	6	4.13	0.5
Pembina R.	00AL07BC0990	11	2	92			4.15	
Lesser Slave R. near lake	00AL07BK2100	11	2	92	15.6	13.2	12.54	0.3
Lesser Slave R. near lake	00AL07BK2100	11	2	92			12.62	
Lesser Slave R. at Mitsue	00AL07BK2110	11	2	92		12.4	12.18	0.4
Lesser Slave R. at Mitsue	00AL07BK2110	11	2	92			12.11	
Lesser Slave R. 0.5 km u/s Driftwood R.	00AL07BK2130	12	2	92		11.9	11.32	1
Lesser Slave R. at mouth	00AL07BK2150	12	2	92	15.1	10.7	10.62	1.2
Lesser Slave R. at mouth	00AL07BK2150	12	2	92			10.54	
Lac La Biche R.	00AL07CA1500	20	2	92	1.26	6	5.43	0.9
Lac La Biche R.	00AL07CA1500	20	2	92			5.61	
Calling R.	00AL07CB2500	20	2	92	0.047	12.7	12.72	0.6
Calling R.	00AL07CB2500	20	2	92			12.5	
Pelican R.	00AL07CB3900	24	2	92		13.8	12.76	
Pelican R.	00AL07CB3900	24	2	92			13.05	4.4
House R.	00AL07CB4500	24	2	92	1.43	12.8	12.38	1.2
House R.	00AL07CB4500	24	2	92			12.34	
Clearwater R.	00AL07CD1200	25	2	92	48.8	13.3	13.26	0.2
Clearwater R.	00AL07CD1200	25	2	92			13.14	0.2
Muskeg R.	00AL07DA2650	26	2	92	0.489	9.2	9.13	0.5
Muskeg R.	00AL07DA2650	26	2	92			9.36	
Ells R.	00AL07DA3350	26	2	92	1.75	12.9	12.57	0.3
Ells R.	00AL07DA3350	26	2	92			12.7	
Firebag R.	00AL07DC0900	10	3	92	9.89	6.7	6.68	0.7
Firebag R.	00AL07DC0900	10	3	92			6.8	
Richardson R.	00AL07DD1140	10	3	92	12	8.9	8.93	0.9
Richardson R.	00AL07DD1140	10	3	92			8.92	

TABLE 2.3 CONTINUED

SITE	NAQUADAT CODE	DAY	MONTH	YEAR	DISCHARGE (m3/s)	METER D O (mg O2/L)	WINKLER D.O. (mg O2/L)	BOD5 (mg/L)
1992 WAPITI/SMOKY MAINSTEM DATA								
Wapiti at Highway 40 Br.	00AL07GE2015	11	3	92	32.3	13.1	12.76	0.6
Wapiti at d/s P&G Haul Rd. Br.	00AL07GE2300	11	3	92		13.4	12.69	0.7
Wapiti at Railroad Br. left	00AL07GE3060	12	3	92				1.2
Wapiti at Railroad Br. right	00AL07GE3050	12	3	92		13.3	12.52	
Wapiti at Railroad Br. right-center	00AL07GE3065	12	3	92		13.3	12.57	
Wapiti 10 km d/s P&G effluent	00AL07GE3500	12	3	92		13.5	12.55	
Wapiti 0.1 km u/s Bear R.	00AL07GE4050	12	3	92		12.8	12.14	1.1
Wapiti u/s Smoky R.	00AL07GJ1000	12	3	92	45.3	12.9	12.53	1.6
Smoky at Bezanson Br.	00AL07GJ2020	13	3	92		12.7	12.71	1
Smoky at Watino	00AL07GJ2060	19	3	92	550		13	2
1992 WAPITI/SMOKY TRIBUTARY DATA								
Bear R.	00AL07GE4500	12	3	92	0.482	13.3	12.28	5.2
Smoky R. u/s Wapiti R.	00AL07GF1015	12	3	92	42.1	13.2	12.93	0.2
1991 WAPITI/SMOKY MAINSTEM DATA								
Wapiti at Highway 40 Br.	00AL07GE2015	27	2	91	16	12.63	12.28	0.5
Wapiti at Highway 40 Br.	00AL07GE2015	27	2	91			12.18	0.4
Wapiti at d/s P&G Haul Rd. Br.	00AL07GE2300	27	2	91		12.56	12.28	0.7
Wapiti at d/s P&G Haul Rd. Br.	00AL07GE2300	27	2	91			12.18	1.2
Wapiti at Railroad Br. left	00AL07GE3050	27	2	91		12.35	12.08	
Wapiti at Railroad Br. left	00AL07GE3050	27	2	91			12.18	
Wapiti at Railroad Br. left/right	00AL07GE3060	27	2	91				2.6
Wapiti at Railroad Br. left/right	00AL07GE3060	27	2	91				2.8
Wapiti at Railroad Br. left/right	00AL07GE3060	27	2	91				2
Wapiti at Railroad Br. right	00AL07GE3065	27	2	91		12.43	12.18	
Wapiti at Railroad Br. right	00AL07GE3065	27	2	91			12.28	
Wapiti 10 km d/s P&G effluent	00AL07GE3500	28	2	91		13.4	12.63	2.2
Wapiti 10 km d/s P&G effluent	00AL07GE3500	28	2	91			12.48	2.3
Wapiti 10 km d/s P&G effluent	00AL07GE3500	28	2	91			12.58	2
Wapiti 0.1 km u/s Bear R.	00AL07GE4050	28	2	91		13.5	12.08	2.1
Wapiti 0.1 km u/s Bear R.	00AL07GE4050	28	2	91			11.88	2
Wapiti 0.1 km u/s Bear R.	00AL07GE4050	28	2	91			11.98	1.9
Wapiti 6 km u/s Smoky R.	00AL07GE5000	28	2	91		12.7	11.53	1.6
Wapiti 6 km u/s Smoky R.	00AL07GE5000	28	2	91			11.48	1.6
Wapiti 6 km u/s Smoky R.	00AL07GE5000	28	2	91			11.43	1.6
Wapiti u/s Smoky R.	00AL07GJ1000	28	2	91		12.4	11.25	1.7
Wapiti u/s Smoky R.	00AL07GJ1000	28	2	91			11.25	1.5
Wapiti u/s Smoky R.	00AL07GJ1000	28	2	91			11.2	1.6
Smoky at Bezanson Br.	00AL07GJ2020	1	3	91		12.3	11.56	1
Smoky at Bezanson Br.	00AL07GJ2020	1	3	91			11.54	0.9
Smoky 0.1 km u/s Puskwaskau R.	00AL07GJ2030	5	3	91		12.15	11.13	0.7
Smoky 0.1 km u/s Puskwaskau R.	00AL07GJ2030	5	3	91			11.33	0.5
Smoky 25 km u/s Little Smoky	00AL07GJ2050	5	3	91		12.06	10.93	0.3
Smoky 25 km u/s Little Smoky	00AL07GJ2050	5	3	91			11.03	0.3
Smoky at Watino	00AL07GJ2060	6	3	91		11.9	10.65	1.1
Smoky at Watino	00AL07GJ2060	6	3	91			10.66	1
Smoky at Watino	00AL07GJ2060	6	3	91	34.1			1
Smoky R. at mouth	00AL07GJ5000	11	3	91		10.44	10.5	0.3
Smoky R. at mouth	00AL07GJ5000	11	3	91			10.52	0.2
1991 WAPITI/SMOKY TRIBUTARY DATA								
Bear R.	00AL07GE4500	28	2	91		14	12.77	
Bear R.	00AL07GE4500	28	2	91	0.622		12.82	2
Smoky R. u/s Wapiti R.	00AL07GF1015	1	3	91	25.7	12.9	12.24	0.2
Smoky R. u/s Wapiti R.	00AL07GF1015	1	3	91			12.34	0.3
Simonette R.	00AL07GF3500	1	3	91		12	11.56	
Simonette R.	00AL07GF3500	1	3	91			11.63	0.5
Puskwaskau R.	00AL07GJ2032	5	3	91	0.003	13.17	12.24	
Puskwaskau R.	00AL07GJ2032	5	3	91			12.14	0.5
Little Smoky R.	00AL07GH1500	5	3	91		10.26	9.43	
Little Smoky R.	00AL07GH1500	5	3	91	3.24		9.43	0.5

TABLE 2.4

SUMMARY OF ANNUAL AVERAGE RESULTS FROM LONG-TERM TESTING

	BODu (mg/L)		K1 (1/day)	
	AE	MILL	AE	MILL
WELDWOOD				
1989	212.0		0.036	
1990	105.2	86.1	0.045	0.035
1991	210.9	65.3	0.030	0.099
1992	192.6	71.6	0.035	0.036
ALBERTA NEWSPRINT				
1989				
1990				
1991	782.1	72.9	0.055	0.035
1992	673.7	44.1	0.029	0.028
MILLAR WESTERN				
1989	2106.0		0.045	
1990	737.9	355.6	0.010	0.018
1991	963.0	512.3	0.039	0.019
1992	1135.9	351.1	0.027	0.017
SLAVE LAKE PULP				
1989				
1990				
1991	3263.9	5454.1	0.041	0.026
1992	1967.5	562.3	0.020	0.018

AE, Alberta Environment

TABLE 2.5

FINAL BOD LOADING AND KINETIC INFORMATION
USED FOR WELDWOOD

YY	MM	DD	DATA SOURCE	BODu	MEASURED BOD5	K1	BODU/ BOD5
90	3	8	AE	93.7	20.0	0.05	4.7
90	3	8	AE	84.3	20.0	0.047	4.2
90	3	8	AE	87.1	20.0	0.052	4.4
90	3	8	AE	77.8	20.0	0.06	3.9
90	3	23	AE	121.7	24.0	0.037	5.1
90	3	23	AE	115.4	24.0	0.035	4.8
90	3	23	AE	133.5	24.0	0 .037	5.6
90	3	23	AE	128.1	24.0	0.042	5.3
91	2	9	AE	218.3	28.0	0.031	7.8
91	2	9	AE	233.2	28.0	0.024	8.3
91	2	9	AE	201.2	28.0	0.034	7.2
91	2	9	AE	190.7	28.0	0.032	6.8
92	1	29	AE	184.0	28.7	0.041	6.4
92	1	29	AE	177.1	28.7	0.039	6.2
92	1	29	AE	202.8	28.7	0.031	7.1
92	1	29	AE	206.5	28.7	0.029	7.2
90	4	25	Mill	121.1	75.0	0.045	1.6
90	8	28	Mill	61.7	18.6	0.029	3.3
90	11	27	Mill	82.6	31.3	0.038	2.6
90	11	28	Mill	79.0	26.6	0.028	3.0
91	2	12	Mill	78.4	16.0	0.037	4.9
91	2	13	Mill	77.1	12.0	0.044	6.4
91	7	23	Mill	92.7	12.4	0.026	7.5
91	10	2	Mill	66.5	29.8	0.029	2.2
92	1	21	Mill	72.1	28.7	0.039	2.5
92	4	14	Mill	86.3	27.3	0.021	3.2
92	7	3	Mill	56.6	20.5	0.049	2.8
			MEAN	123.3	26.0	0.037	5.0
			STD. DEV.	55.0	10.9	0.009	1.9
			MINIMUM	56.6	12.0	0.021	1.6
			MAXIMUM	233.2	75.0	0.060	8.3

TABLE 2.6

FINAL BOD LOADING AND KINETIC INFORMATION USED FOR ALBERTA NEWSPRINT

YY	MM	DD	DATA SOURCE	BODu	MEASURED BOD5	K1	BODU/ BOD5
91	1	17	Mill	156.1	15.0	0.023	10.4
91	3	20	Mill	40.8	13.1	0.083	3.1
91	5	8	Mill	28.6	6.0	0.052	4.8
91	7	3	Mill	44.4	4.0	0.027	11.1
91	10	30	Mill	53.4	5.0	0.017	10.7
91	11	7	Mill	57.1	3.0	0.023	19.0
91	12	12	Mill	129.7	24.0	0.018	5.4
92	5	22	Mill	29.2	3.0	0.03	9.7
92	9	30	Mill	58.9	6.0	0.025	9.8
			MEAN	66.5	8.8	0.033	9.3
			STD. DEV.	42.6	6.7	0.020	4.4
			MINIMUM	28.6	3.0	0.017	3.1
			MAXIMUM	156.1	24.0	0.083	19.0

TABLE 2.7

FINAL BOD LOADING AND KINETIC INFORMATION USED FOR MILLAR WESTERN

YY	MM	DD	DATA SOURCE	BODu	MEASURED BOD5	K1	BODU/ BOD5
90	2	23	AE	664.6	107.0	0.006	6.2
90	2	23	AE	685.9	107.0	0.008	6.4
90	2	23	AE	656	107.0	0.007	6.1
90	2	23	AE	693.2	107.0	0.007	6.5
90	2	23	AE	669.5	107.0	0.006	6.3
90	2	23	AE	599.4	107.0	0.007	5.6
90	2	23	AE	905.3	107.0	0.003	8.5
90	2	23	AE	608.4	107.0	0.007	5.7
90	3	15	AE	901.8	113.0	0.013	8.0
90	3	15	AE	857.2	113.0	0.012	7.6
90	3	15	AE	825.4	113.0	0.016	7.3
90	3	15	AE	718.4	113.0	0.015	6.4
90	3	23	AE	791	83.0	0.011	9.5
90	3	23	AE	754.6	83.0	0.012	9.1
90	3	23	AE	750.8	83.0	0.014	9.0
90	3	23	AE	724.2	83.0	0.017	8.7
90	4	9	Mill	328.8	79.0	0.022	4.2
90	4	9	Mill	350.0	79.0	0.013	4.4
90	4	9	Mill	130.6	79.0	0.026	1.7
90	4	9	Mill	245.7	79.0	0.018	3.1
90	4	9	Mill	232.4	79.0	0.021	2.9
90	7	17	Mill	211.0	18.0	0.009	11.7
90	7	17	Mill	711.0	18.0	0.002	39.5
90	10	26	Mill	462.3	65.0	0.025	7.1
90	10	26	Mill	529.0	65.0	0.027	8.1
91	1	11	Mill	586.5	160.0	0.028	3.7
91	1	11	Mill	619.9	160.0	0.023	3.9
91	4	22	Mill	480.3	92.0	0.021	5.2
91	4	22	Mill	530.0	92.0	0.019	5.8
91	7	23	Mill	477.8	42.0	0.015	11.4
91	7	23	Mill	409.4	42.0	0.018	9.7
91	11	5	Mill	578.8	71.0	0.009	8.2
91	11	5	Mill	415.4	71.0	0.015	5.9
92	3	11	Mill	215.7	60.0	0.013	3.6
92	3	11	Mill	225.1	60.0	0.018	3.8
92	6	8	Mill	323.6	61.0	0.013	5.3
92	6	8	Mill	349.6	61.0	0.013	5.7
92	9	22	Mill	531.2	43.0	0.017	12.4
92	9	22	Mill	461.2	43.0	0.026	10.7
			MEAN	543.9	83.6	0.015	7.6
			STD. DEV.	207.6	31.3	0.007	5.8
			MINIMUM	130.6	18.0	0.002	1.17
			MAXIMUM	905.3	160.0	0.028	39.5

TABLE 2.8

FINAL BOD LOADING AND KINETIC INFORMATION USED FOR SLAVE LAKE PULP

YY	MM	DD	DATA SOURCE	BODu	MEASURED BOD5	K1	BODU/ BOD5
92	1	16	Mill	477	39.1	0.009	12.2
92	1	16	Mill	446.7	39.1	0.01	11.4
92	1	16	Mill	463.8	39.1	0.01	11.9
92	1	16	Mill	495.7	39.1	0.007	12.7
92	4	10	Mill	639.3	191.0	0.025	3.3
92	4	10	Mill	691.3	191.0	0.024	3.6
92	4	10	Mill	748	191.0	0.021	3.9
92	4	10	Mill	745.8	191.0	0.021	3.9
92	7	11	Mill	659.5	125.0	0.016	5.3
92	7	11	Mill	650.6	125.0	0.016	5.2
92	7	11	Mill	630.3	125.0	0.017	5.0
92	7	11	Mill	635.5	125.0	0.018	5.1
92	9	10	Mill	370.1	127.0	0.028	2.9
92	9	10	Mill	388.2	127.0	0.028	3.1
92	9	10	Mill	468.1	127.0	0.019	3.7
92	9	10	Mill	487.1	127.0	0.02	3.8
			MEAN	562.3	120.5	0.018	6.1
			STD. DEV.	121.1	54.0	0.006	3.5
			MINIMUM	370.1	39.1	0.007	2.9
			MAXIMUM	748.1	191.0	0.028	12.7

TABLE 2.9

SUMMARY OF PAIRED BOD_5 TESTS

WELDWOOD			ANC			MILLAR			SLP		
DATE	AE	MILL	DATE	AE	MILL	DATE	AE	MILL	DATE	AE	MILL
90.02.14	56.2	52.8	91.02.13	6.1*	10.0	90.01.25	58.5	99.0	91.02.22	104.9*	155.1
90.02.15	53.1*	82.0	92.02.03	10.9*	9.0	90.02.20	30.5*	200.0	92.02.11	23.7*	111.9
91.02.09	25.0*	28.0				91.02.14	35.1*	118.0			
92.01.29	26.3*	28.7				92.02.04	20.1*	43.0			
AE, Alberta Environment; ANC, Alberta Newsprint Company; Millar, Millar Western; SLP, Slave Lake Pulp											
Differences based on AE BOD_5 minus MILL BOD_5											
AE-MILL	AVG	-7.7			1.0			-79.0			-69.2
	MIN	-2.4			1.9			-22.9			-50.2
	MAX	-28.9			-3.9			-169.0			-88.2
Coefficient of variation BOD_5 test based upon AE triplicate sampling.											
			AVG	14.2%							
			MAX	38.2%							
			MIN	2.4%							

* Average of 3 results.

TABLE 2.10

EFFLUENT LOADING INFORMATION USED FOR THE 1991 AND 1992 MODELLING

SOURCE	DATE	FLOW	BOD ULTIMATE (mg/L)	DISSOLVED OXYGEN (mg/L)
WELDWOOD	1991	1.07	140.0	7.15
WELDWOOD	1992	1.11	143.5	6.45
ALBERTA NEWSPRINT	1991	0.192	93.0	6.20
ALBERTA NEWSPRINT	1992	0.230	83.7	7.35
MILLAR WESTERN	1991	0.144	896.8	3.75
MILLAR WESTERN	1992	0.140	326.8	5.40
WHITECOURT STP	1991	0.039	15.2	5.90
WHITECOURT STP	1992	0.040	35.2	5.65
SLAVE LAKE PULP	1991	0.033	945.5	6.43
SLAVE LAKE PULP	1992	0.030	682.6	6.43
ATHABASCA STP	1991	0.010	216.0	5.0
ATHABASCA STP	1992	0.010	27.4	5.72
FT. McMURRAY STP	1991	0.127	22.0	10.5
FT. McMURRAY STP	1992	0.140	30.0	11.02
SUNCOR	1991	0.372	16.6	5.5
SUNCOR	1992	0.280	22.4	2.36

TABLE 2.11

RATE COEFFICENTS USED FOR 1991/1992 MODELLING BASED ON MACDONALD AND HAMILTON (1989)

	SOD ($mg0_2/L/Day$)			BOD DECAY (Day^{-1})		
LOCATION	**1989**	**1991**	**1992**	**1989**	**1991**	**1992**
d/s Weldwood	0.07-0.65	0.09-0.90	0.11-0.96	0.035	0.035	0.035
d/s Alberta Newsprint		0.02	0.03	-	0.020	0.020
d/s Millar Western	0.01-0.85	0.02-0.42	0.01-0.15	0.050	0.020	0.020
d/s Slave Lake Pulp		0.04-0.06	0.01-0.04	-	0.020	0.020

TABLE 2.12

SUMMARY OF AVERAGE SEDIMENT OXYGEN DEMAND MEASUREMENTS ($gO_2/m^2/day$)

	1989[a]	1990[b]	1992[c]	1993[d]
HINTON	0.142		0.033	0.27
WINDFALL	0.008	0.010	-0.003	0.010
WHITECOURT	0.486	0.590	0.530	
FT. ASSINABOINE	0.188	0.070		0.140
SMITH		0.080	0.100	0.110
ATHABASCA			0.210	0.170
ALPAC			0.250	

[a] Casey and Noton (1989)
[b] Casey (1990)
[c] Monenco (1992)
[d] Hardy-Agra (1993)

TABLE 2.13

SUMMARY OF TIME OF TRAVEL DATA FOR THE SUBREACHES

Subreach	Length (km)	Travel times: Leading Edge (hrs)	Peak (hrs)	Centroid (hrs)	Trailing Edge (hrs)	DOSTOC Hydraulic Reach	Partial Length (km)	Computed Travel Times: Vel Coef E	Vel Exp F	Flow Q (m^3/s)	Mean Vel V (m/s)	Travel Time (hrs)	Subreach Travel Time (hrs)
Athabasca - Deep Cr.	24.3	11.60	12.56	12.67	20.77	A	24.3	0.0698	0.3554	167	0.43	15.69	15.69
Deep Cr. - ALPAC	19.7	10.95	11.82	11.99	12.04	A	19.7	0.0698	0.3554	169	0.43	12.66	12.66
ALPAC - Calling R.	32.9	18.04	18.70	19.44	21.75	A	32.9	0.0698	0.3554	174	0.44	20.93	20.93
Calling R. - Iron Pt.	47.9	20.77	22.22	23.22	40.93	A	47.9	0.0698	0.3554	181	0.44	30.05	30.05
Iron Pt. - Upper Wells	45.4	18.76	20.85	21.60	18.64	A	15.2	0.0698	0.3554	186	0.45	9.44	
						B	30.2	0.1657	0.2710	186	0.68	12.28	21.73
Upper Wells - Boivin Cr.	62.7	28.22	32.97	36.20	53.31	B	62.7	0.1657	0.2710	103	0.58	29.93	29.93
Boivin Cr. - Brule Pt.	54.8	34.19	39.43	38.11	44.87	B	27.1	0.1657	0.2710	105	0.58	12.87	
						C	3.2	0.7960	0.2141	105	2.16	0.41	
						D1	24.5	0.5035	0.1879	105	1.21	5.64	18.92
Brule Pt. - Algar R.	38.4	19.97	25.16	25.15	45.11	D1	38.4	0.5035	0.1879	105	1.21	8.84	8.84
Algar R. - Ft.McMurray	65.6	37.73	38.69	42.95	61.81	D1	8.1	0.5035	0.1879	106	1.21	1.86	
						E	3.2	0.0325	0.5243	106	0.37	2.37	
						D2	27.0	0.5035	0.1879	106	1.21	6.20	
						F	27.3	0.0267	0.6330	106	0.51	14.84	25.27
Ft.McMurray - McLean Cr.	18.7	8.66	10.03	10.27	17.00	F	2.7	0.0267	0.6330	129	0.58	1.30	
						G	16.0	0.2081	0.1360	129	0.40	11.03	12.32
McLean Cr. - Muskeg R.	31.9	20.99	23.60	23.67	32.66	G	31.9	0.2081	0.1360	129	0.40	21.99	21.99
Muskeg R. - Ells R.	21.5	12.40	12.92	13.74	28.88	G	21.5	0.2081	0.1360	130	0.40	14.80	14.80
TOTAL	463.8	242.28	268.95	279.01	397.77		463.8						233.13

TABLE 2.14

RIVER AND TRIBUTARY FLOWS USED IN THE 1991 AND 1992 WAPITI/SMOKY RIVER VERIFICATION

1991				
SITE	**BALANCED RIVER FLOW (m^3/s)**	**BALANCED TRIBUTARY FLOW (m^3/s)**	**MODELLED RIVER FLOW (m^3/s)**	**MODELLED TRIBUTARY FLOW (m^3/s)**
Wapiti @ Hwy.40	16.0		16.0	
Wapiti u/s Bear R.	16.0		16.0	
Bear R.		0.622		0.622
Wapiti u/s Mouth	16.6		16.622	
Smoky R. u/s Wapiti		22.0		22.2
Simonette R.		3.18		3.18
Smoky R. u/s Puskwaskau	42.0		42.0	
Little Smoky R.		3.24		3.0
Smoky R. @ Watino	45.0		45.0	
Smoky R. @ Mouth	45.0		45.0	
1992				
SITE	**ESTIMATED RIVER FLOW (m^3/s)**	**ESTIMATED TRIBUTARY FLOW (m^3/s)**	**MODELLED RIVER FLOW (m^3/s)**	**MODELLED TRIBUTARY FLOW (m^3/s)**
Wapiti @ Hwy. 40	32.4		32.4	
Wapiti u/s Bear R.	35.9		32.4	
Bear R.		0.48		0.48
Wapiti u/s Mouth	36.4		32.88	
Smoky R. u/s Wapiti		171.0		171.0
Simonette R.				3.18
Smoky R. u/s Puskwaskau	282.0		291.5	
Little Smoky R.				3.0
Smoky R. @ Watino	548.0		548.0	
Smoky R @ Mouth			548.0	

TABLE 2.15

WATER QUALITY DATA USED FOR DISSOLVED OXYGEN MODELLING

	1991			1992		
SOURCE	**FLOW (m^3/s)**	**DO (mg/L**	**BODU (mg/L)**	**FLOW (m^3/s)**	**DO (mg/L)**	**BODU (mg/L)**
HEADWATER AND TRIBUTARY						
Headwater		12.23	2.88		12.93	3.84
Bear R.		12.79	12.8		12.28	33.28
Smoky R.		12.29	1.6		12.93	1.28
Simonette R.		11.6	3.2		11.60	3.2
Little Smoky R.		9.43	3.2		9.43	3.2
EFFLUENT						
Grand Prairie STP	0.225	2.0	30.0	0.225	4.4	18.8
Weyerhaeuser Storm	0.016	7.0	52.5	0.016	6.6	9.6
Weyerhaeuser Main	0.735	8.0	342.4	0.735	1.7	181.0

TABLE 3.1

SUMMARY OF NORTHDAT DATABASE

	DISCHARGE (m^3/day)					BOD LOAD (kg/day)				
	MIN	MAX	MEAN	MEDIAN	N	MIN	MAX	MEAN	MEDIAN	N
MEAN DAILY STATISTICS										
Weldwood	9600	133000	105970	107820	757	53	8100	2479	2291	712
ANC	534	24374	18188	15627	585	3	2148	161	100	570
Millar Western	1523	18860	12912	13141	785	93	5864	1045	936	781
Slave Lake Pulp	115	5862	3833	4029	452	2	9380	870	512	439
7- DAY RUNNING MEAN DAILY STATISTICS										
Weldwood	27650	127060	105750	107000	755	492	7472	2484	2331	755
ANC	8571	21468	15186	15185	580	27	1510	161	103	567
Millar Western	8795	15424	12901	13024	784	219	2959	1041	1358	784
Slave Lake Pulp	1410	5382	3848	3929	447	33	5778	874	668	445

TABLE 3.2

SUMMARY OF THE PROBABILISTIC MODELLING RESULTS

RIVER FLOW SCENARIO	PROBABILITY OF MODEL PREDICTION ≤ 5mg/L			PROBABILITY OF RIVER FLOW ≤ SCENARIO
	SMITH	GRAND RAPIDS		
Athabasca 7Q10	0.0136	0.0344	Hinton	0.063
			Whitecourt	0.041
			Athabasca	0.006
			Ft. McMurray	0.010
Measured 1989	0.0170	0.0034	Hinton	0.141
			Whitecourt	0.041
			Athabasca	0.070
			Ft. McMurray	0.036
Measured 1990	0.0	0.0	Hinton	0.187
			Whitecourt	0.114
			Athabasca	0.247
			Ft. McMurray	0.083
Measured 1992	0.0	0.0	Hinton	0.386
			Whitecourt	0.254
			Athabasca	0.174
			Ft. McMurray	0.262

TABLE 3.3

RANKED AVERAGES OF ABSOLUTE VALUE OF PERCENT CHANGE IN DISSOLVED OXYGEN CONCENTRATIONS FROM 20% INCREASE AND 20% DECREASE IN PARAMETERS

SITE	PARAMETER	PERCENT CHANGE
U/S BERLAND	HEADWATER D.O. LOAD	15.8
	MILL BOD AND SOD	2.7
	WELDWOOD BOD AND SOD	2.7
	VELOCITY	2.4
	HEADWATER/TRIBUTARY FLOWS	2.2
	SOD RATE*	2.1
	ICE COVER REAERATION RATE*	1.7
	TRIBUTARY D.O. LOAD	1.6
	OPENWATER REAERATION RATE	0.8
	HEADWATER BOD LOAD	0.7
	BACKGROUND BOD DECAY RATE	0.7
	MILL BOD CONCENTRATIONS	0.5
	EFFLUENT BOD DECAY RATE	0.5
	MILL D.O. CONCENTRATIONS	0.3
	SETTLING RATE	0.1
	TRIBUTARY BOD	0.0
	OTHER EFFLUENT BOD CONCENTRATIONS	0.0
	OTHER EFFLUENT D.O.	0.0
	MILLAR WESTERN BOD AND SOD	0.0
U/S WHITECOURT	HEADWATER D.O. LOAD	11.9
	TRIBUTARY D.O. LOAD	6.1
	ICE COVER REAERATION RATE*	2.9
	MILL BOD AND SOD	2.5
	VELOCITY	2.4
	WELDWOOD BOD AND SOD	2.3
	SOD RATE*	2.2
	HEADWATER/TRIBUTARY FLOWS	2.0
	BACKGROUND BOD DECAY RATE	1.0
	HEADWATER BOD LOAD	0.9
	OPENWATER REAERATION RATE	0.9
	MILL BOD CONCENTRATIONS	0.7
	EFFLUENT BOD DECAY RATE	0.6
	MILL D.O. CONCENTRATIONS	0.3
	SETTLING RATE	0.2
	MILLAR WESTERN BOD AND SOD	0.2
	TRIBUTARY BOD	0.1
	OTHER EFFLUENT BOD CONCENTRATIONS	0.0
	OTHER EFFLUENT D.O.	0.0

* rates were increased from 0.001 1/day to 0.02 1/day compared with 20% for other input variables

TABLE 3.3 CONTINUED

SITE	PARAMETER	PERCENT CHANGE
U/S SMITH	SOD RATE*	19.3
	ICE COVER REAERATION RATE*	18.0
	HEADWATER D.O. LOAD	17.2
	MILL BOD AND SOD	10.7
	VELOCITY	10.4
	TRIBUTARY D.O. LOAD	9.6
	HEADWATER/TRIBUTARY FLOWS	8.3
	MILLAR WESTERN BOD AND SOD	6.9
	WELDWOOD BOD AND SOD	3.8
	BACKGROUND BOD DECAY RATE	3.8
	MILL BOD CONCENTRATIONS	3.3
	HEADWATER BOD LOAD	3.2
	EFFLUENT BOD DECAY RATE	2.9
	SETTLING RATE	2.7
	OPENWATER REAERATION RATE	1.3
	TRIBUTARY BOD	1.1
	MILL D.O. CONCENTRATIONS	0.4
	OTHER EFFLUENT D.O.	0.0
	OTHER EFFLUENT BOD CONCENTRATIONS	0.0
U/S ATHABASCA	HEADWATER D.O. LOAD	18.6
	ICE COVER REAERATION RATE*	13.6
	SOD RATE*	11.0
	TRIBUTARY D.O. LOAD	6.1
	VELOCITY	5.8
	MILL BOD AND SOD	5.7
	HEADWATER/TRIBUTARY FLOWS	4.3
	MILLAR WESTERN BOD AND SOD	3.6
	BACKGROUND BOD DECAY RATE	2.8
	HEADWATER BOD LOAD	2.4
	WELDWOOD BOD AND SOD	1.9
	SETTLING RATE	1.9
	MILL BOD CONCENTRATIONS	1.8
	EFFLUENT BOD DECAY RATE	1.5
	TRIBUTARY BOD	1.0
	OPENWATER REAERATION RATE	0.7
	MILL D.O. CONCENTRATIONS	0.2
	OTHER EFFLUENT D.O.	0.0
	OTHER EFFLUENT BOD CONCENTRATIONS	0.0

* rates were increased from 0.001 1/day to 0.02 1/day compared with 20% for other input variables

TABLE 3.3 CONTINUED

SITE	PARAMETER	PERCENT CHANGE
U/S GRAND RAPIDS	HEADWATER D.O. LOAD	19.6
	ICE COVER REAERATION RATE*	19.4
	SOD RATE*	12.8
	TRIBUTARY D.O. LOAD	6.6
	VELOCITY	6.4
	MILL BOD AND SOD	6.1
	HEADWATER/TRIBUTARY FLOWS	4.5
	MILLAR WESTERN BOD AND SOD	3.9
	BACKGROUND BOD DECAY RATE	3.7
	HEADWATER BOD LOAD	3.3
	SETTLING RATE	2.4
	MILL BOD CONCENTRATIONS	2.1
	WELDWOOD BOD AND SOD	2.0
	EFFLUENT BOD DECAY RATE	1.6
	TRIBUTARY BOD	1.4
	OPENWATER REAERATION RATE	0.7
	MILL D.O. CONCENTRATIONS	0.2
	OTHER EFFLUENT BOD CONCENTRATIONS	0.0
	OTHER EFFLUENT D.O.	0.0

* rates were increased from 0.001 1/day to 0.02 1/day compared with 20% for other input variables

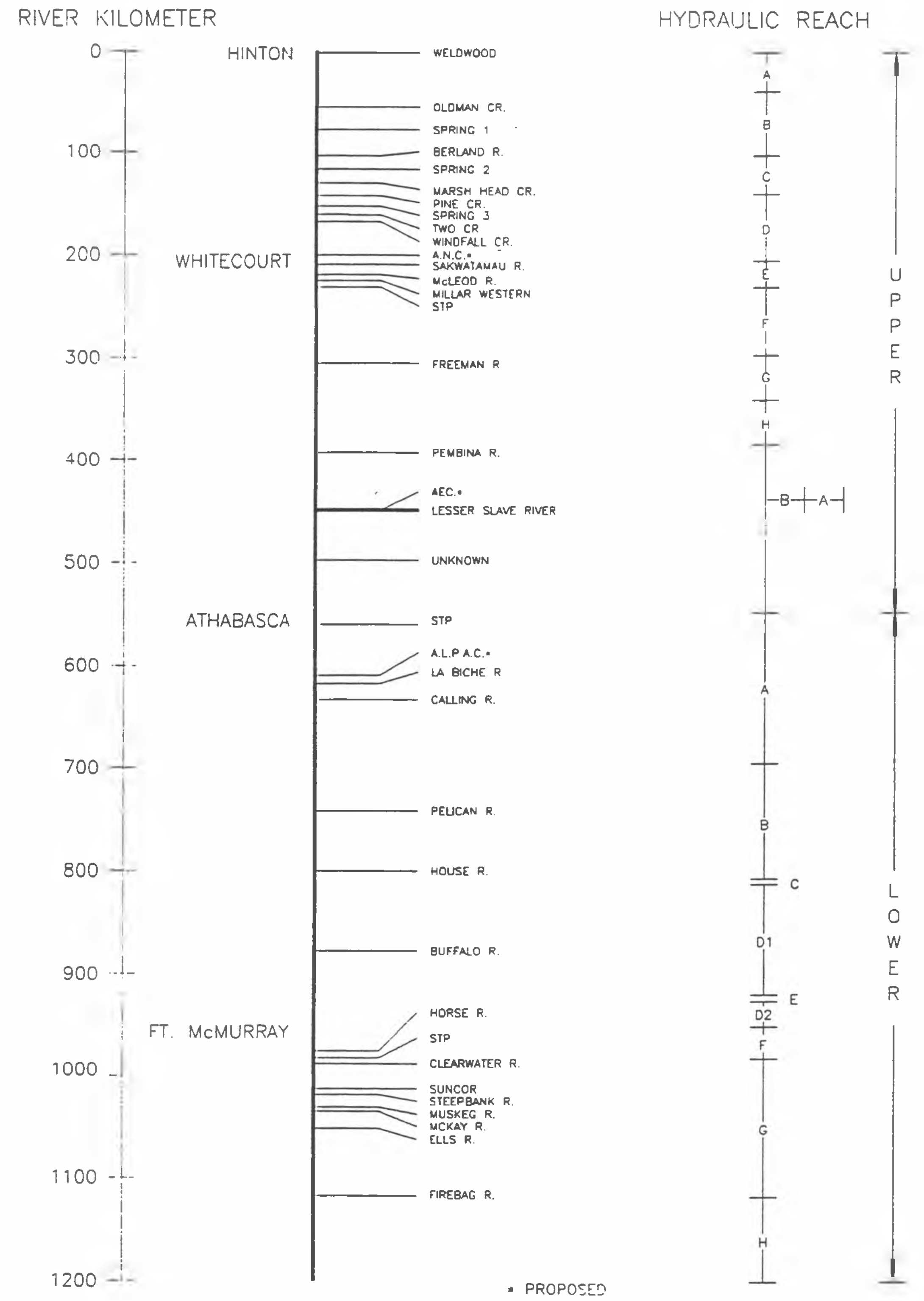


Figure 2.1 April 1993	WATER QUALITY MODELLING SCHEMATIC ATHABASCA RIVER	Environmental Management Associates

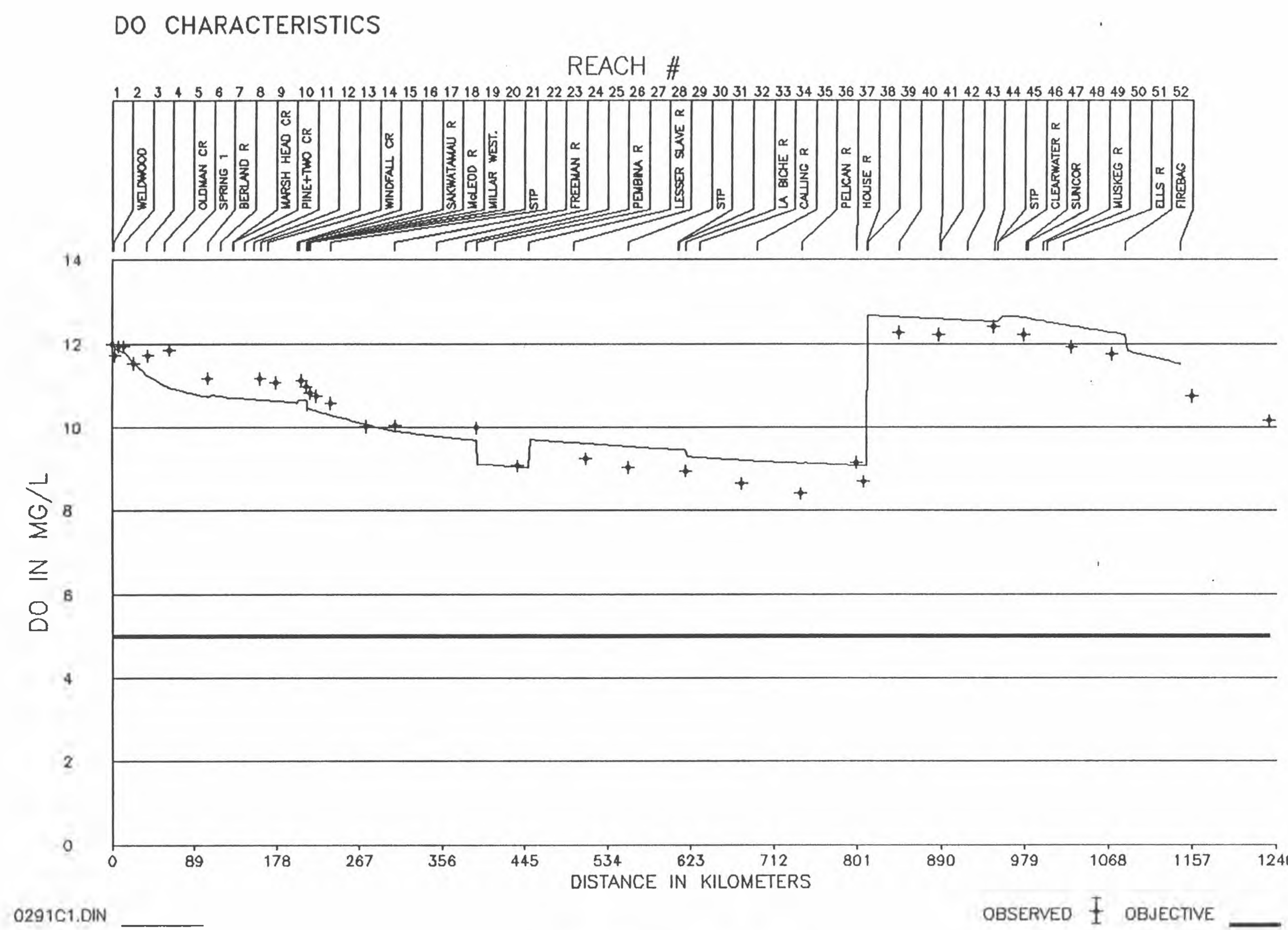


Figure 2.2 September 28, 1993	ATHABASCA RIVER 1991 VERIFICATION	Environmental Management Associates

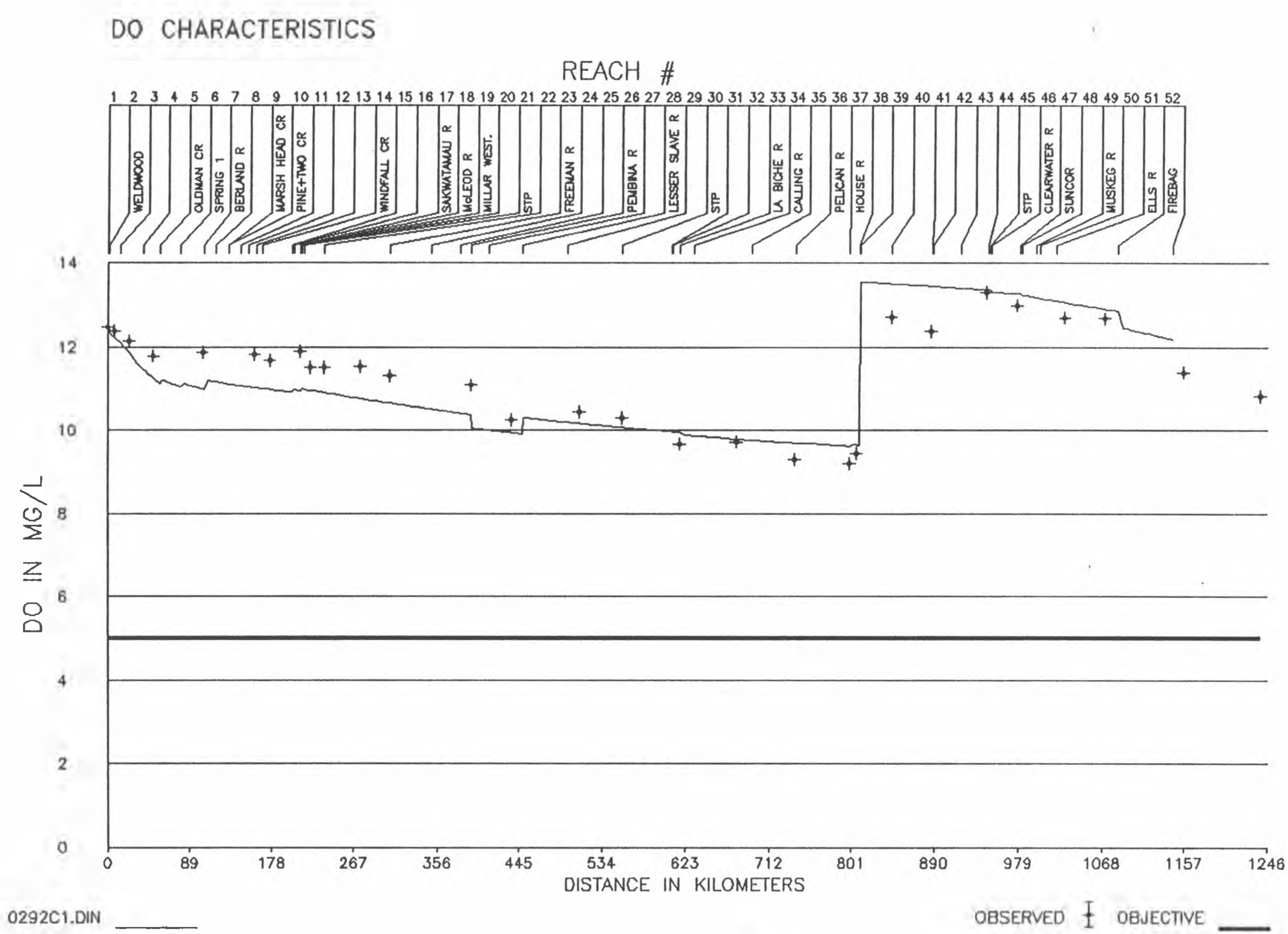
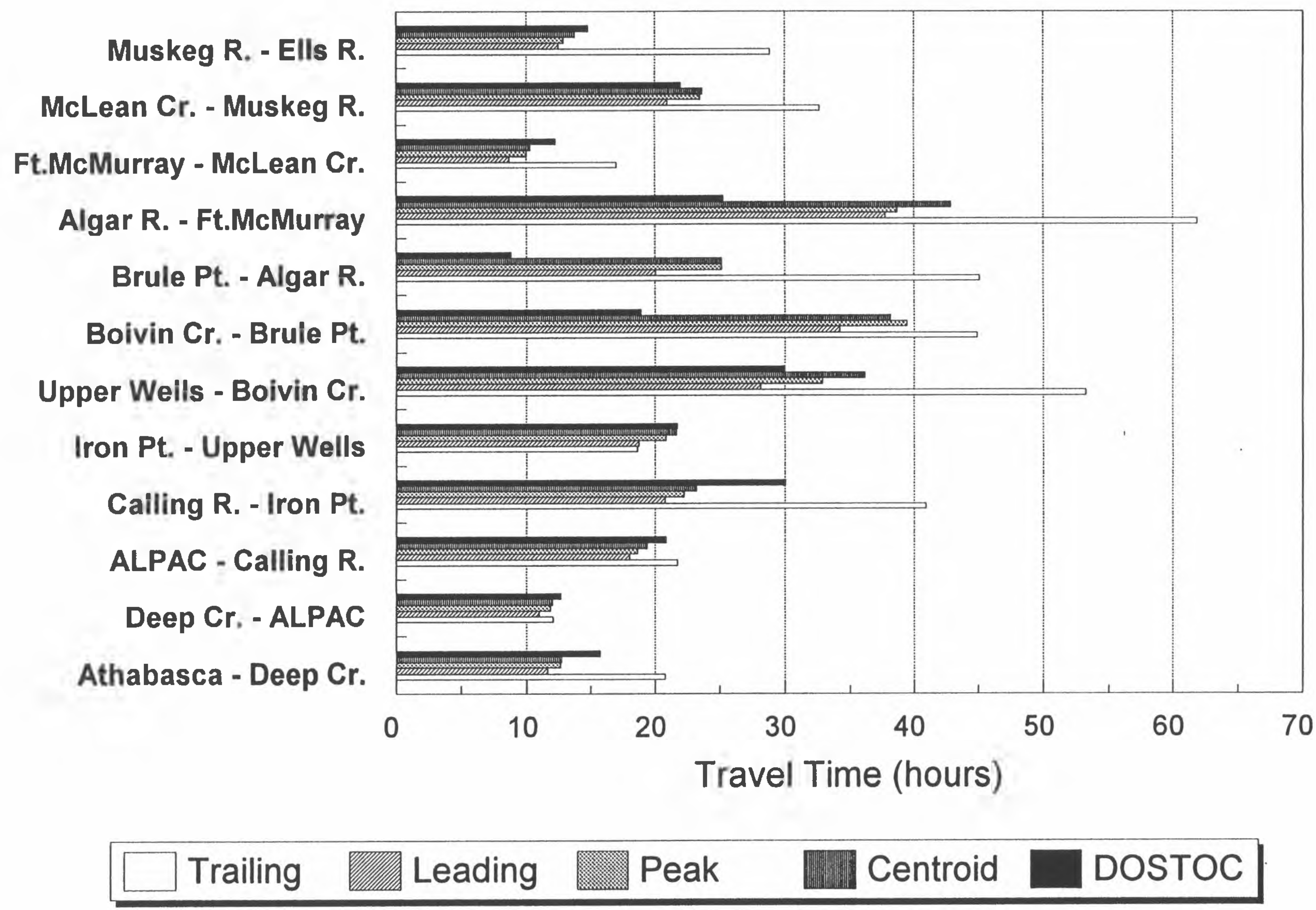


Figure 2.3 September 28, 1993	ATHABASCA RIVER 1992 VERIFICATION	Environmental Management Associates

Figure 2.4 Athabasca River Travel Times

A.E. 1992 Dye Study vs DOSTOC (88-90)



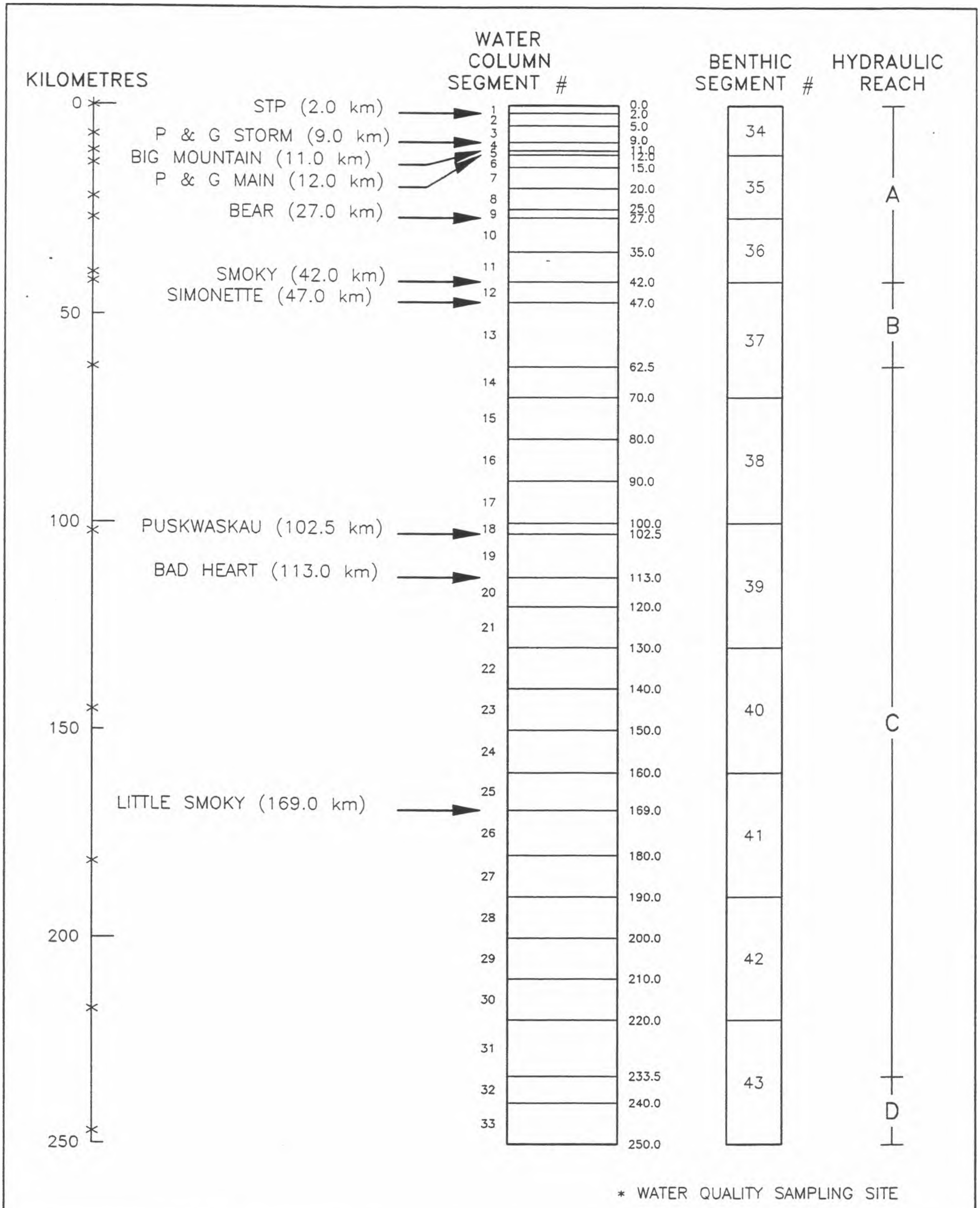


Figure 2.5
May 1993

WAPITI/SMOKY MODEL SCHEMATIC

Environmental Management Associates

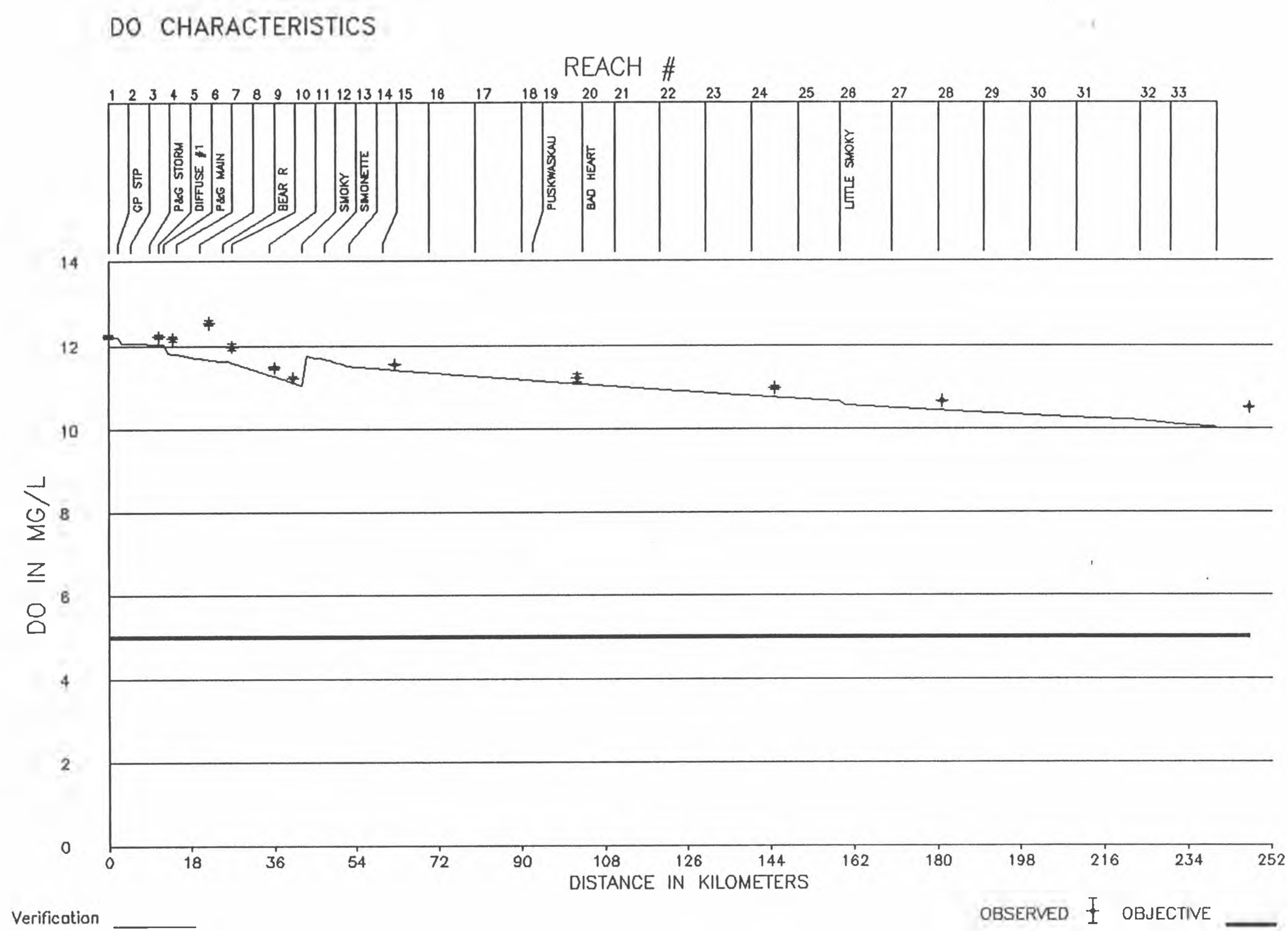


Figure 2.6 September 28, 1993	WAPITI/SMOKY 1991 VERIFICATION	Environmental Management Associates

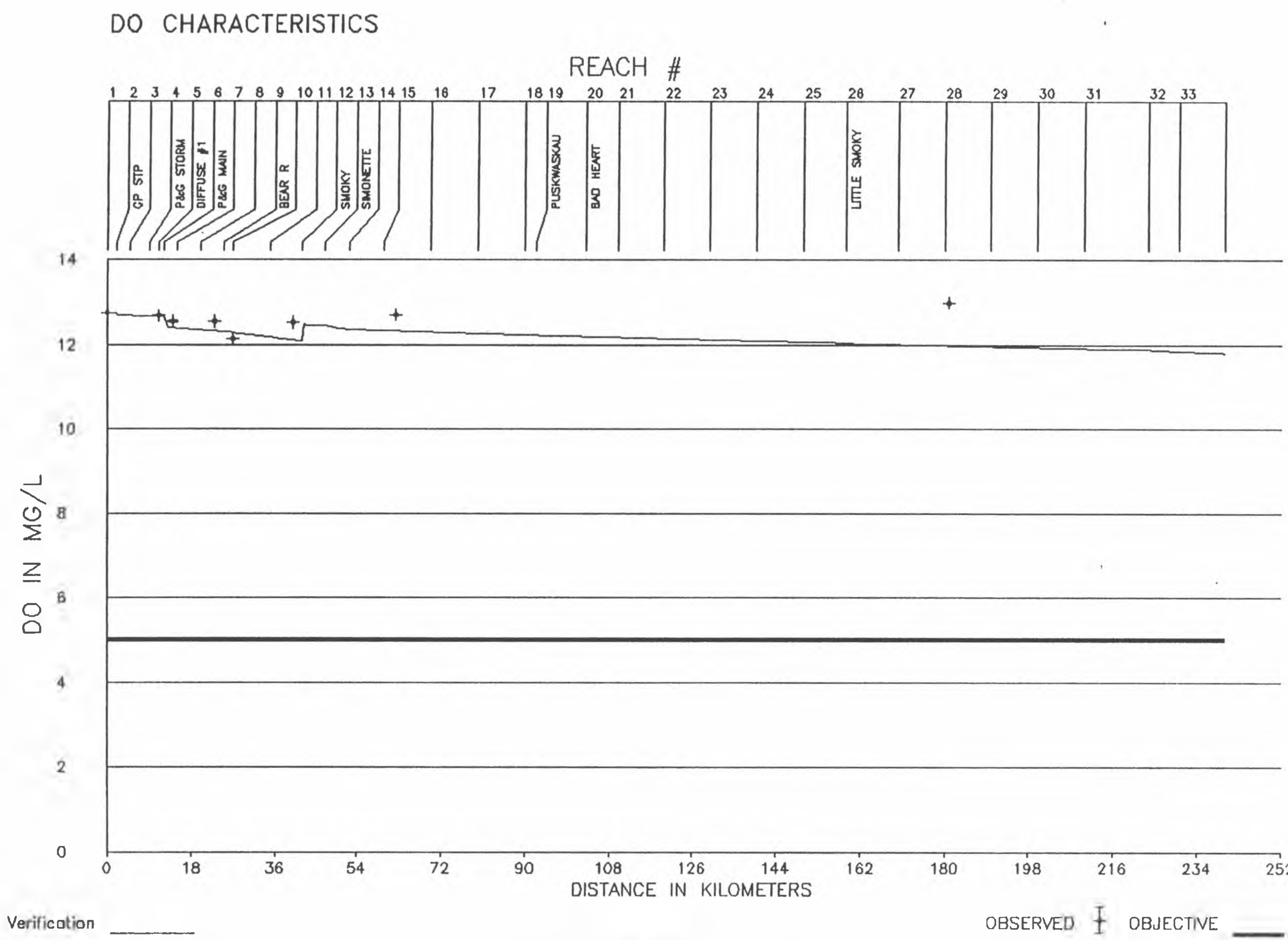
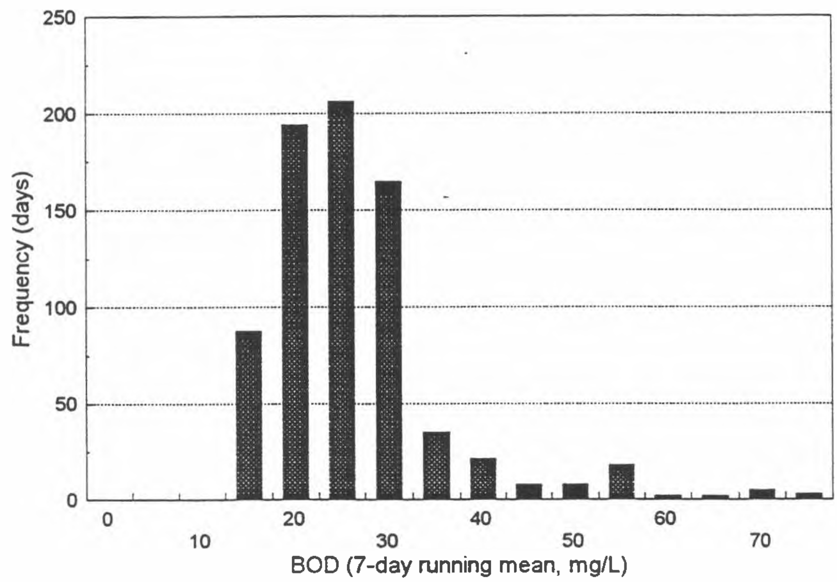


Figure 2.7 September 28, 1993	WAPITI/SMOKY 1992 VERIFICATION	Environmental Management Associates

Figure 3.1 Weldwood Effluent BOD5 and Flow Frequency Histogram

Frequency Distribution of BOD Conc



Frequency Distribution of Discharge

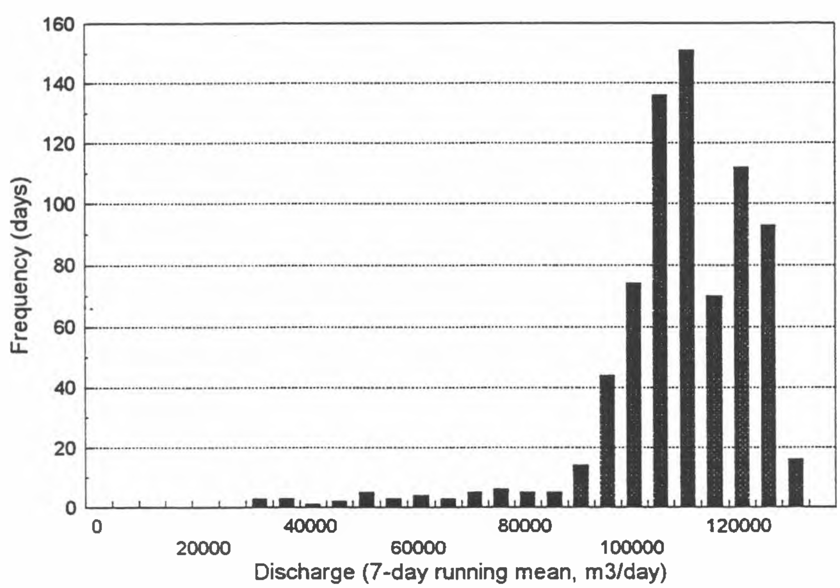
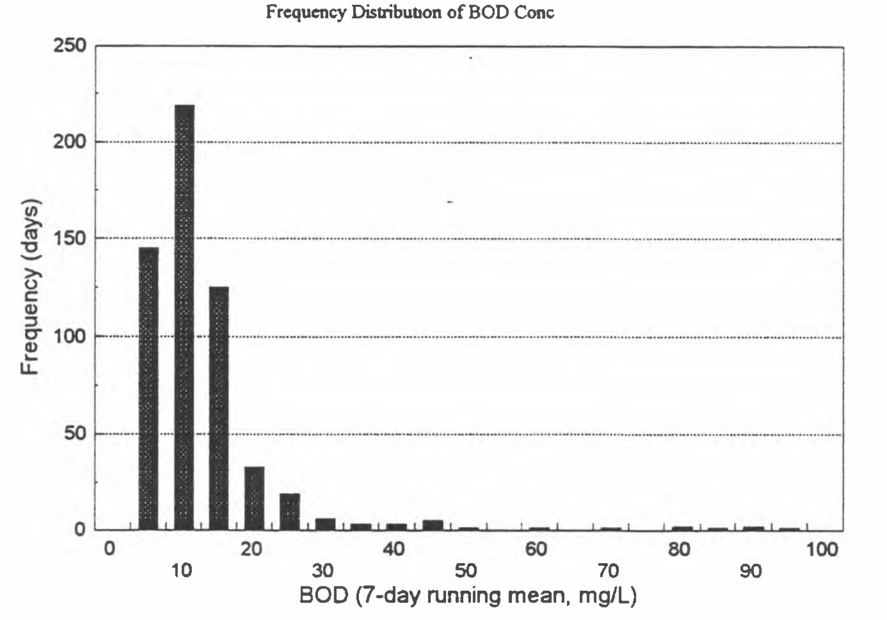


Figure 3.2 Alberta Newsprint Company Effluent BOD5 and Flow Frequency Histogram



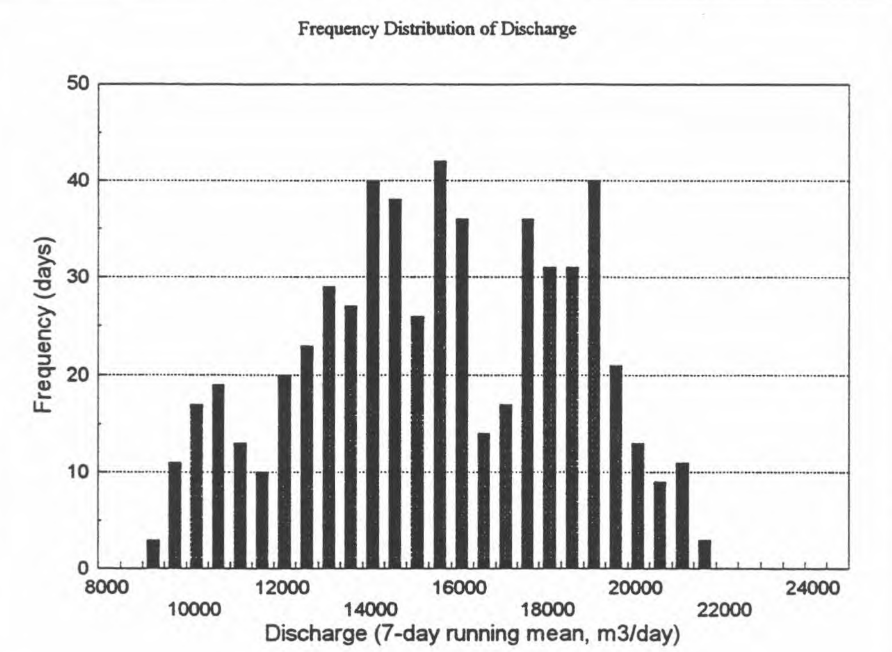
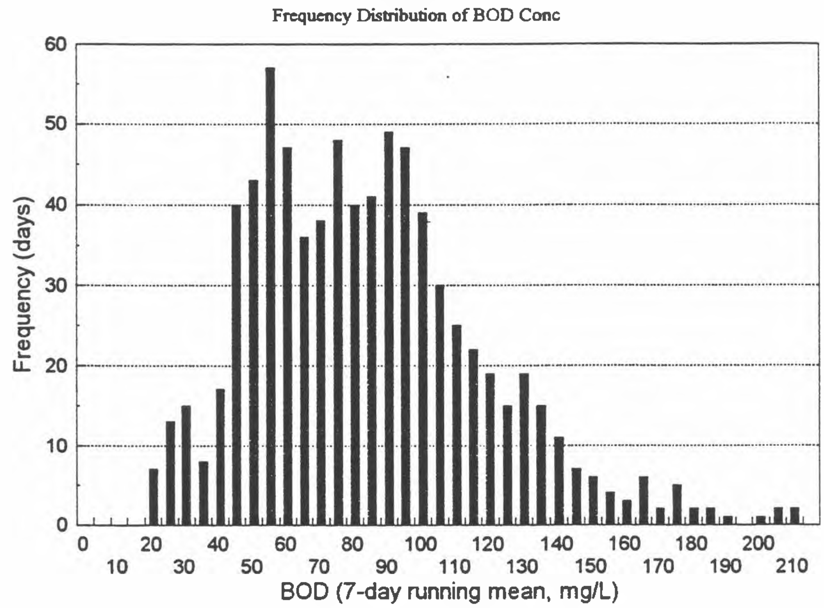


Figure 3.3 Millar Western Effluent BOD5 and Flow Frequency Histogram



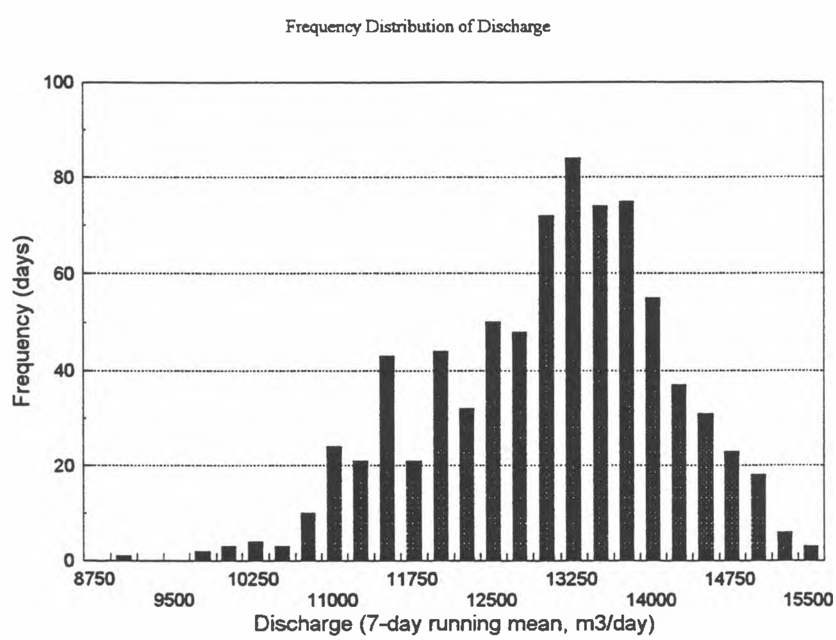
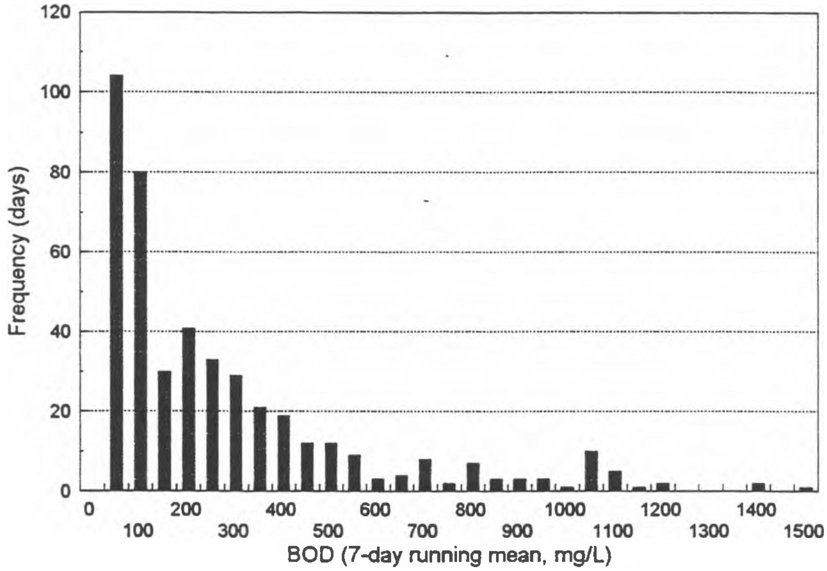


Figure 3.4 Slave Lake Pulp Effluent BOD5 and Flow Frequency Histogram

Frequency Distribution of BOD Conc



Frequency Distribution of Discharge

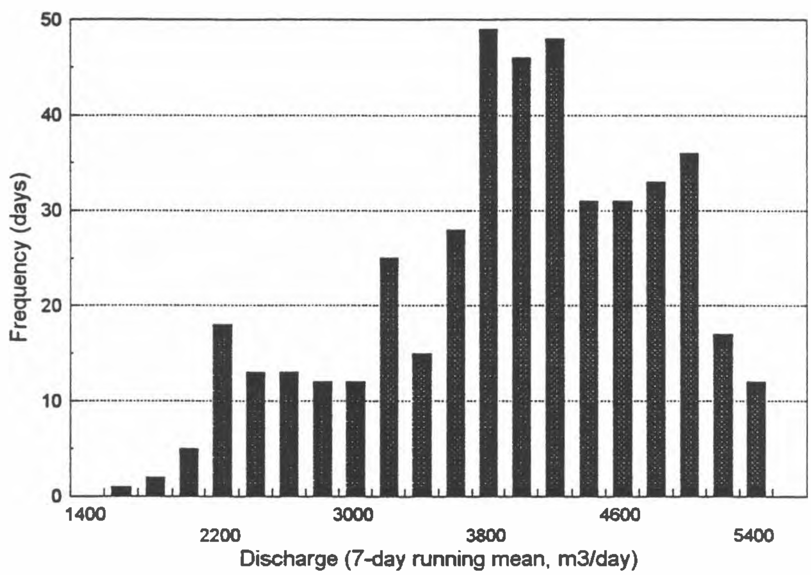
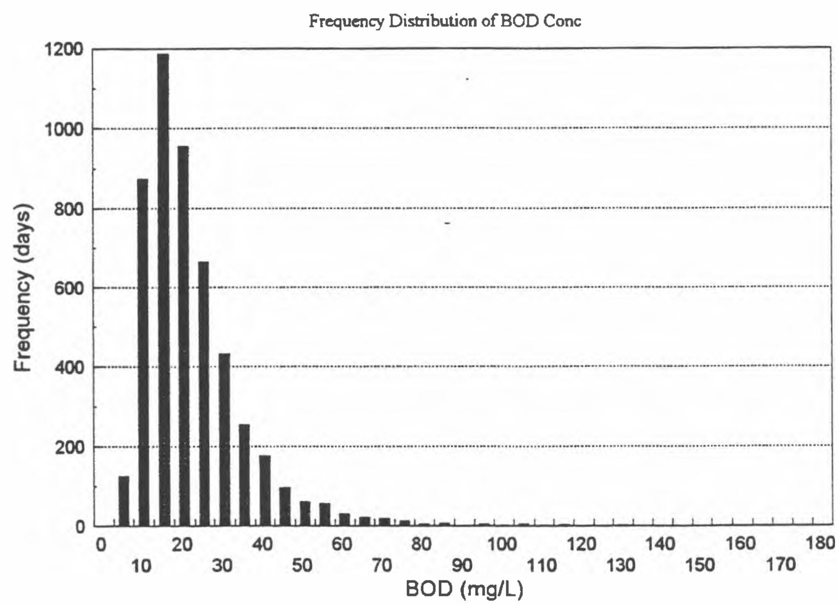
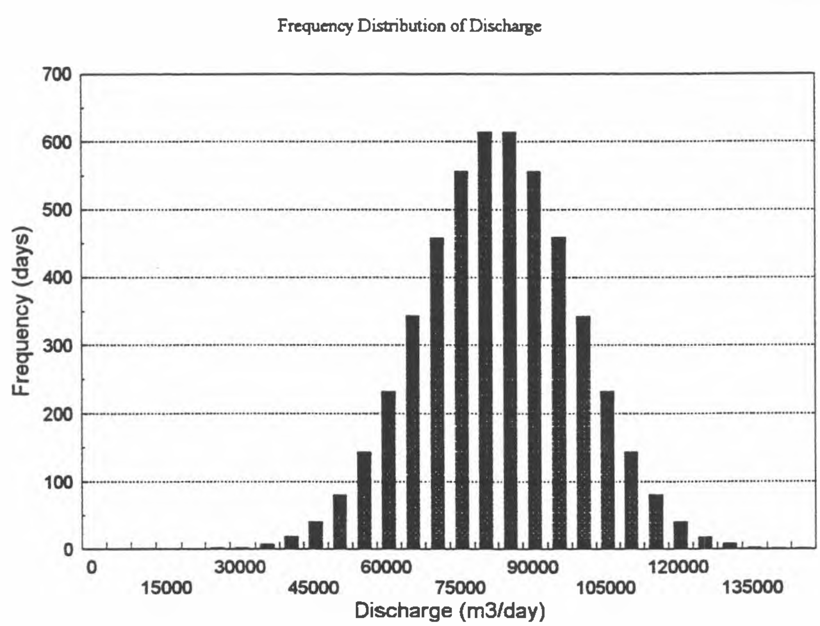


Figure 3.5 Assumed Alberta Pacific Effluent BOD5 and Flow Frequency Histogram





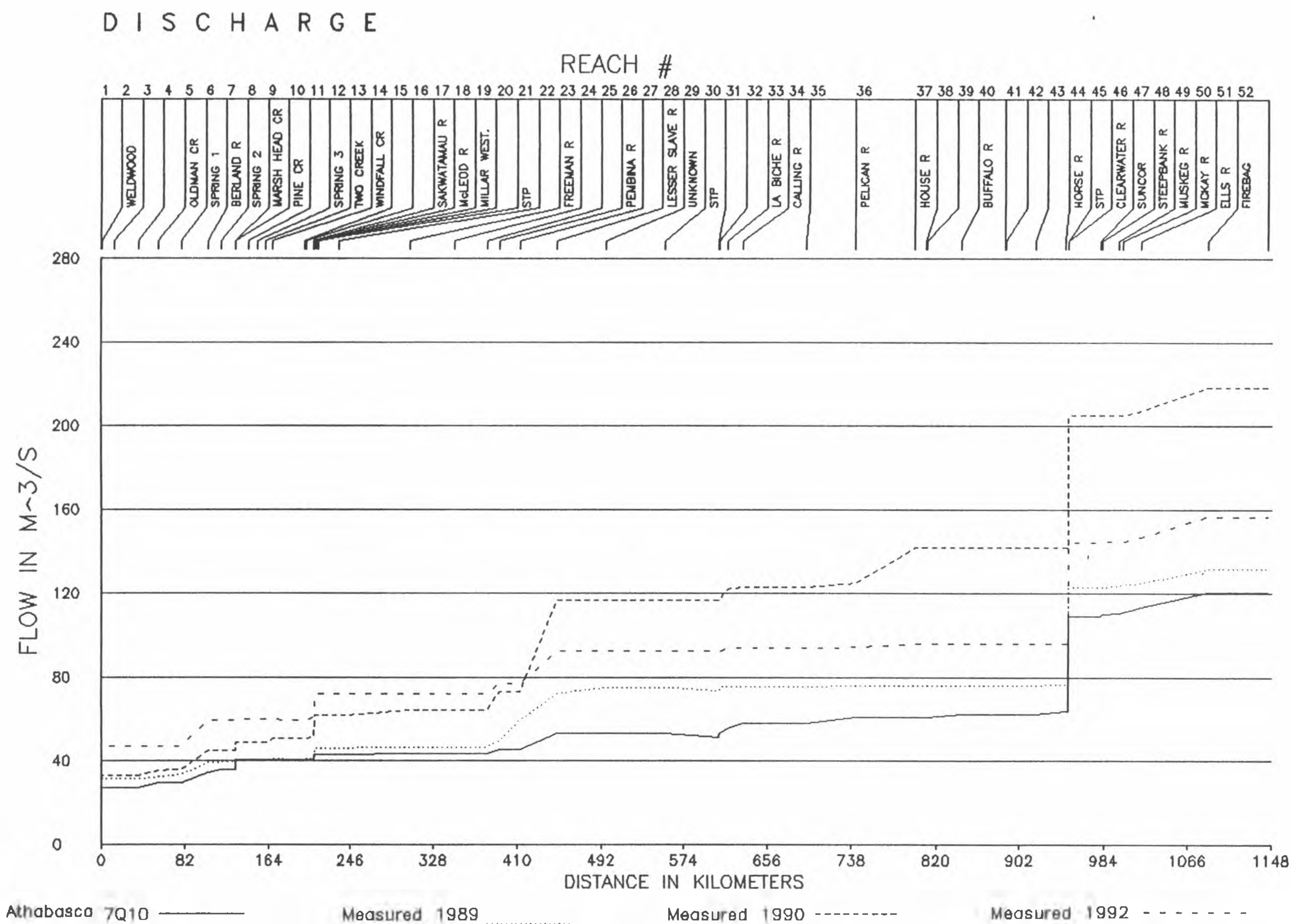


Figure 3.6 April 29, 1993	ATHABASCA RIVER FLOWS USED IN PROBABALISTIC MODELLING	Environmental Management Associates

Figure 3.7 Frequency Distribution of Predicted Dissolved Oxygen

Athabasca 7Q10

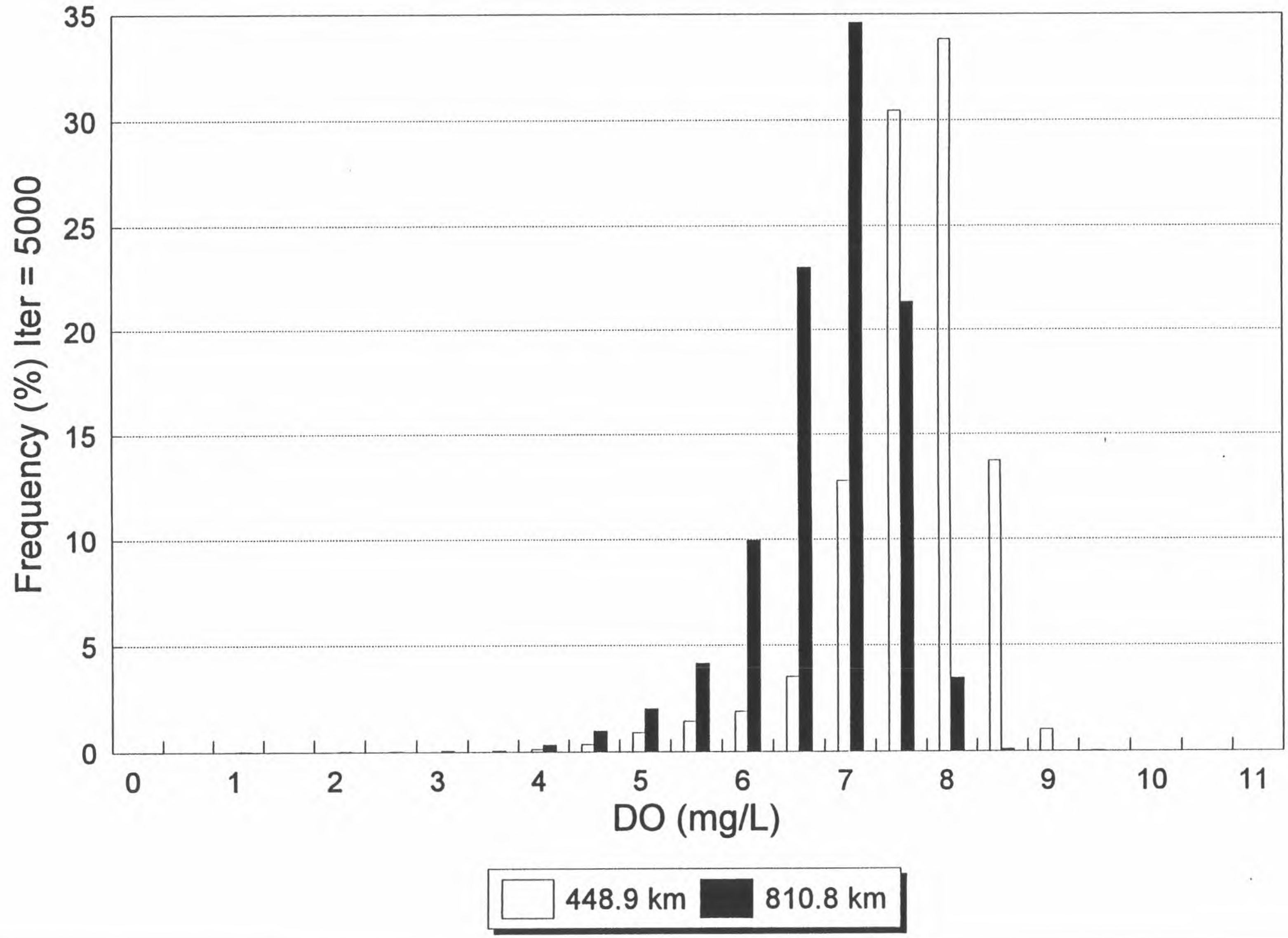


Figure 3.8 Frequency Distribution of Predicted Dissolved

1989 Flows

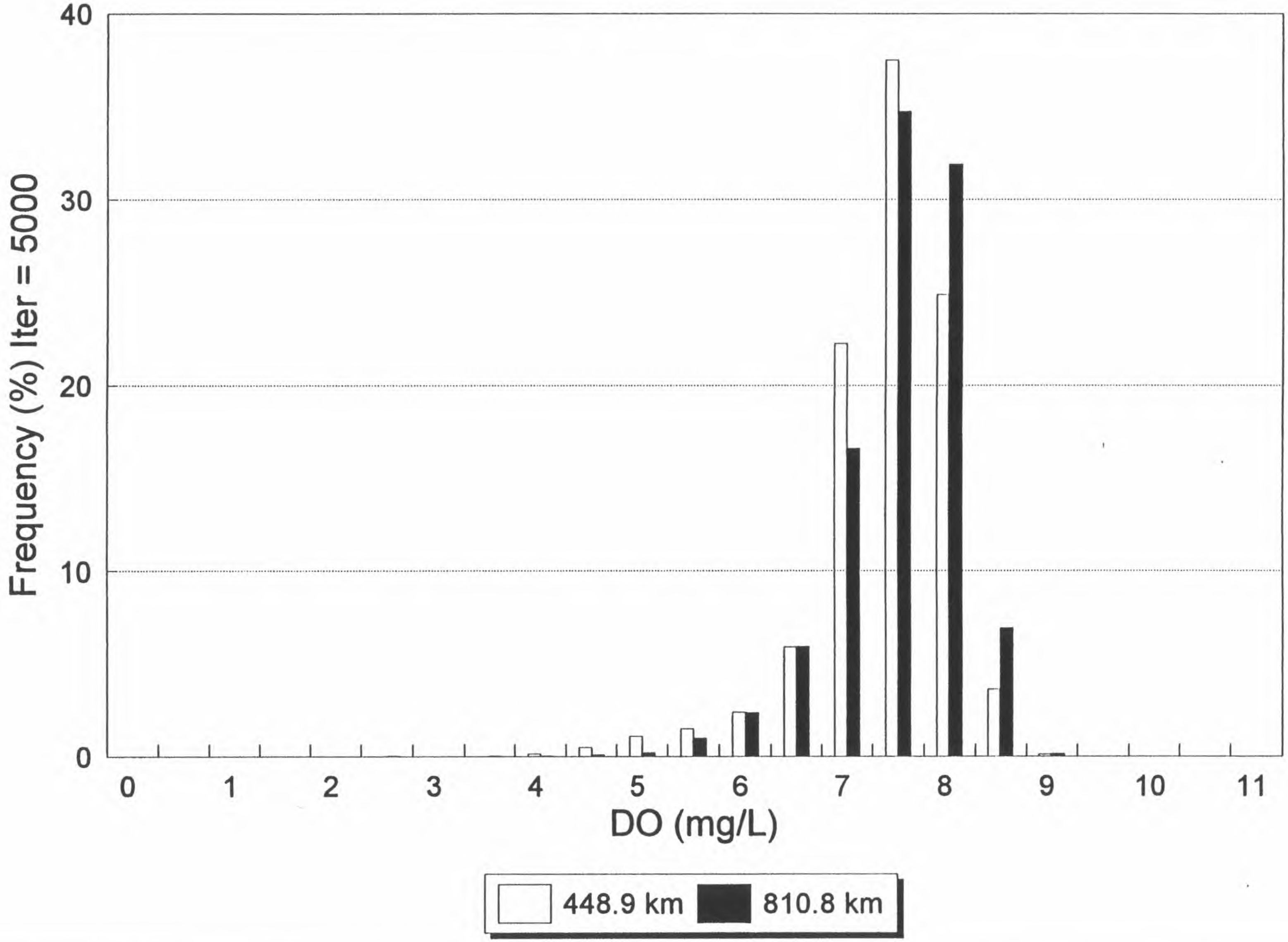


Figure 3.9 Frequency Distribution of Predicted Dissolved Oxygen

1990 Flows

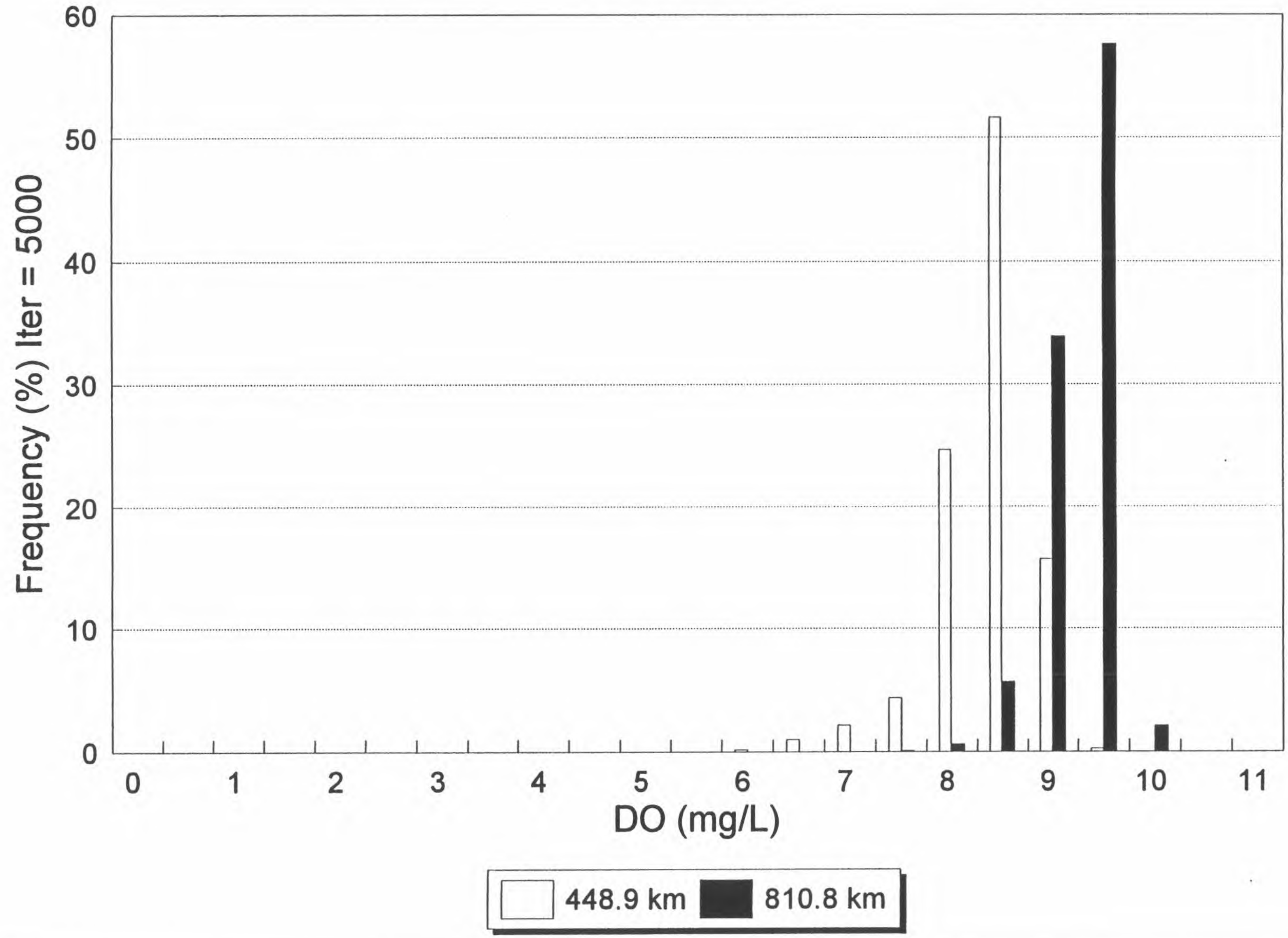
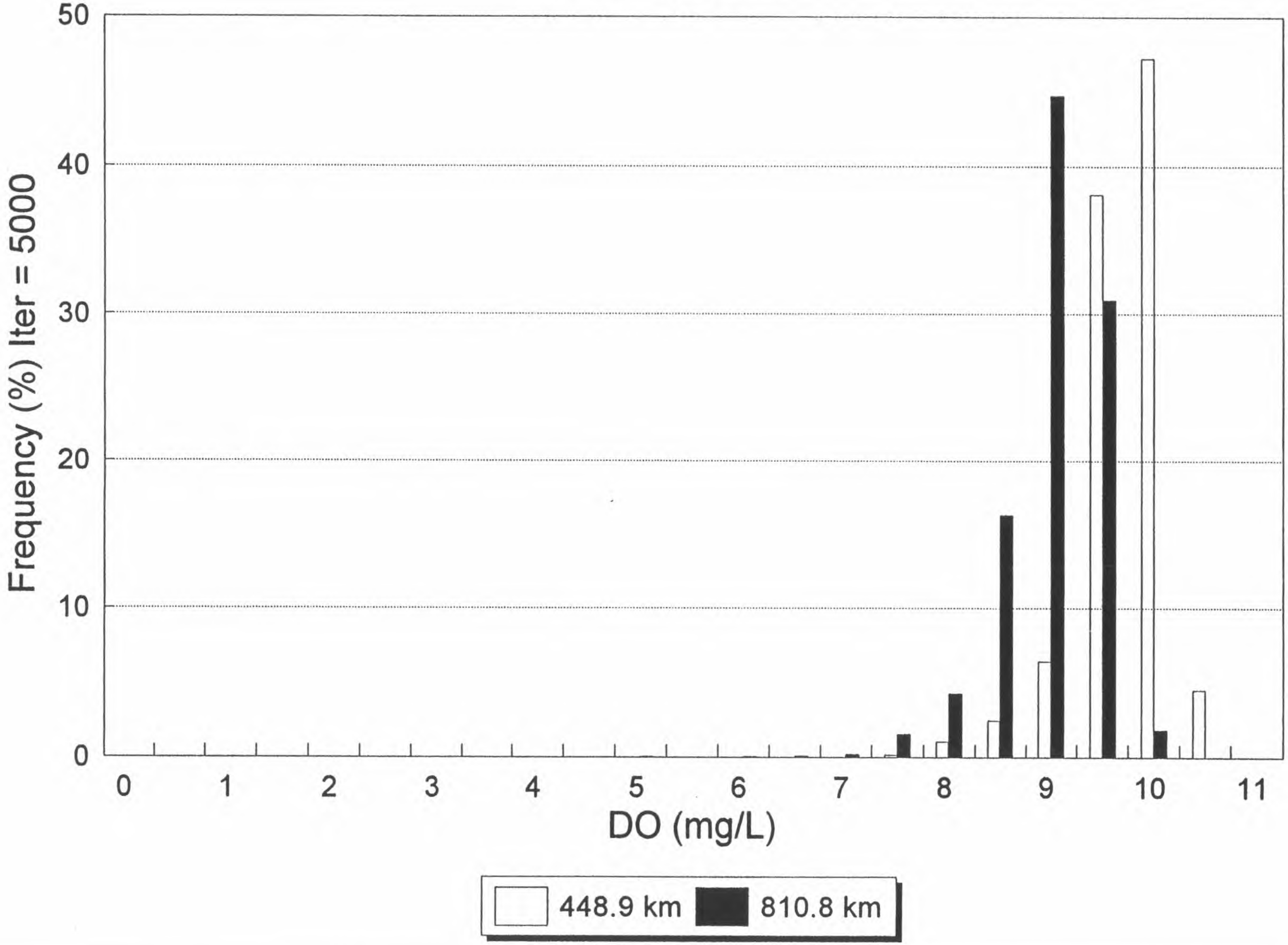


Figure 3.10 Frequency Distribution of Predicted Dissolved Oxygen

1992 Flows



APPENDIX A

BOD ULTIMATE GRAPHS

LIST OF FIGURES FOR APPENDIX A

LIST OF FIGURES FOR APPENDIX A CONCLUDED

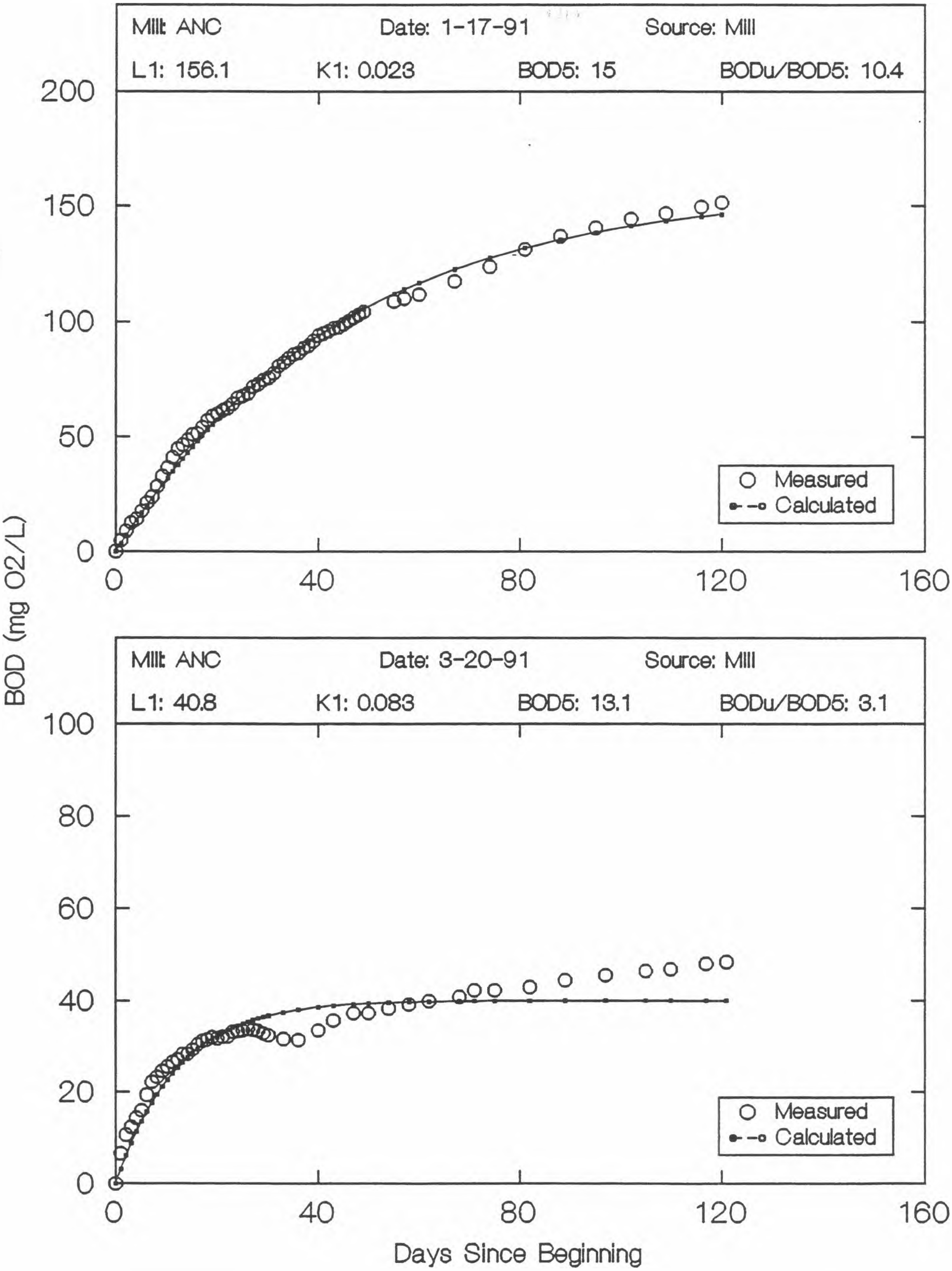


Figure A1-1 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

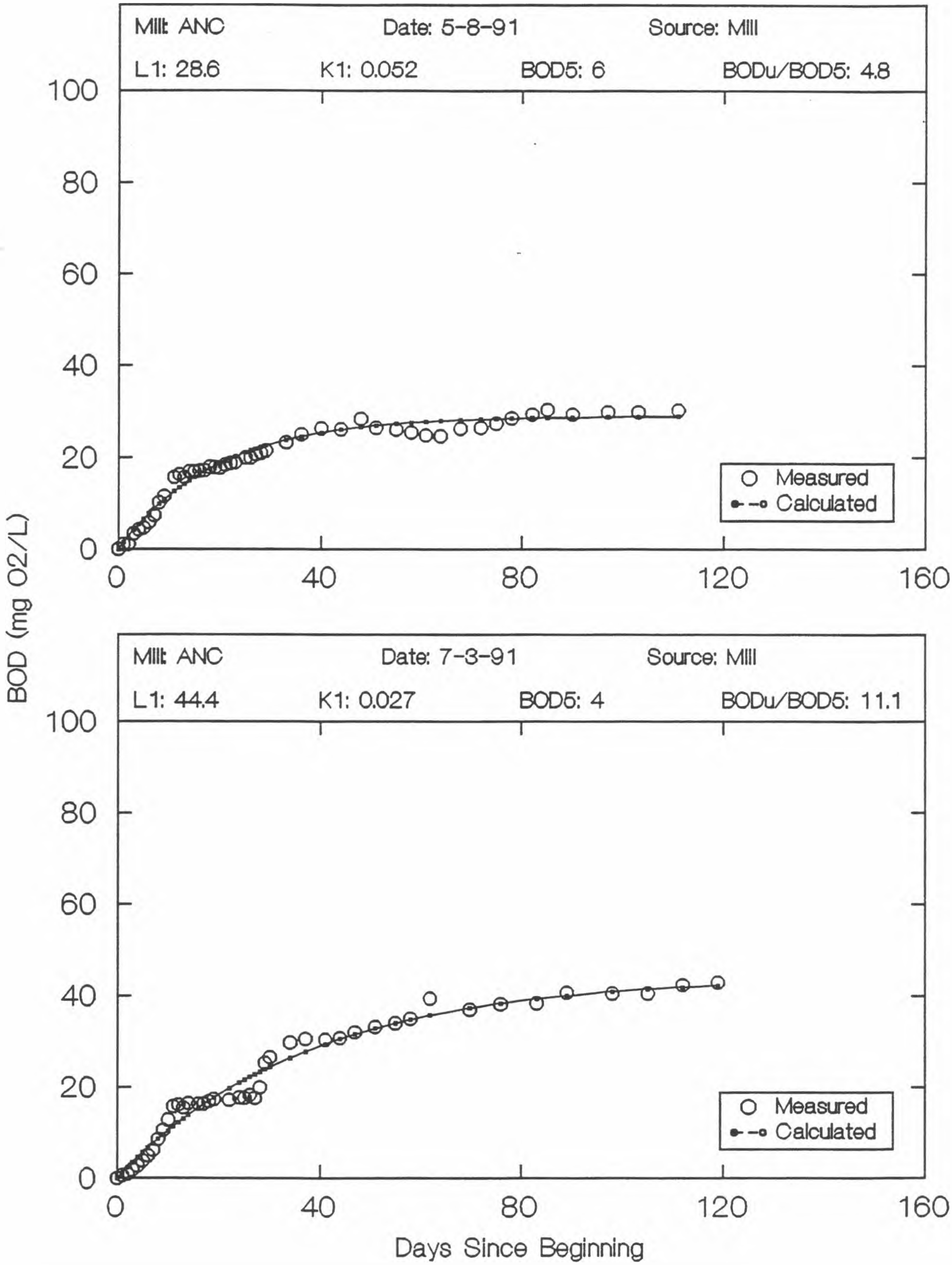


Figure A1-2 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

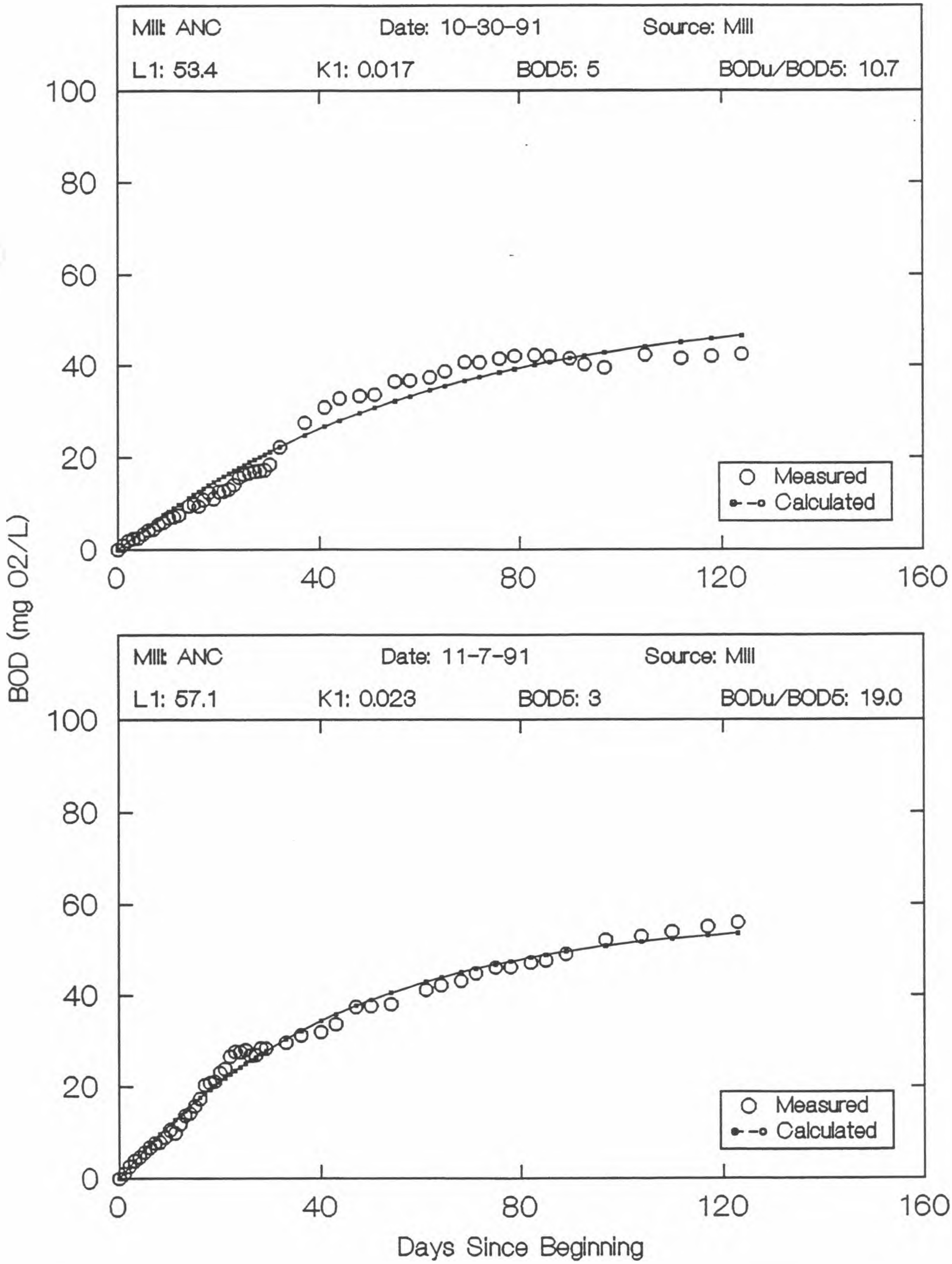


Figure A1-3 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

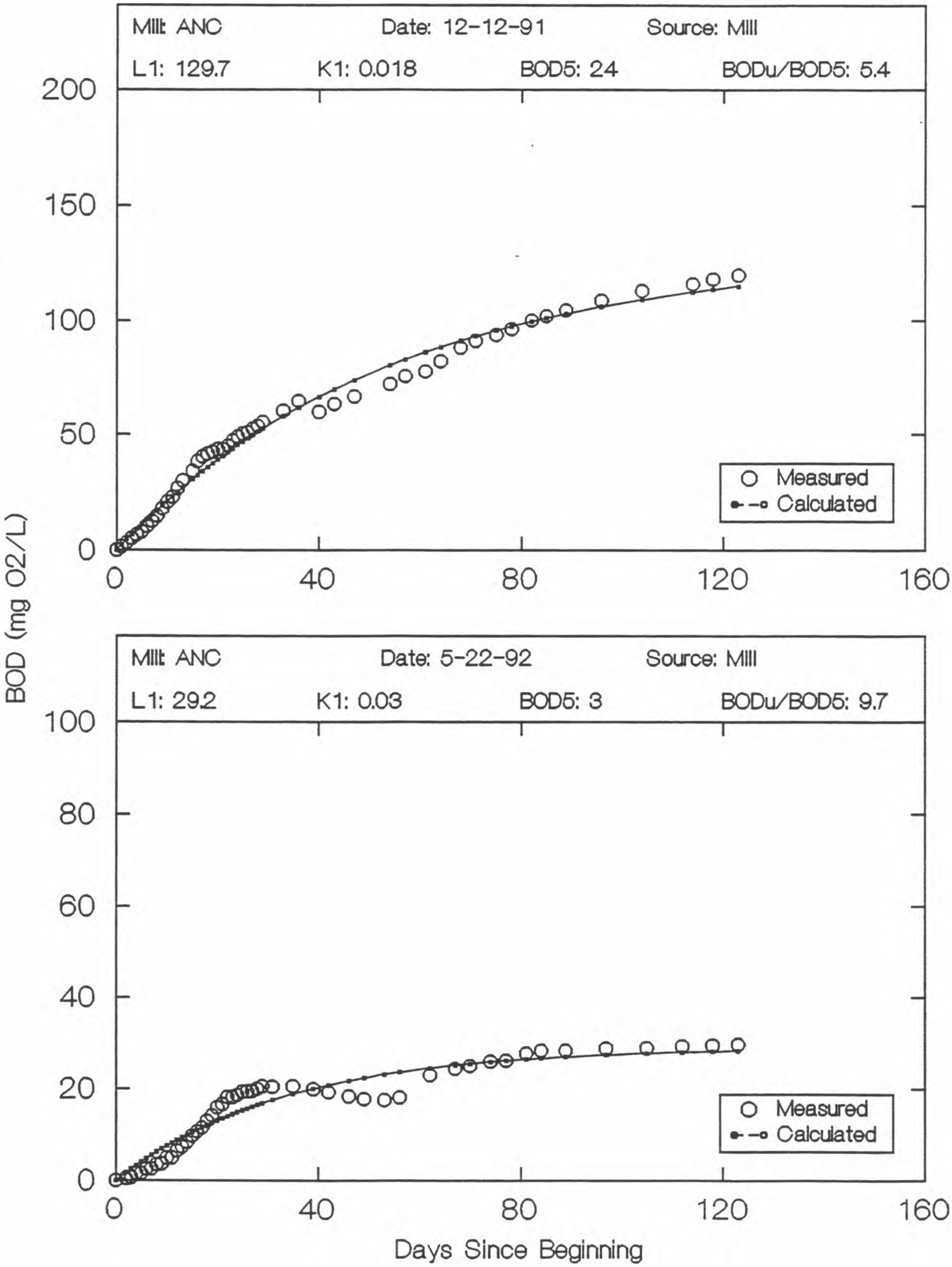


Figure A1-4 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

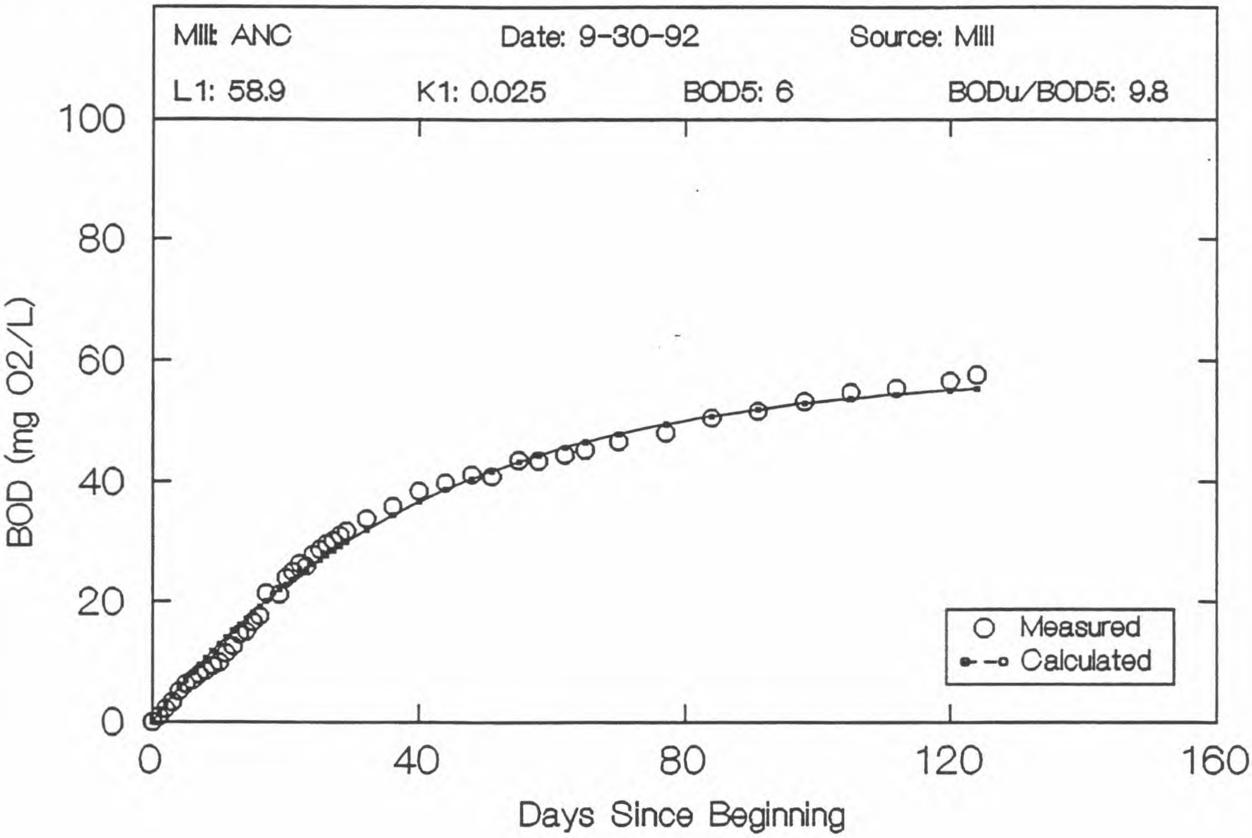


Figure A1-5 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

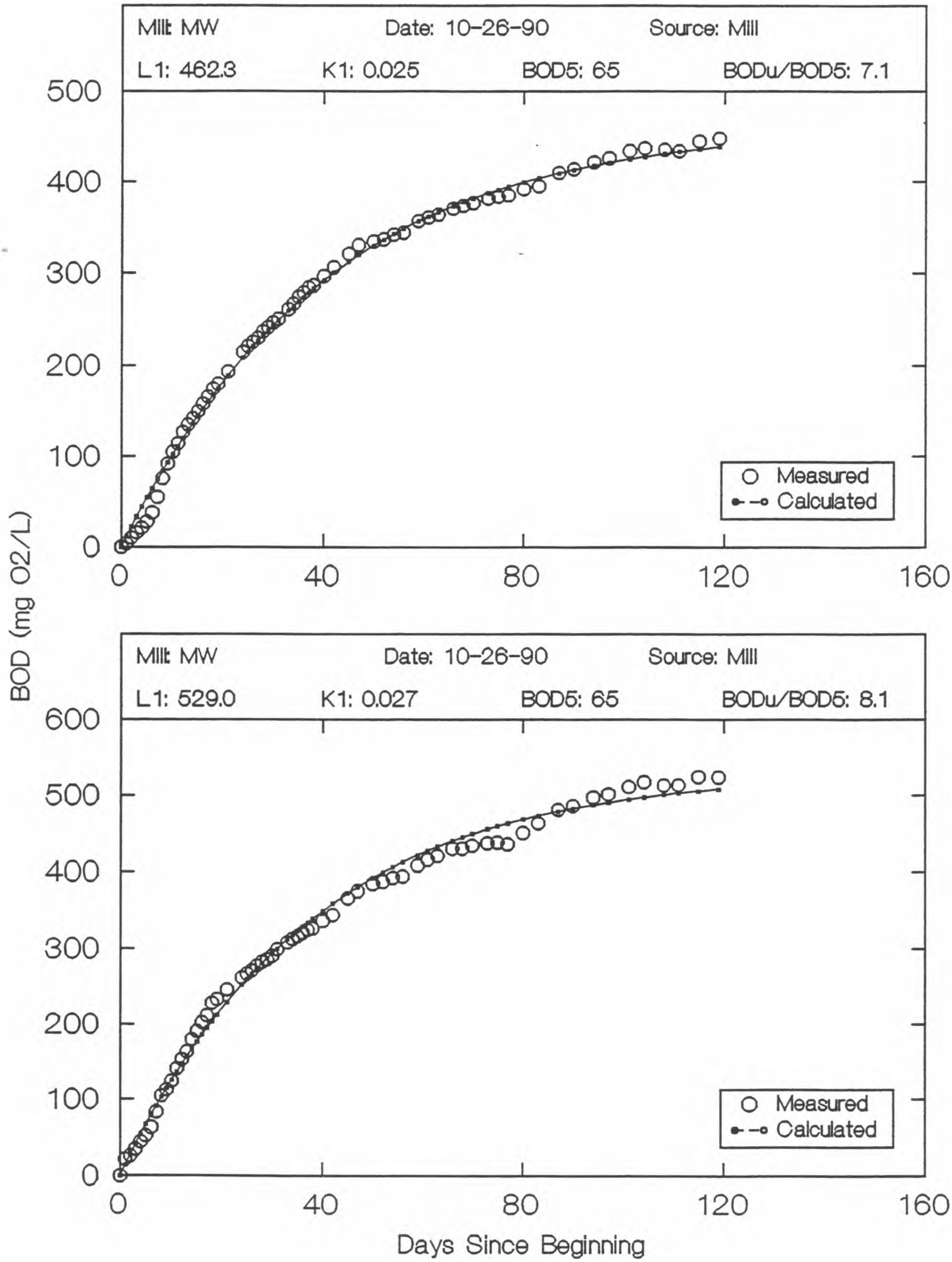


Figure A1-6 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

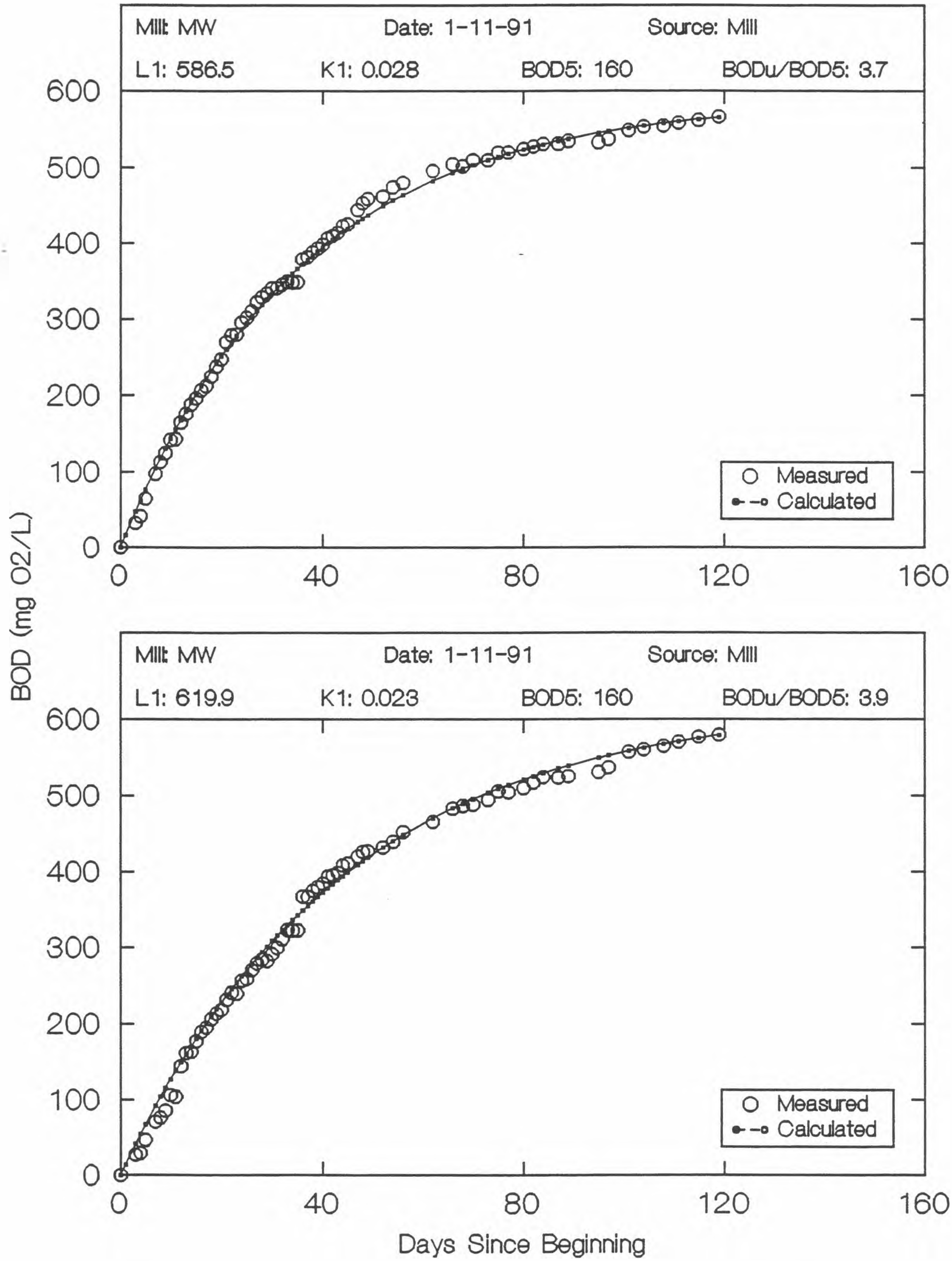


Figure A1-7 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

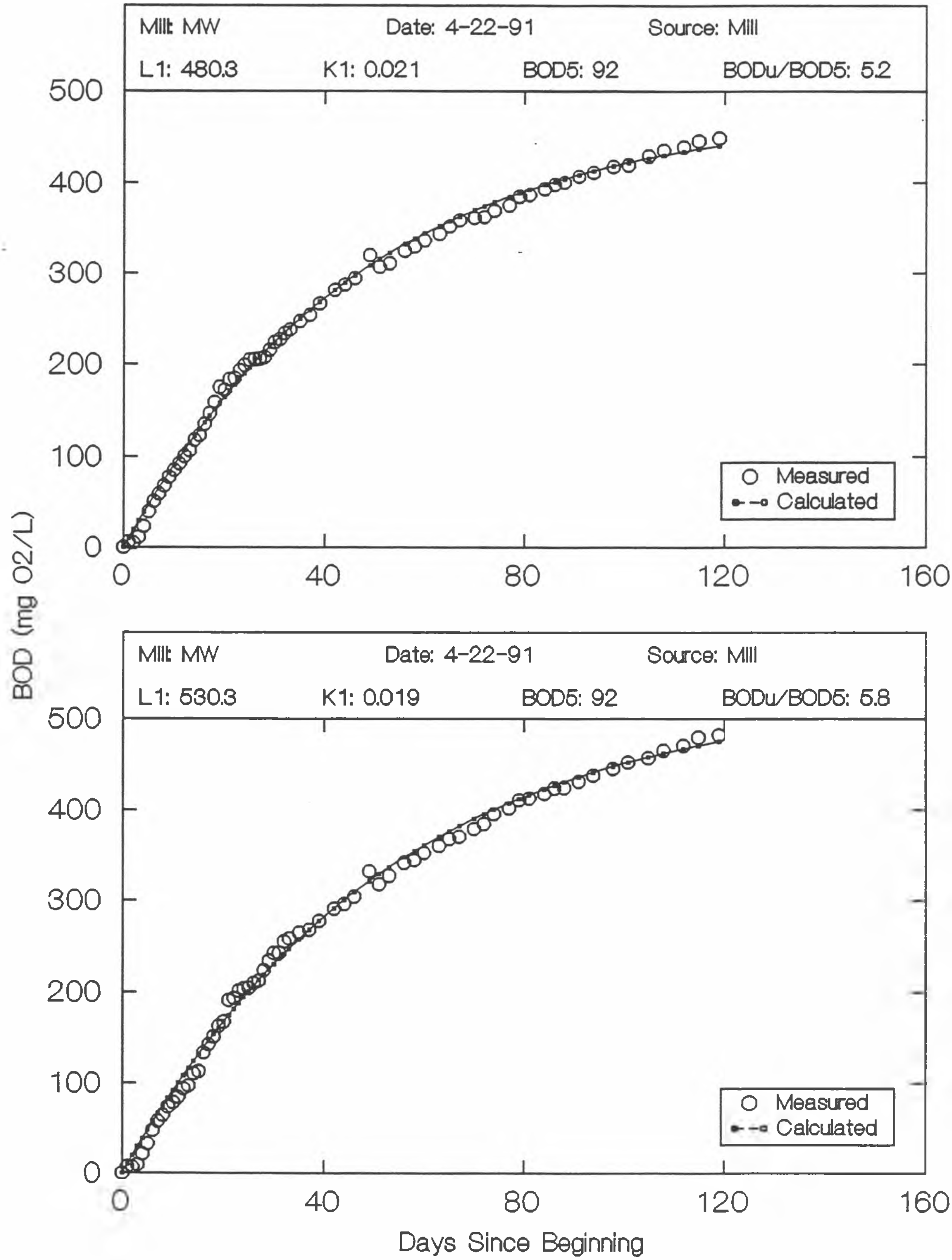


Figure A1-8 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

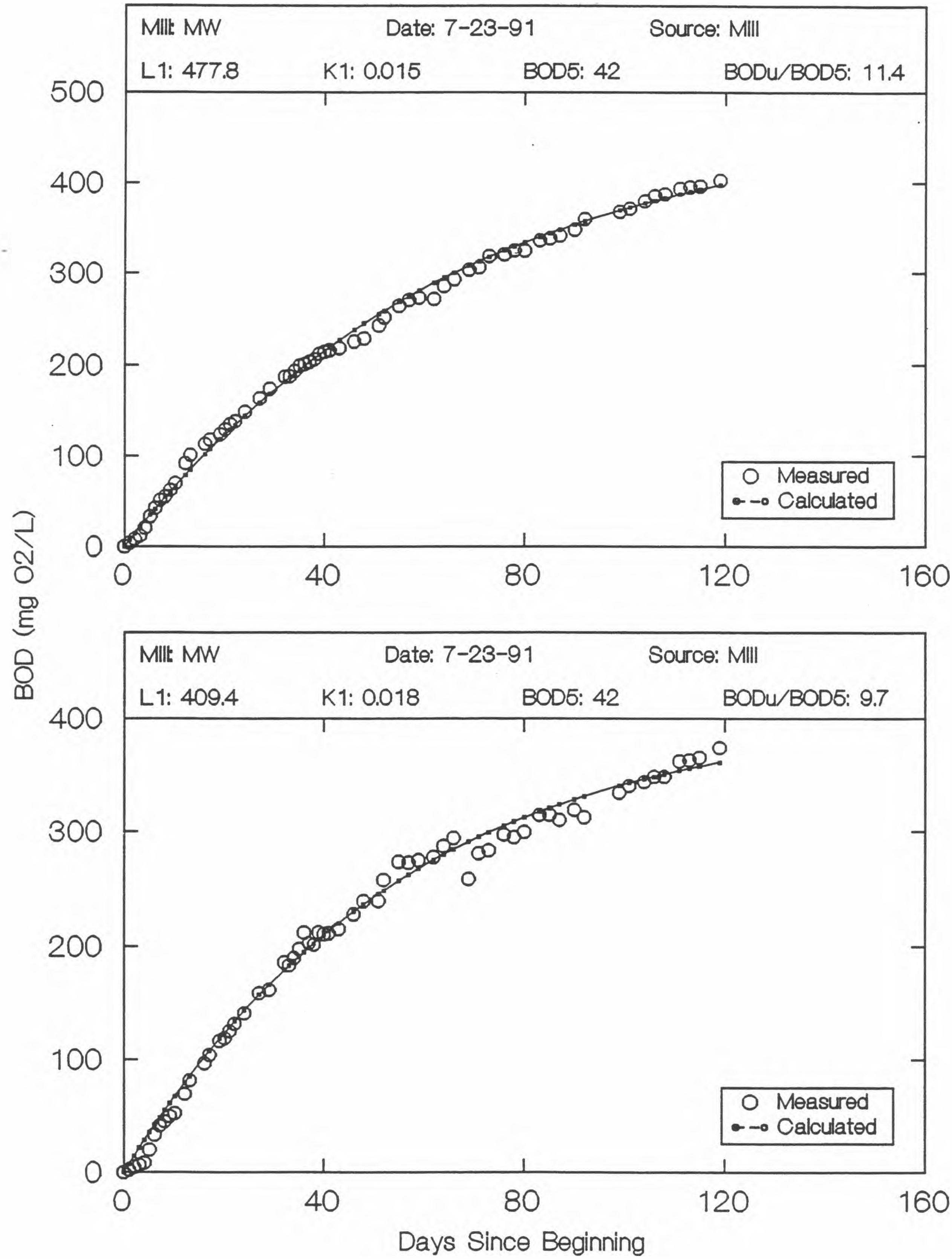


Figure A1-9 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

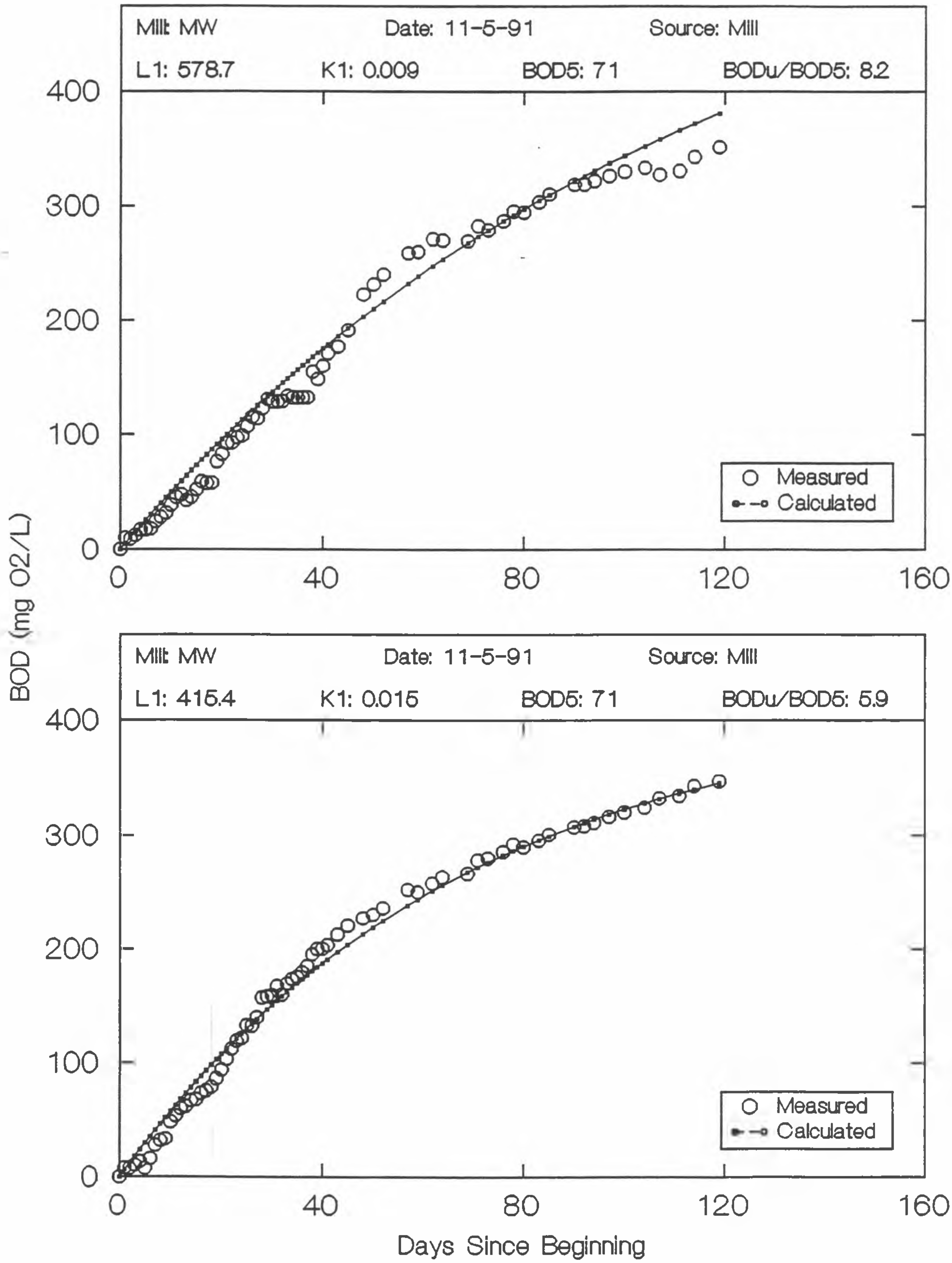


Figure A1-10 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

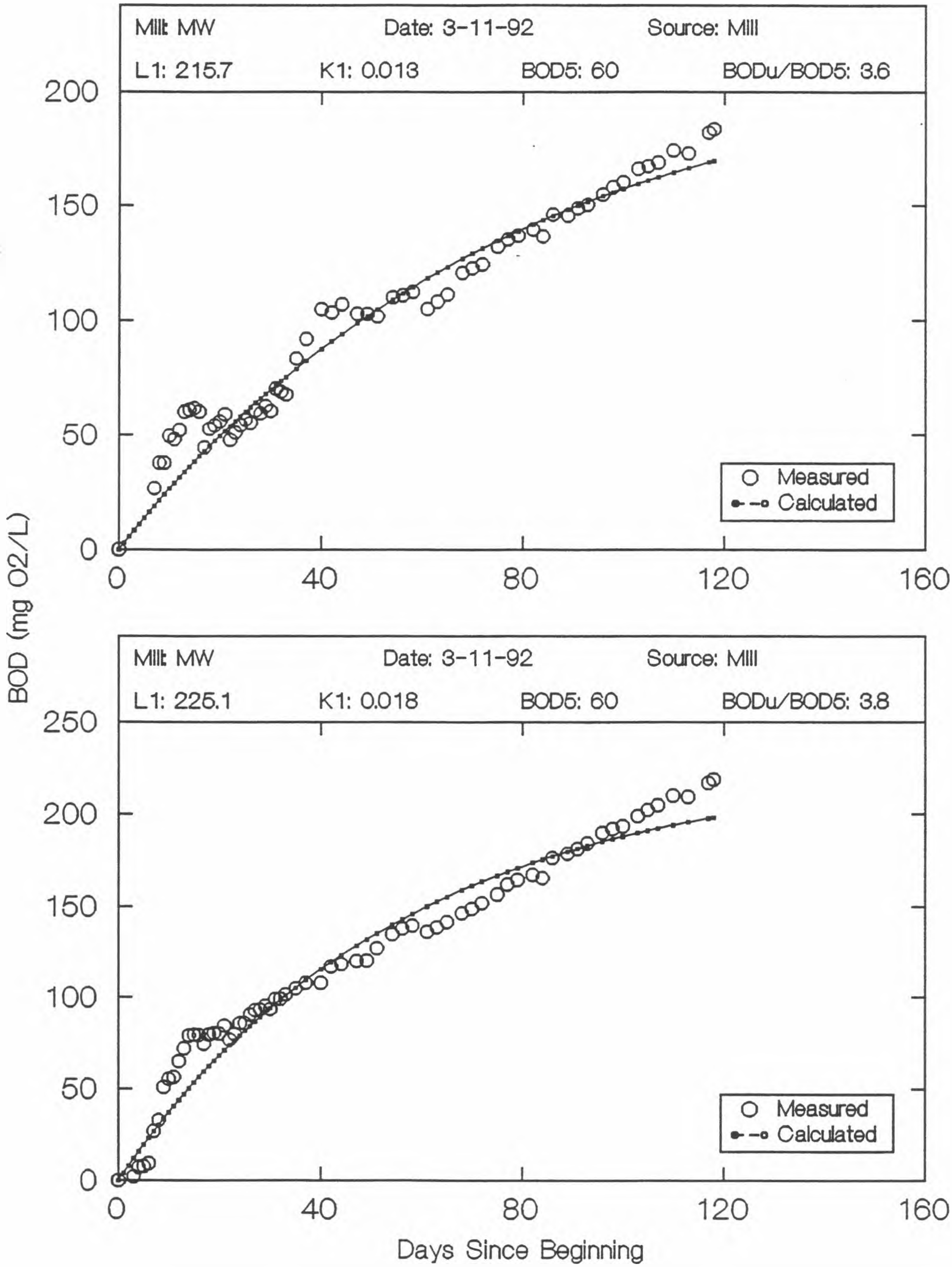


Figure A1-11 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

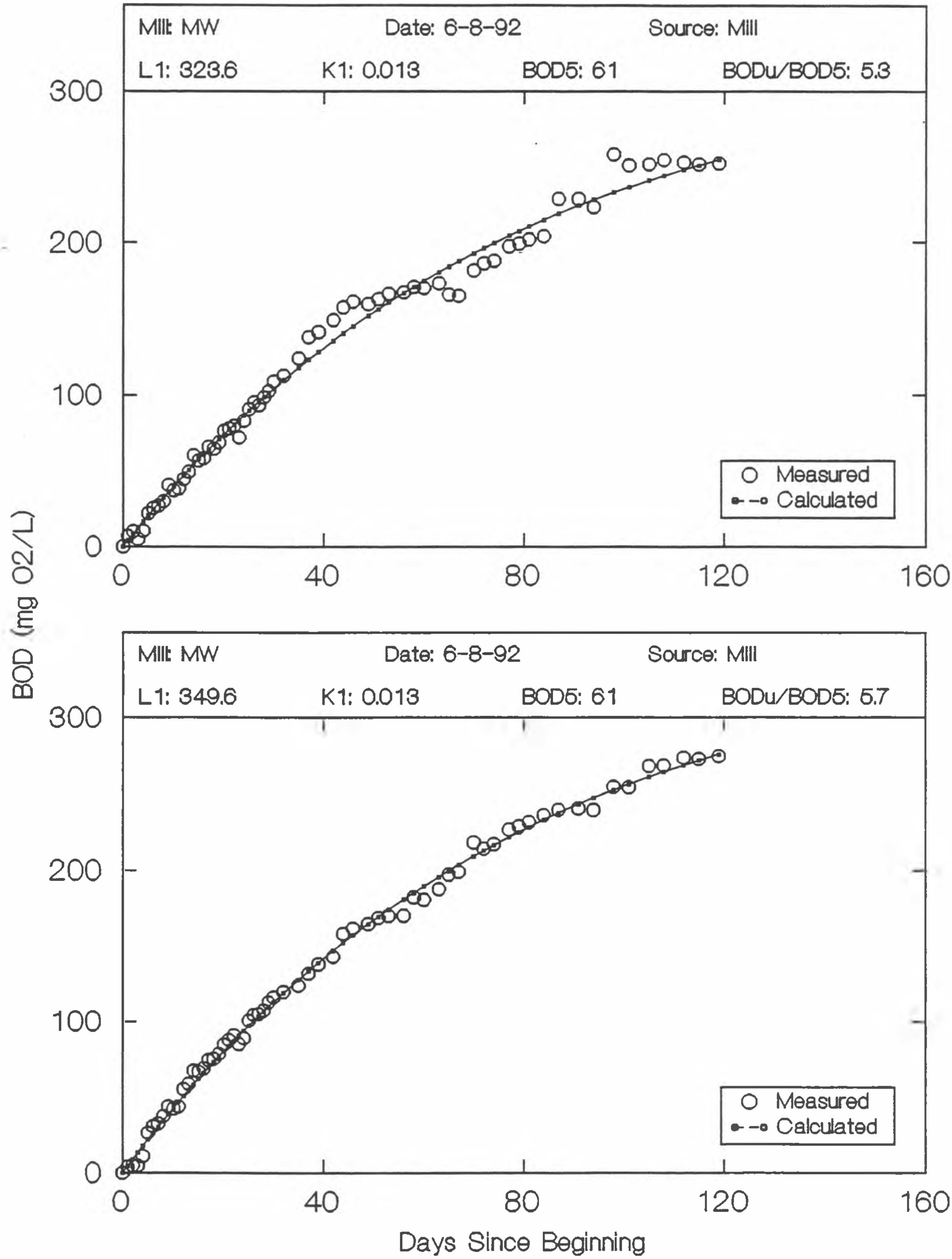


Figure A1-12 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

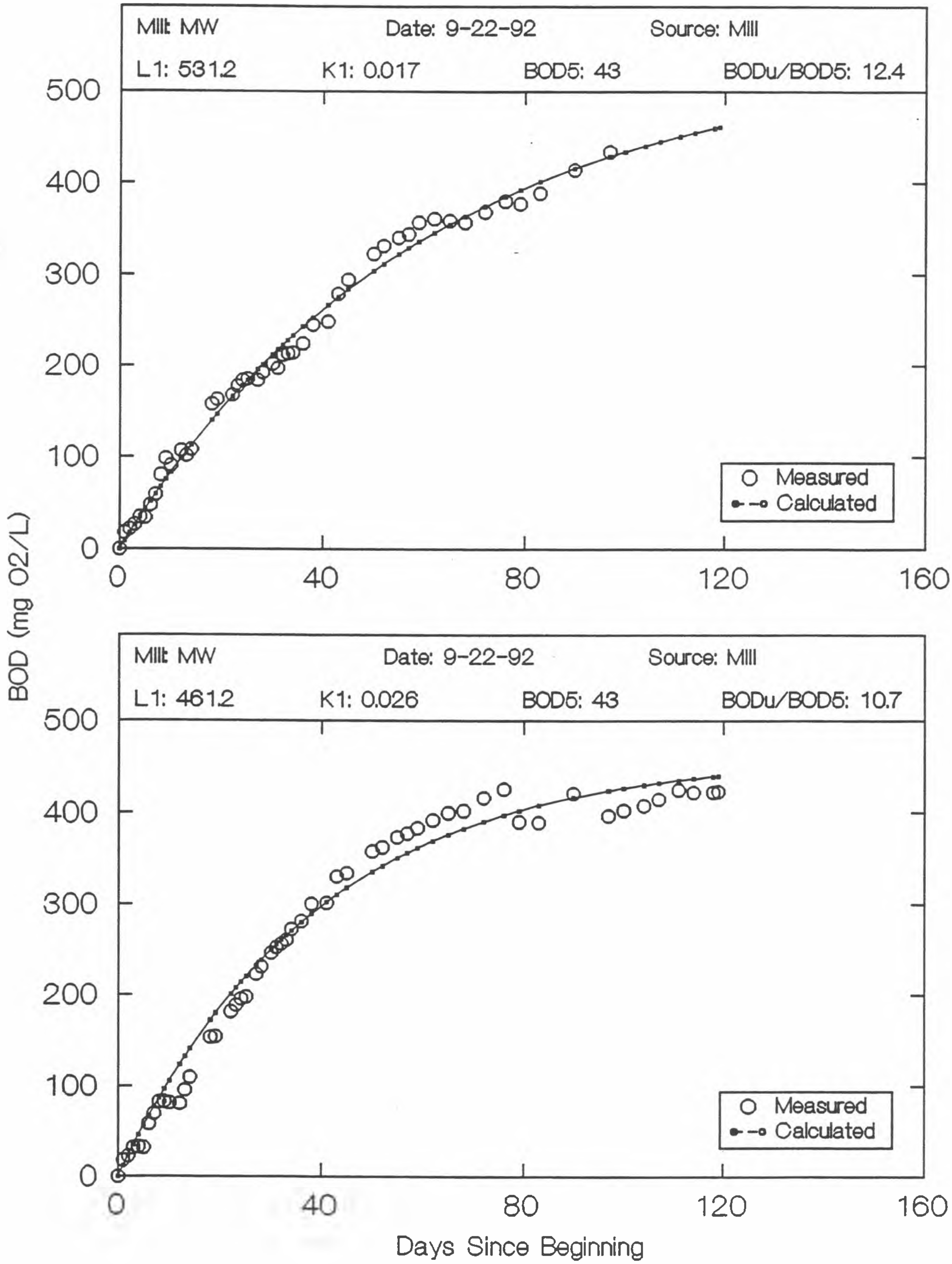


Figure A1-13 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

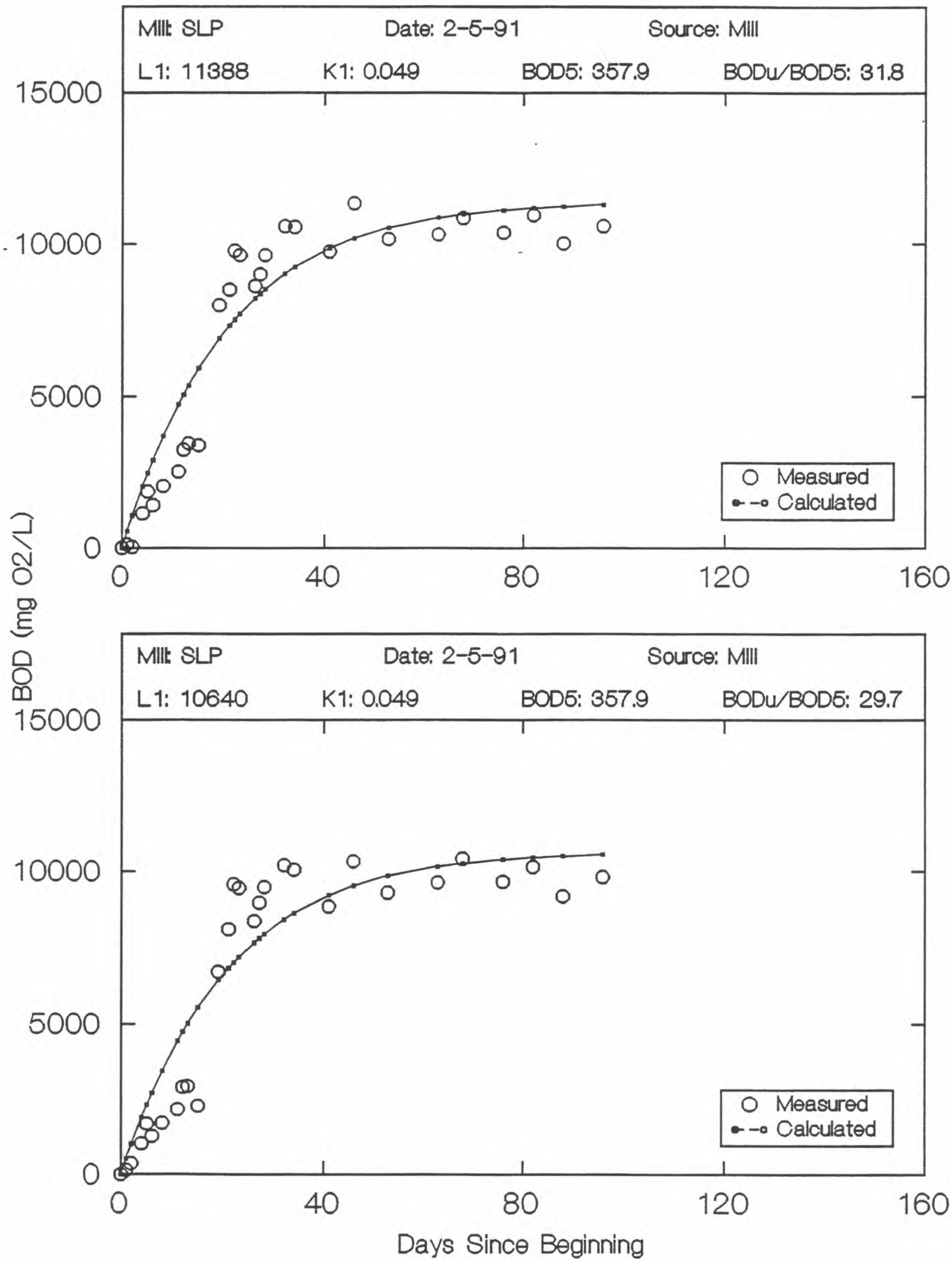
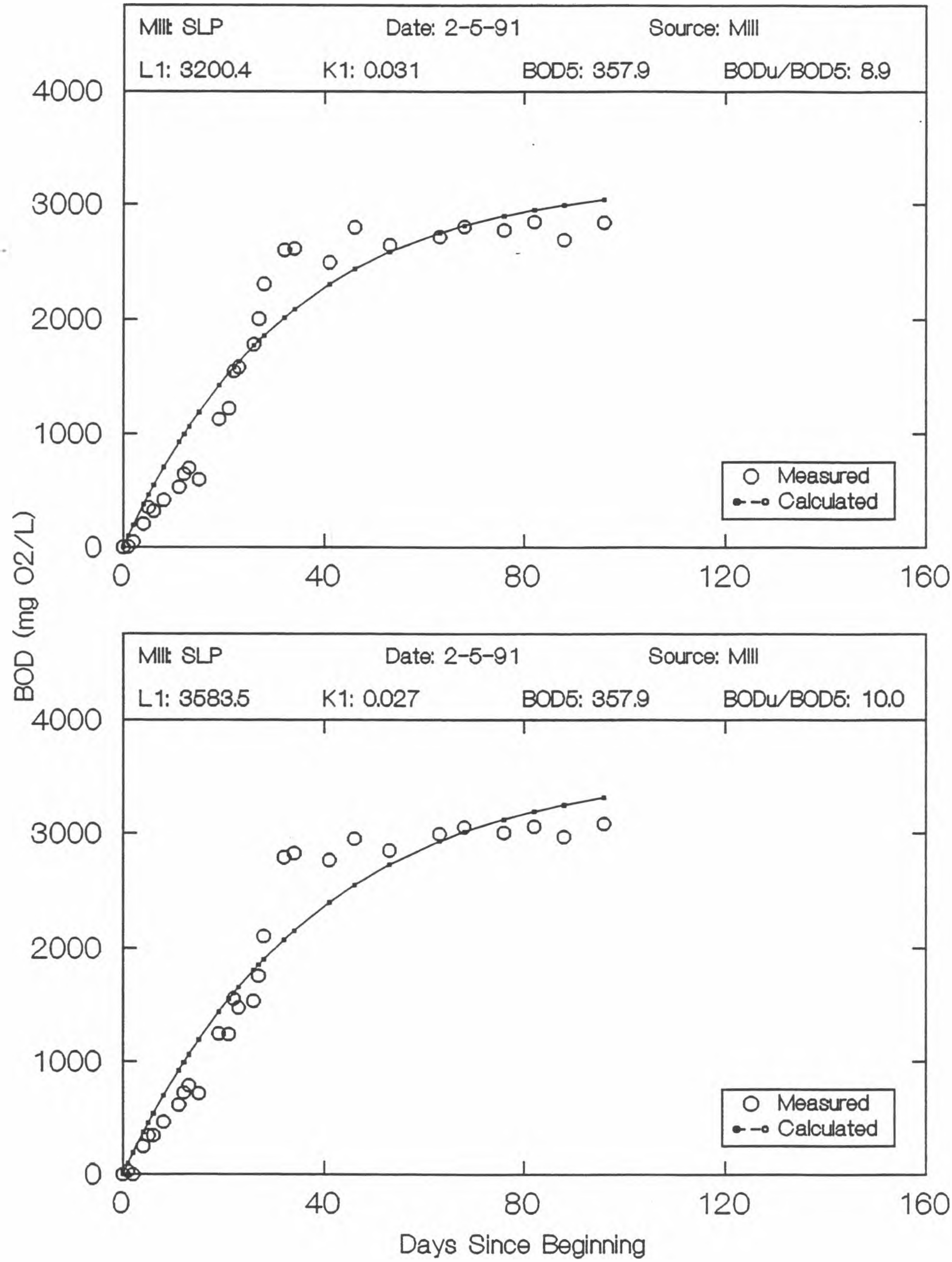


Figure A1-14 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates



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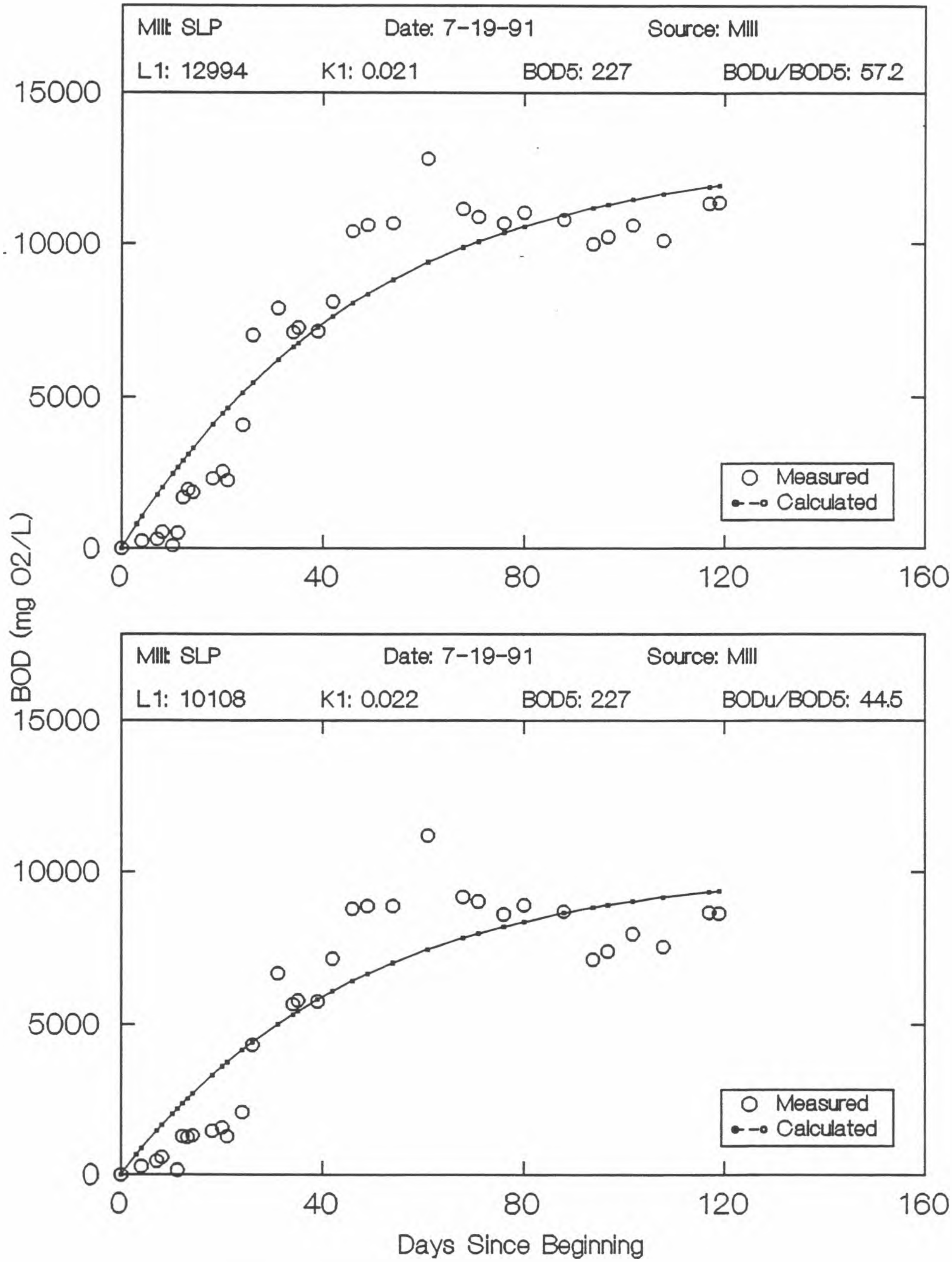


Figure A1-16 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

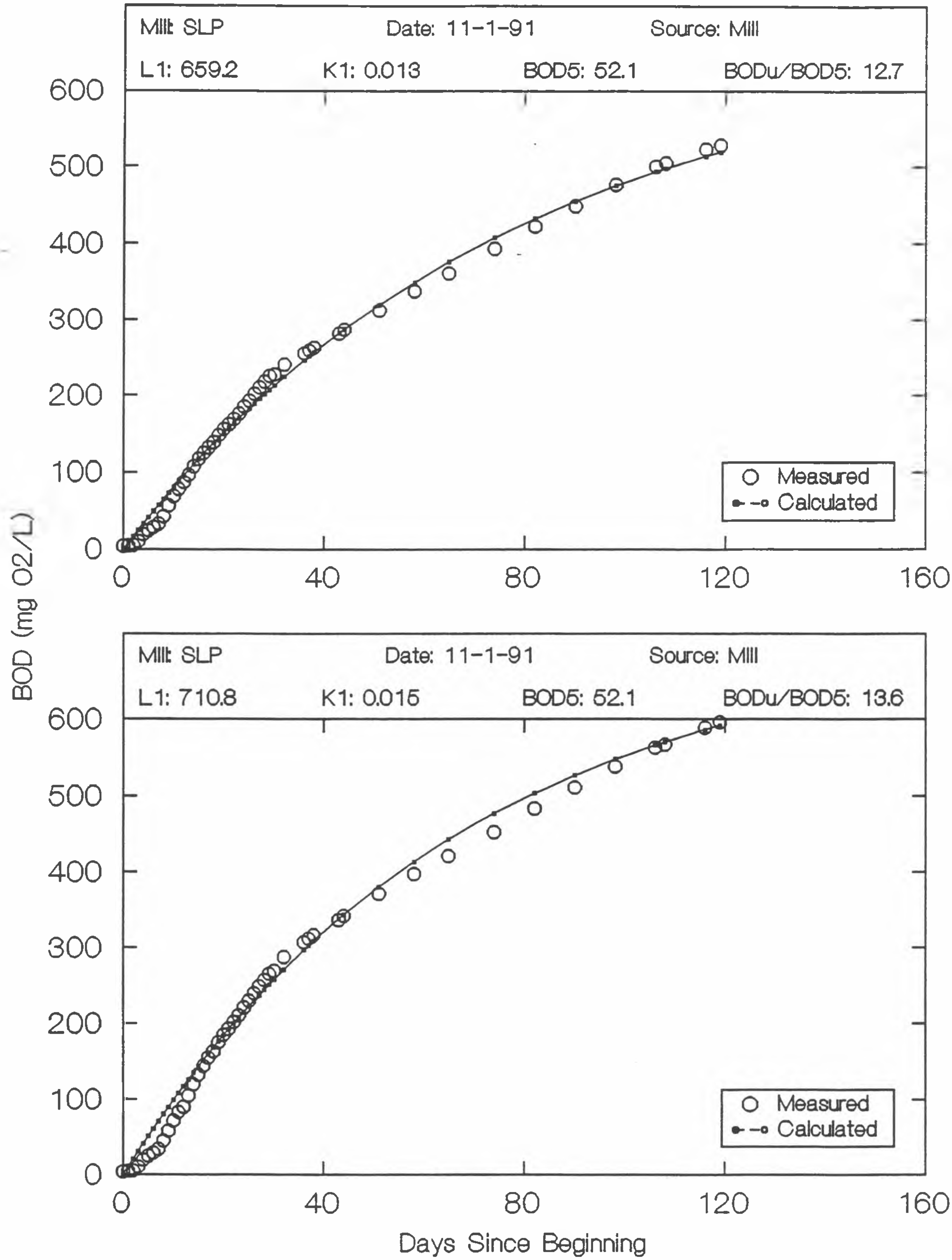


Figure A1-17 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

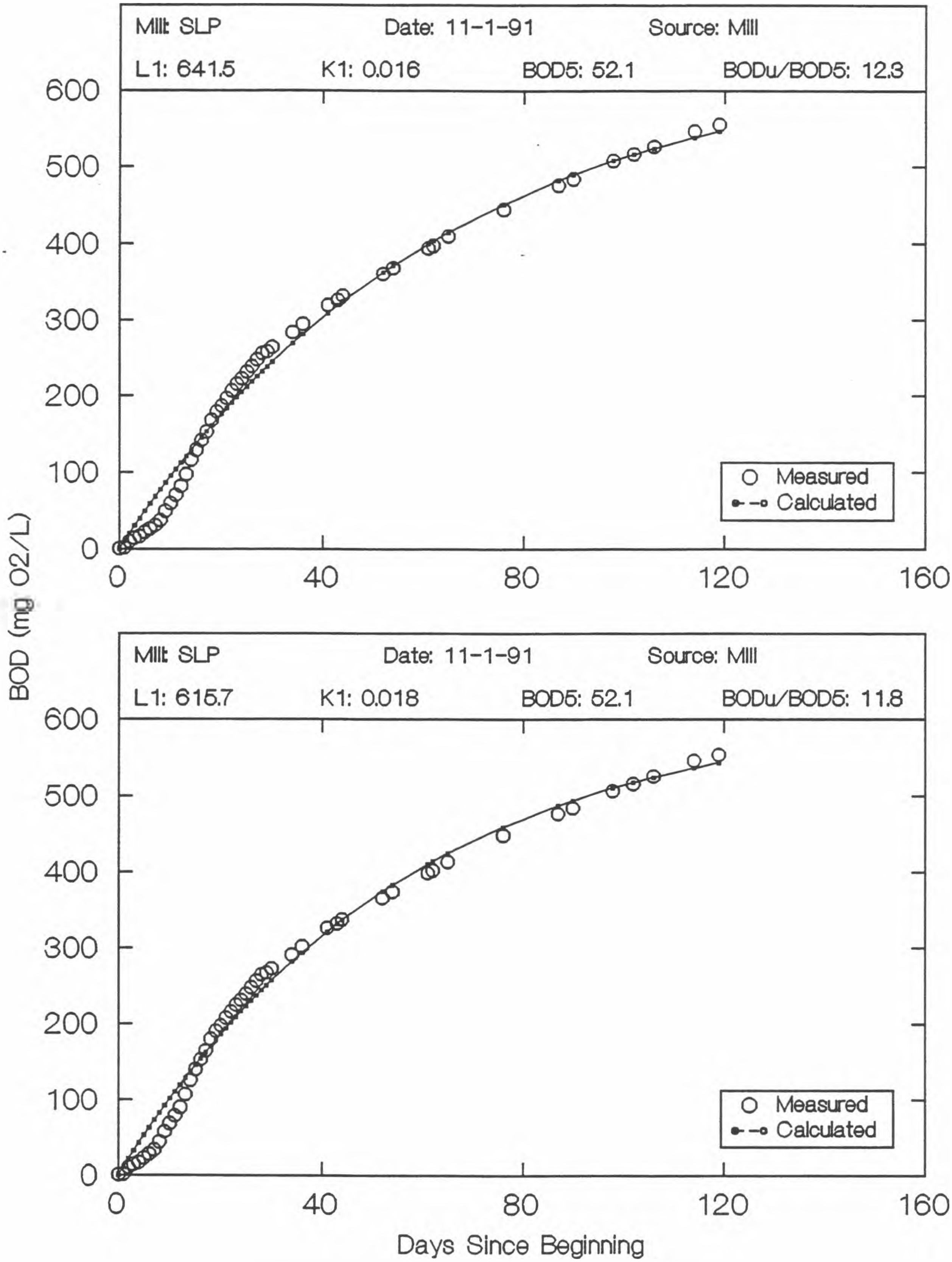


Figure A1-18 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

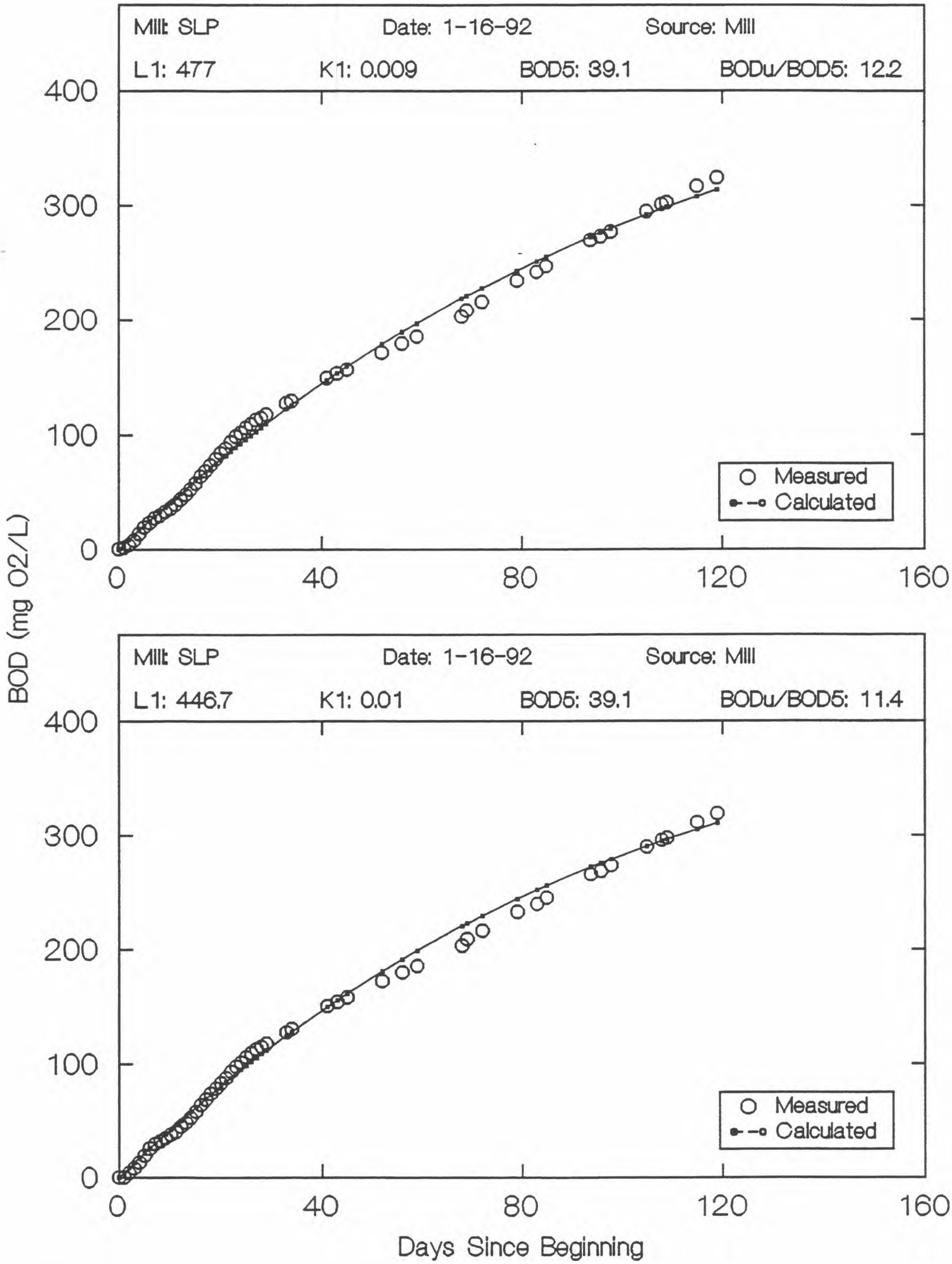


Figure A1-19 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

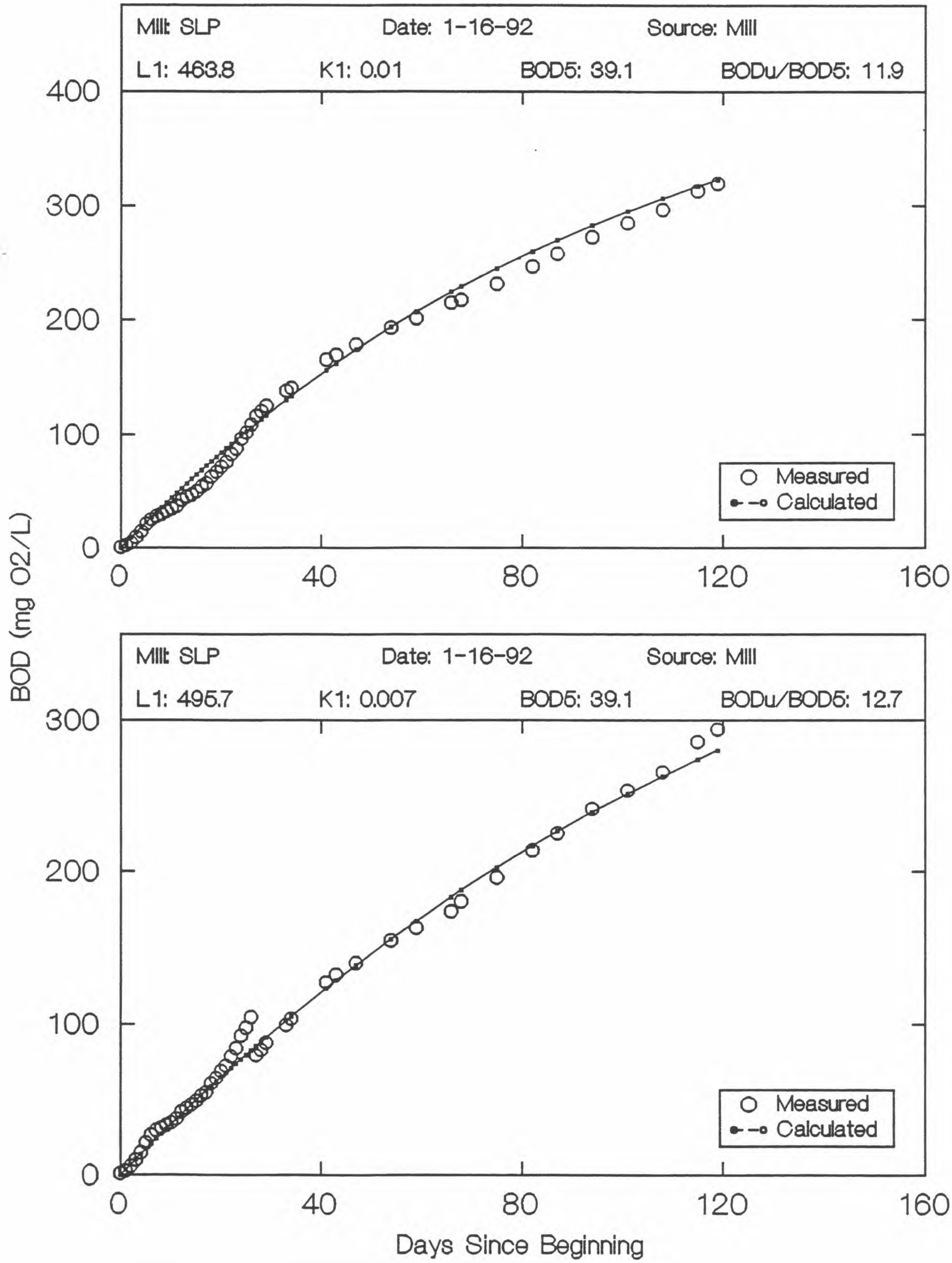


Figure A1-20 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

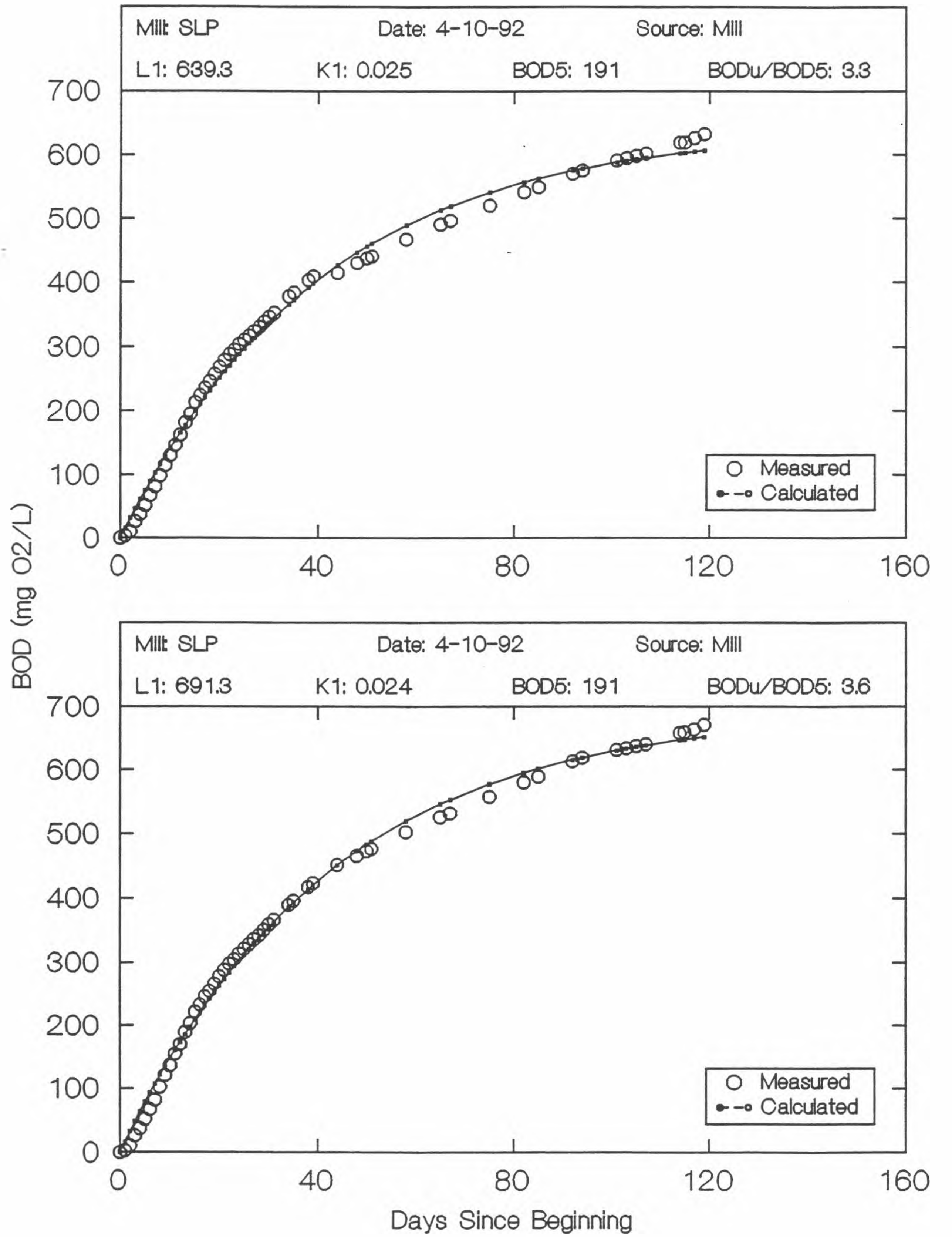


Figure A1-21 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

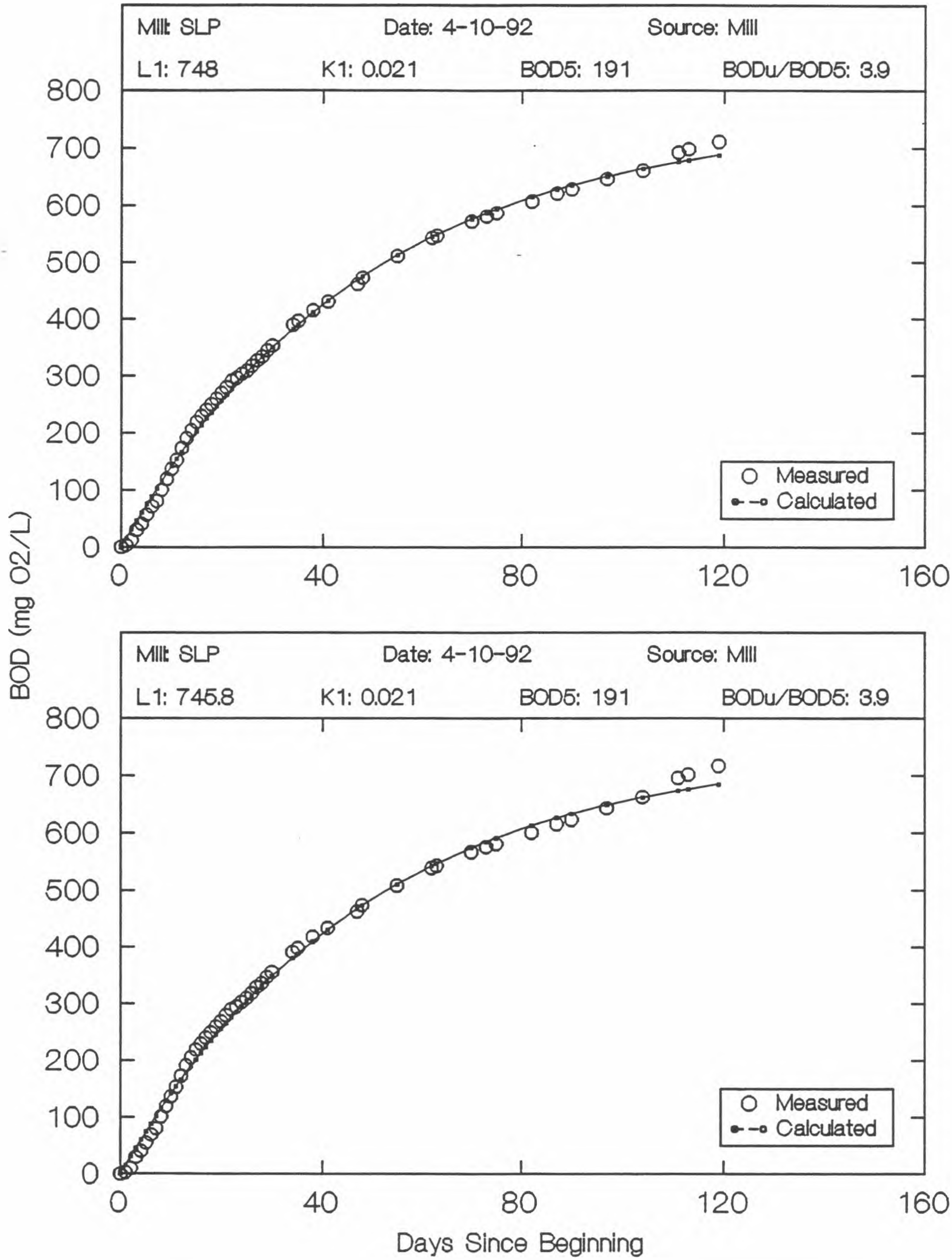


Figure A1-22 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

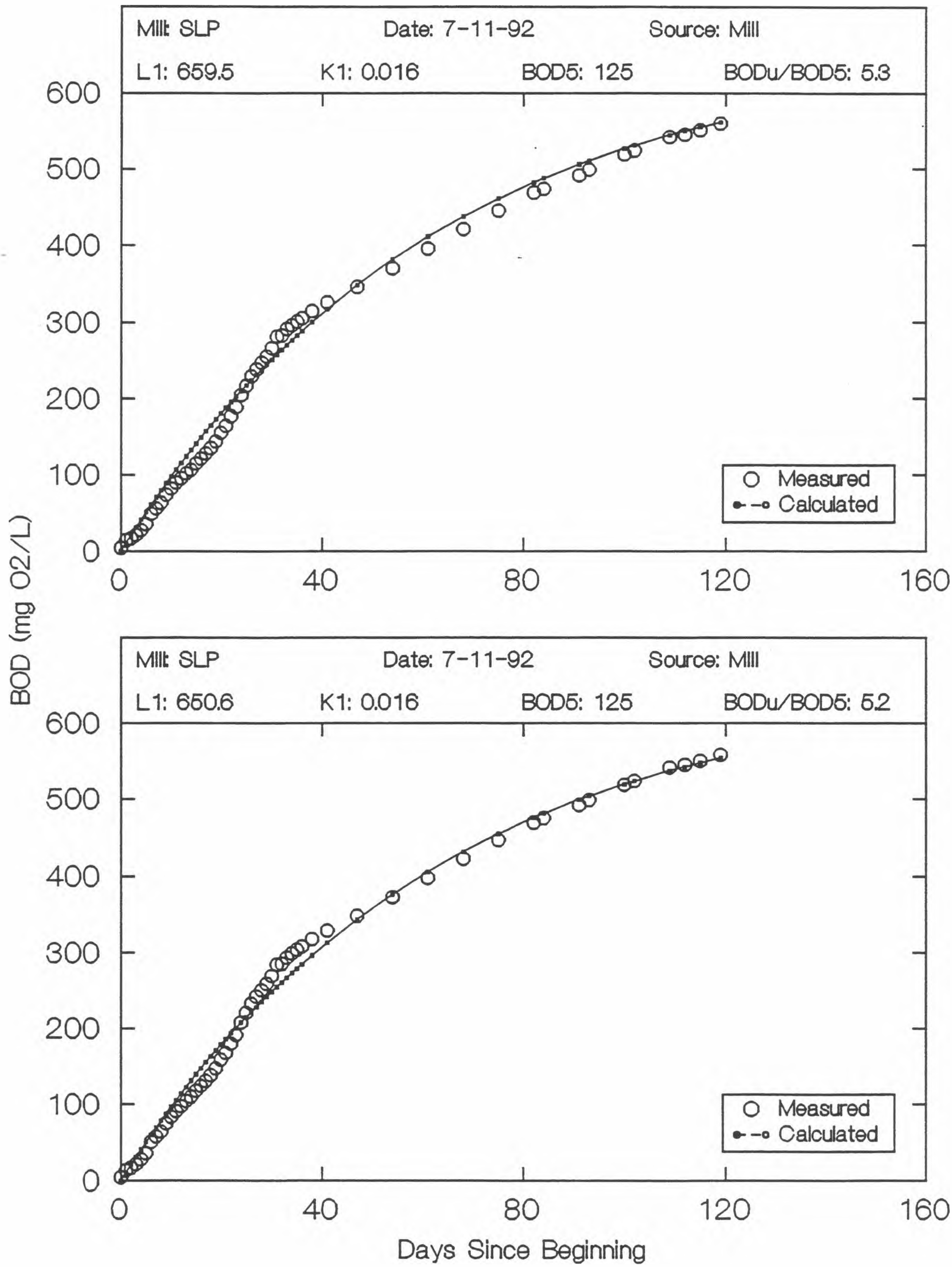


Figure A1-23 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

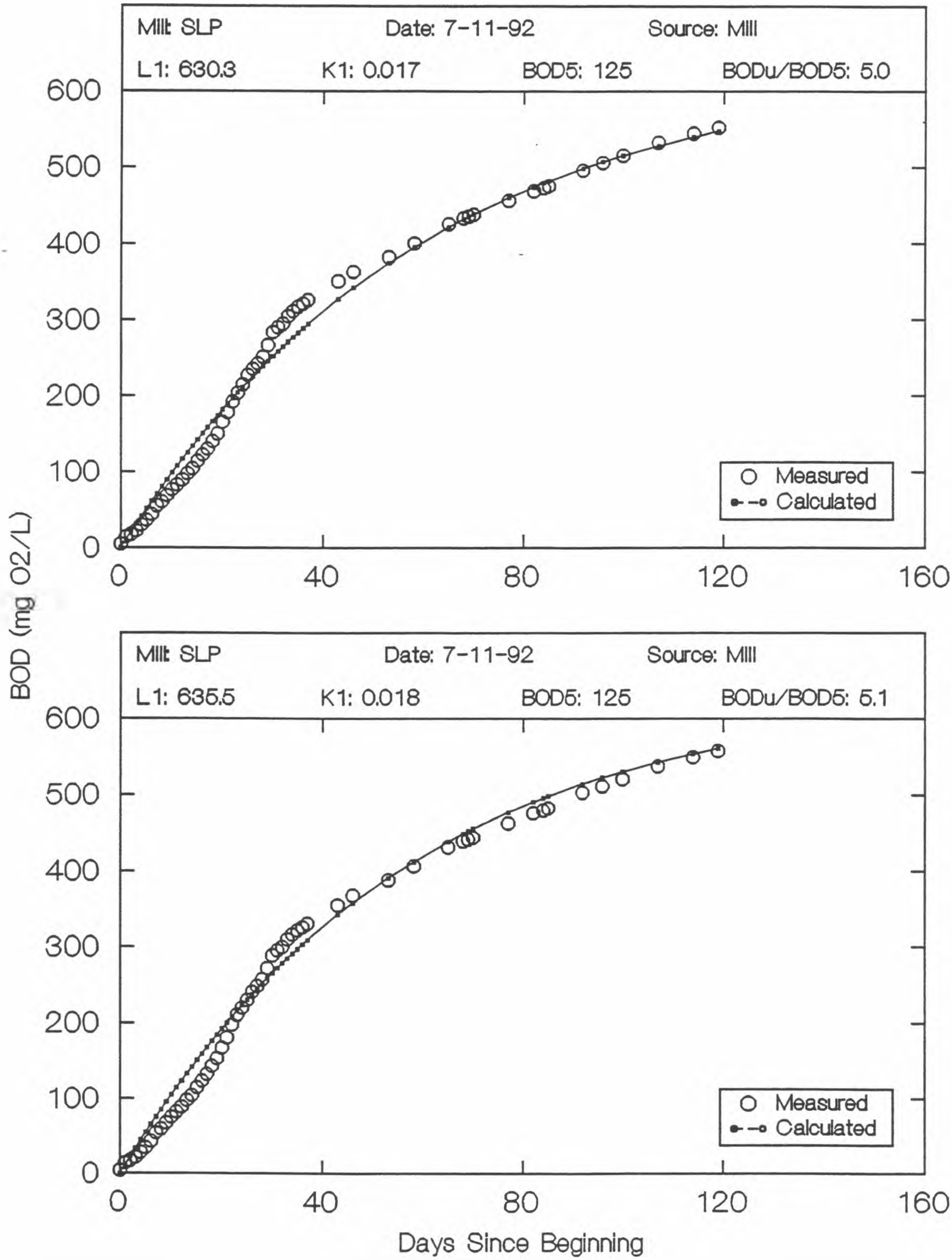


Figure A1-24 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

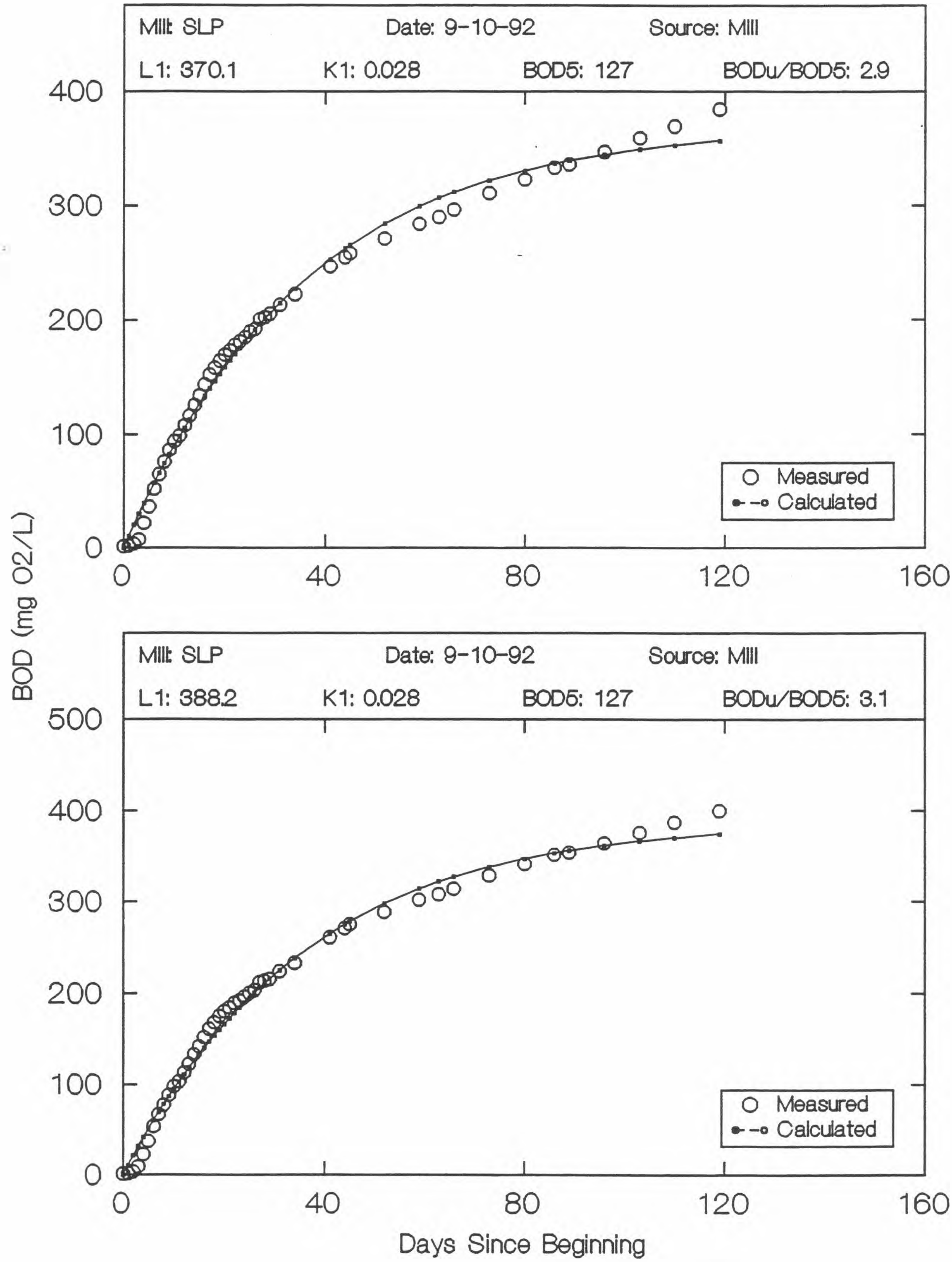
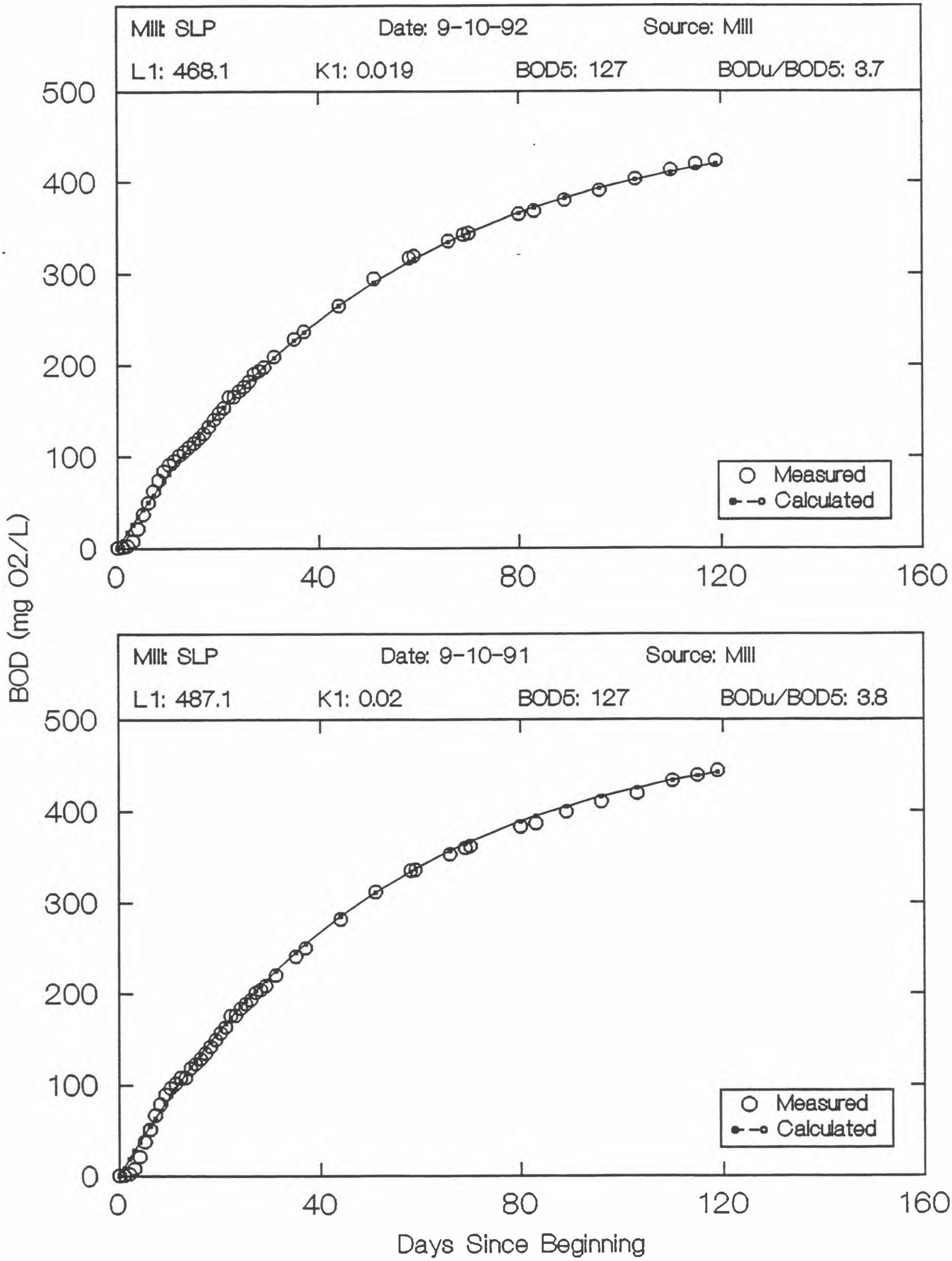


Figure A1-25 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates



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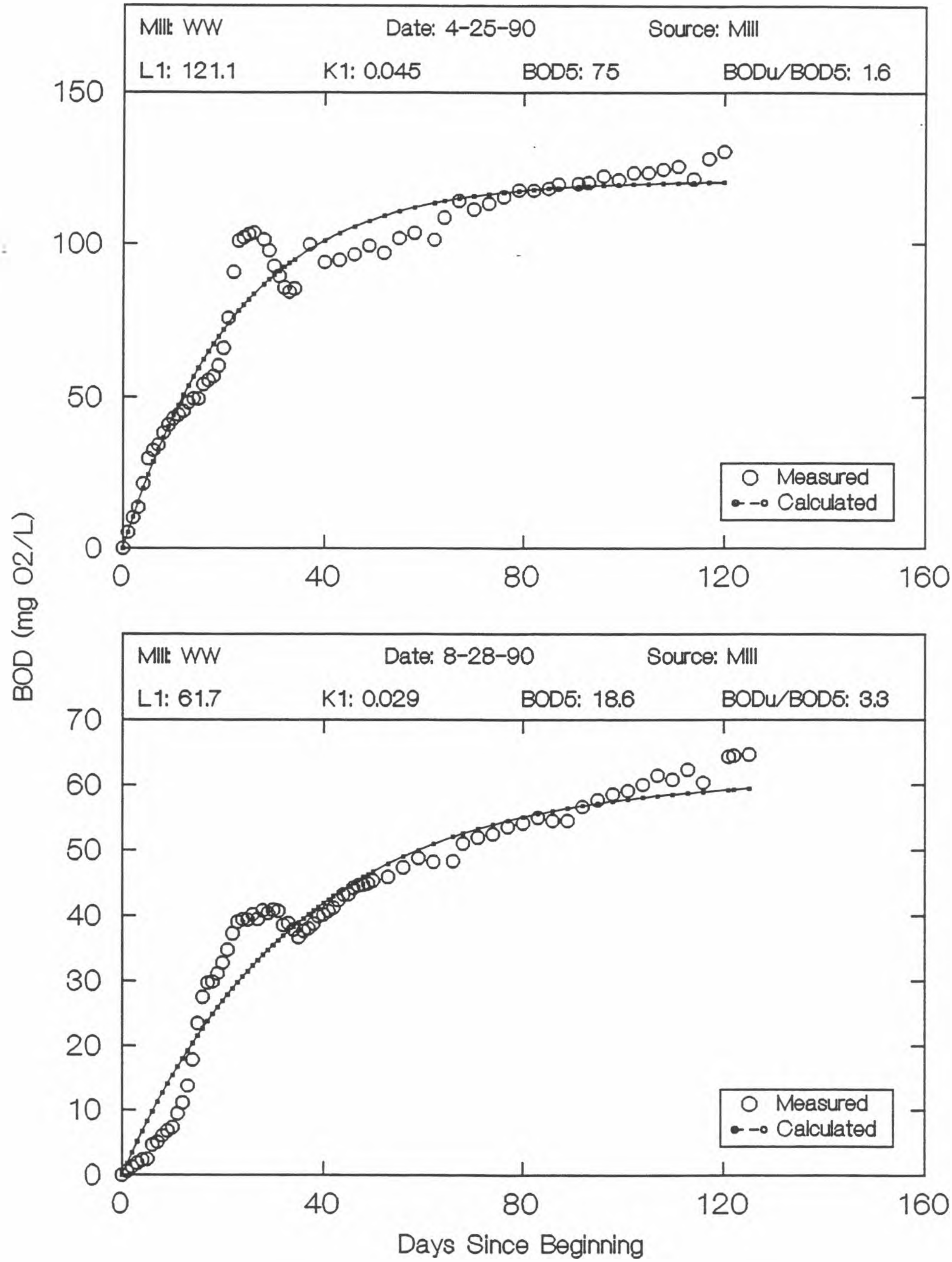


Figure A1-27 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

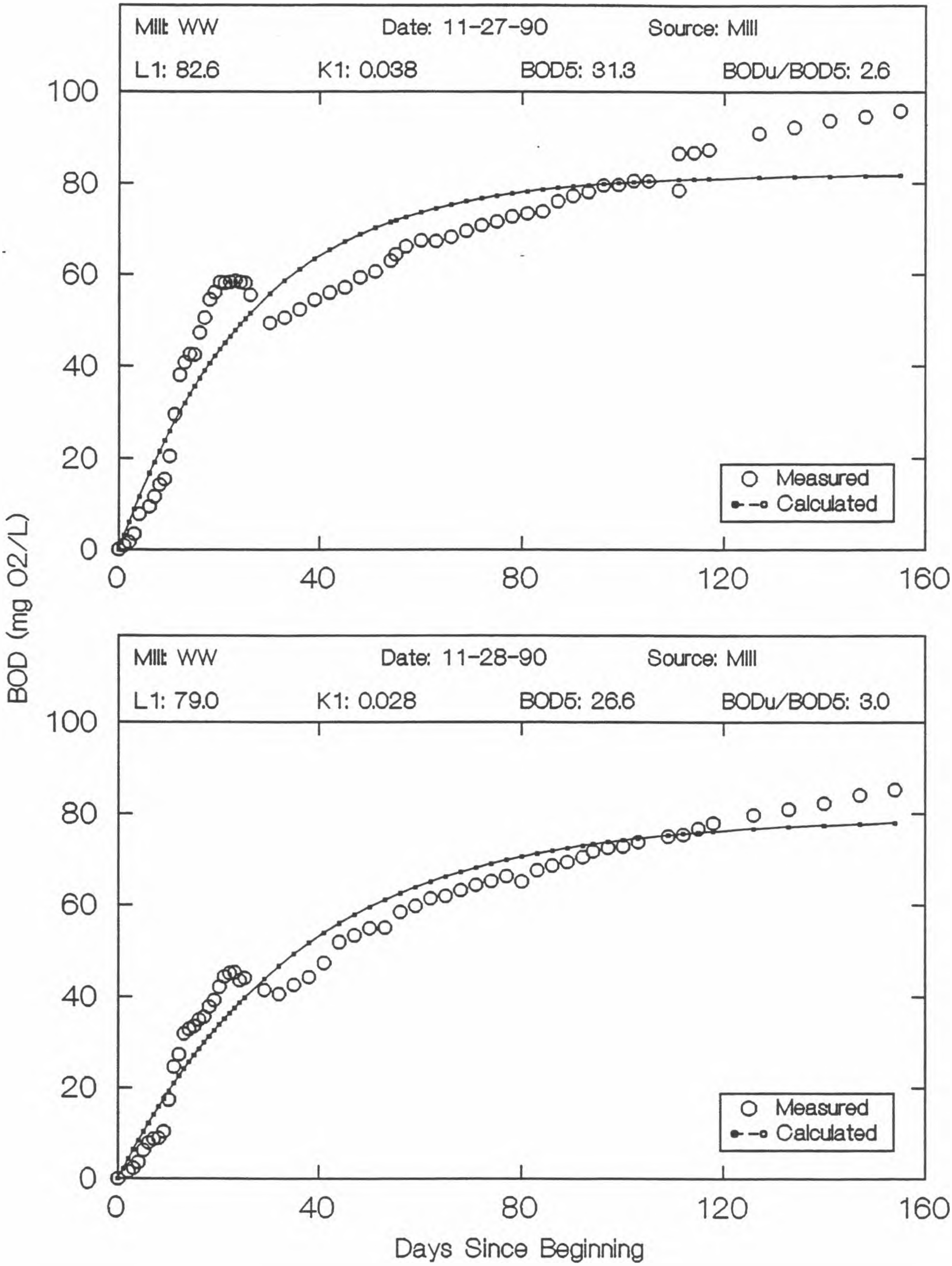


Figure A1-28 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

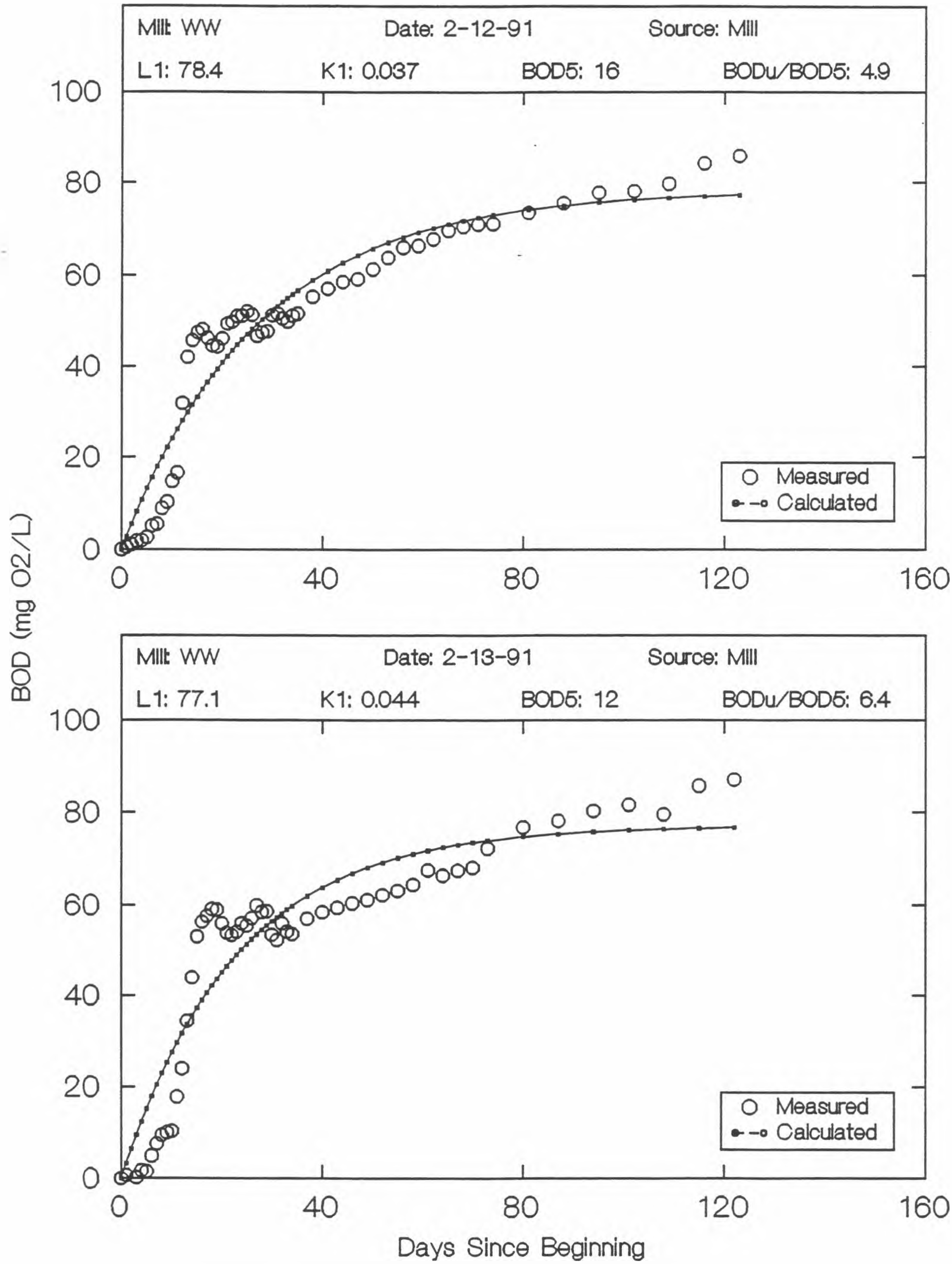
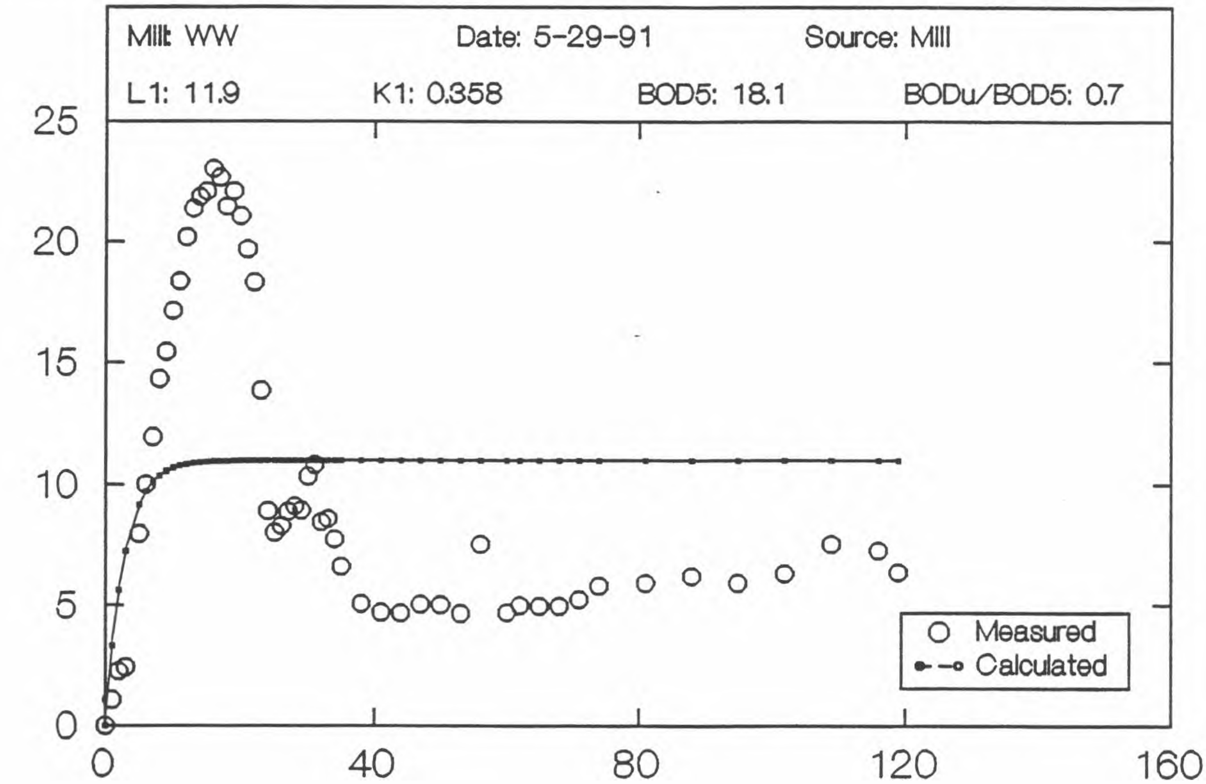


Figure A1-29 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates



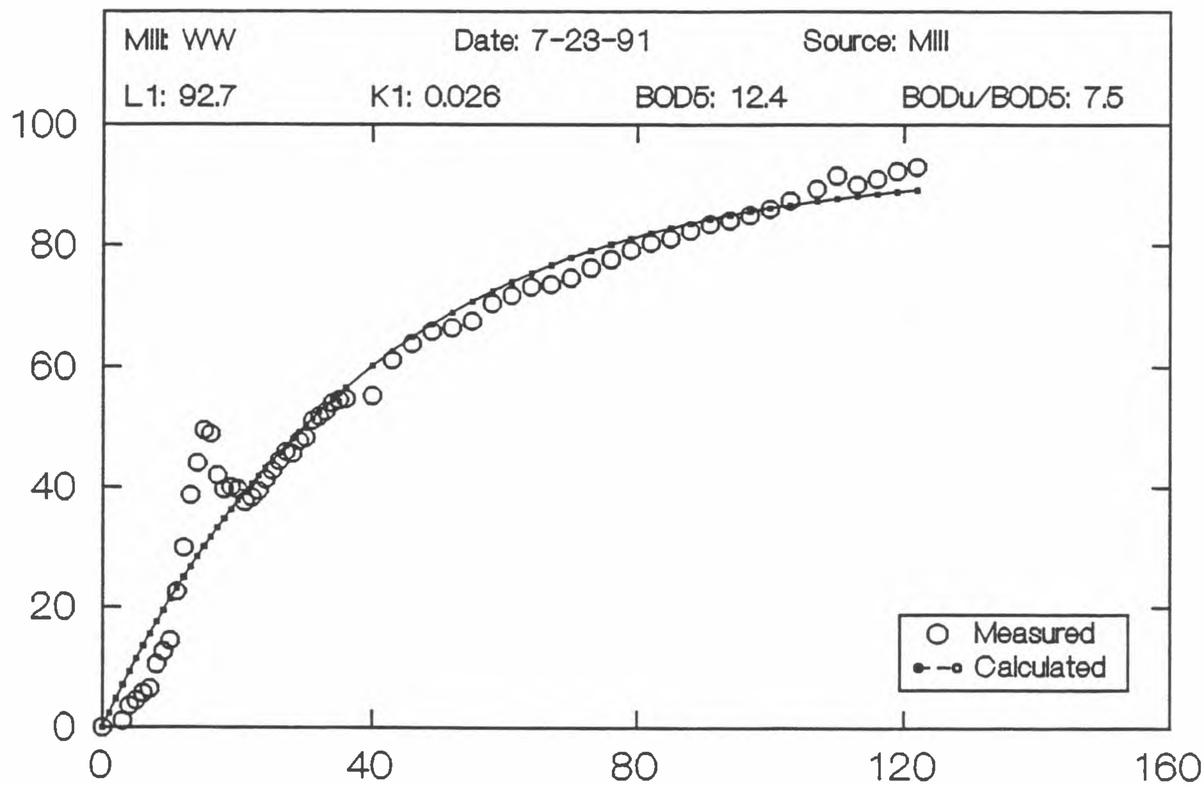


Figure A1-30 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

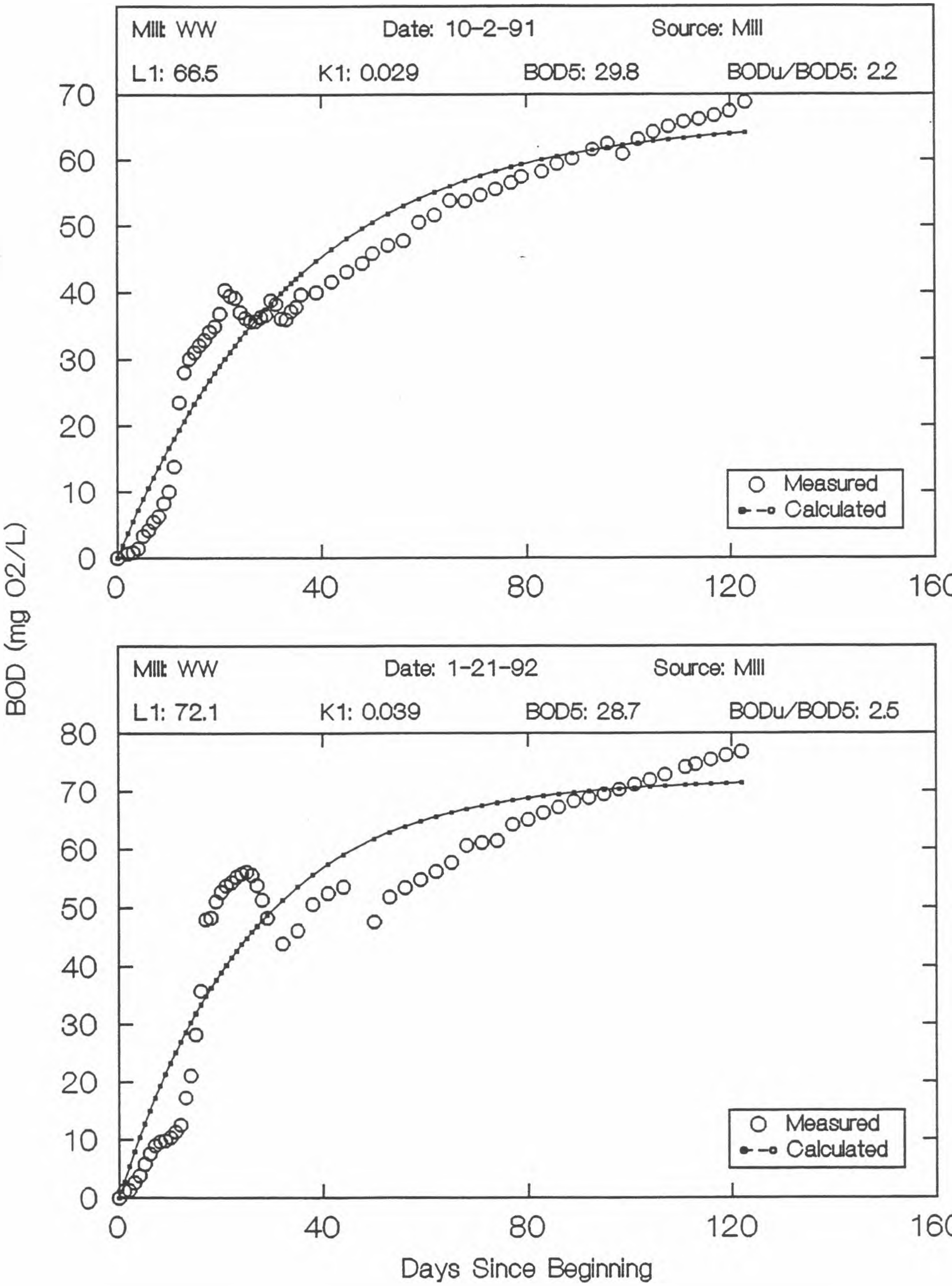


Figure A1-31 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

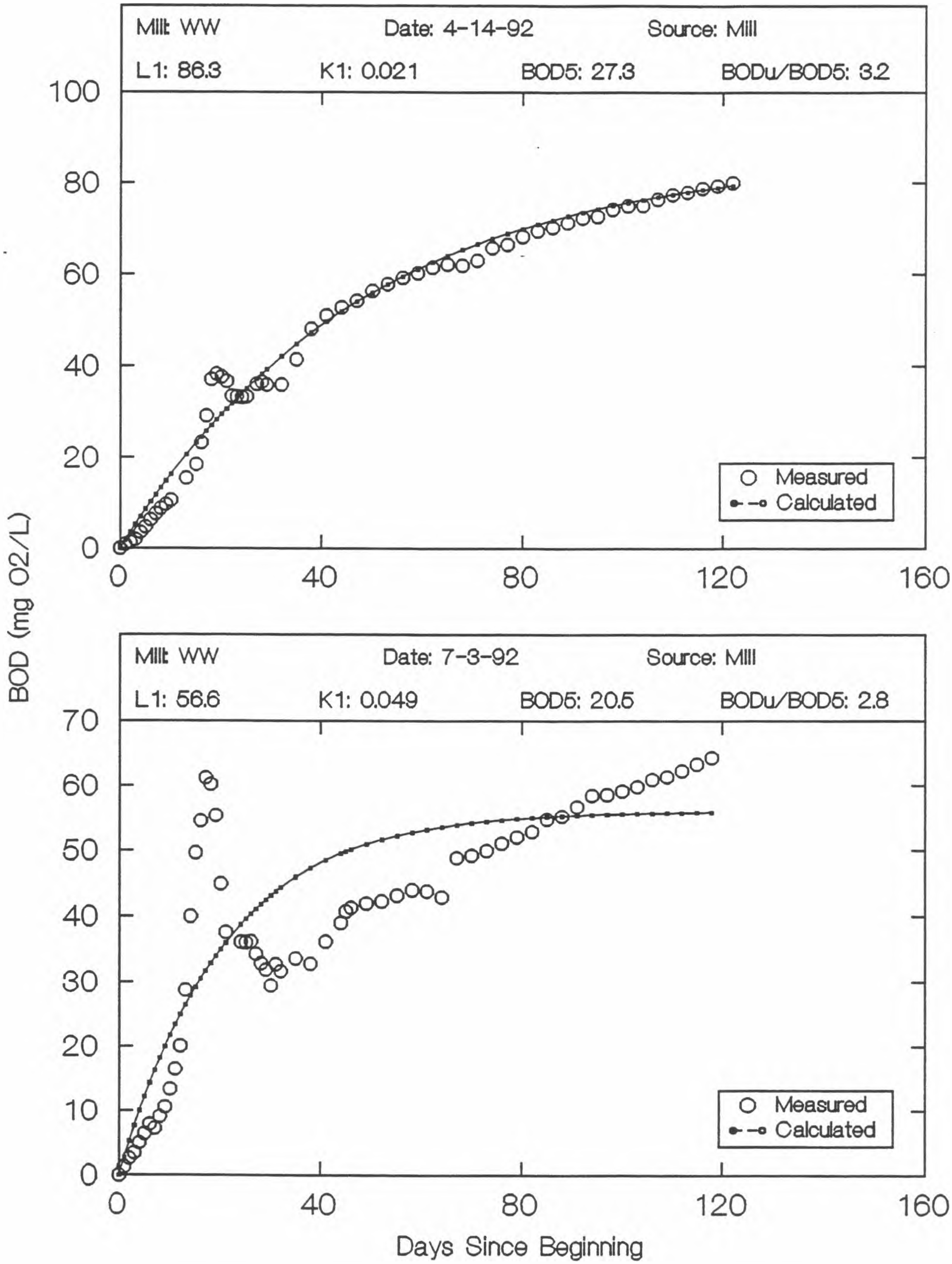


Figure A1-32 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

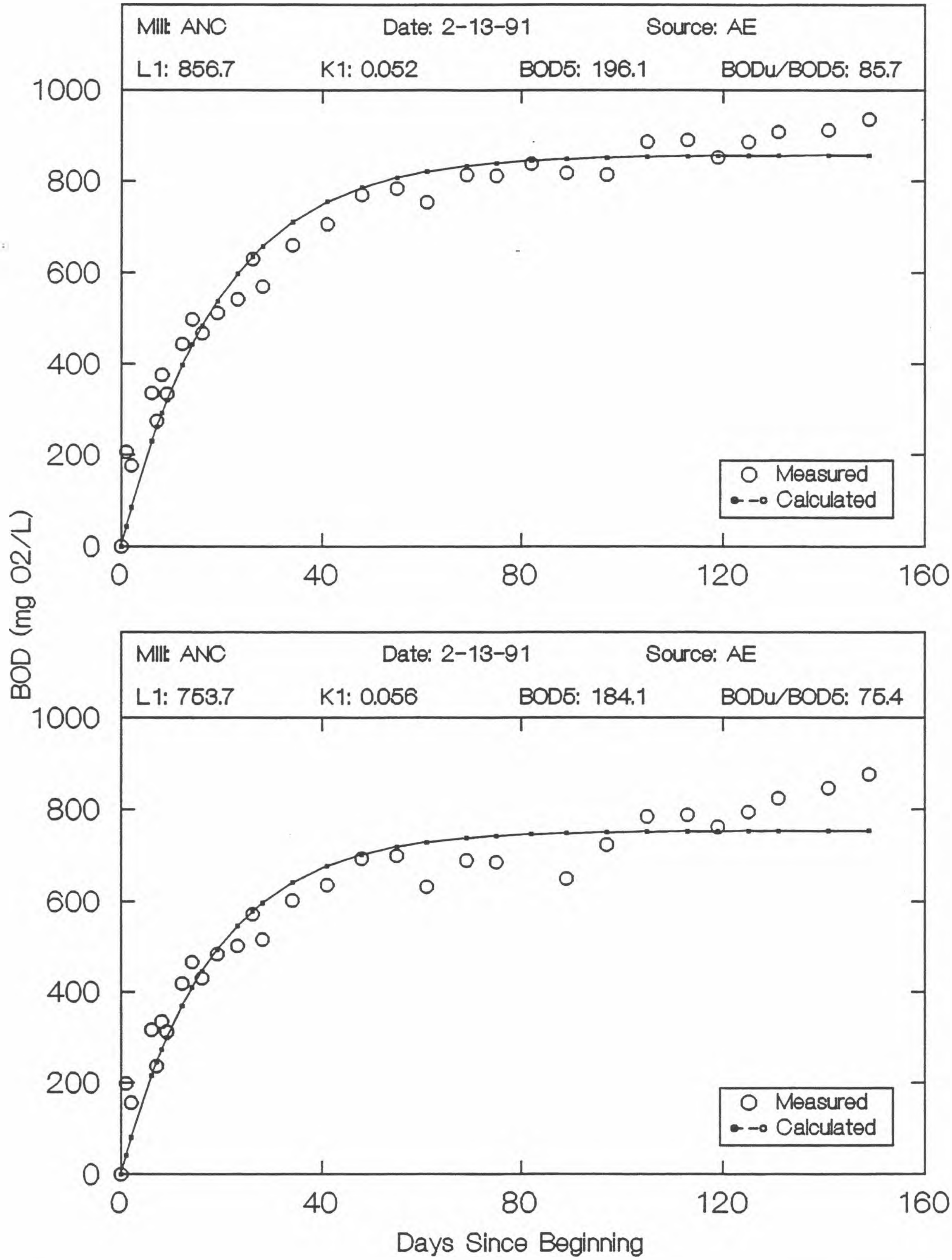


Figure A1-33 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

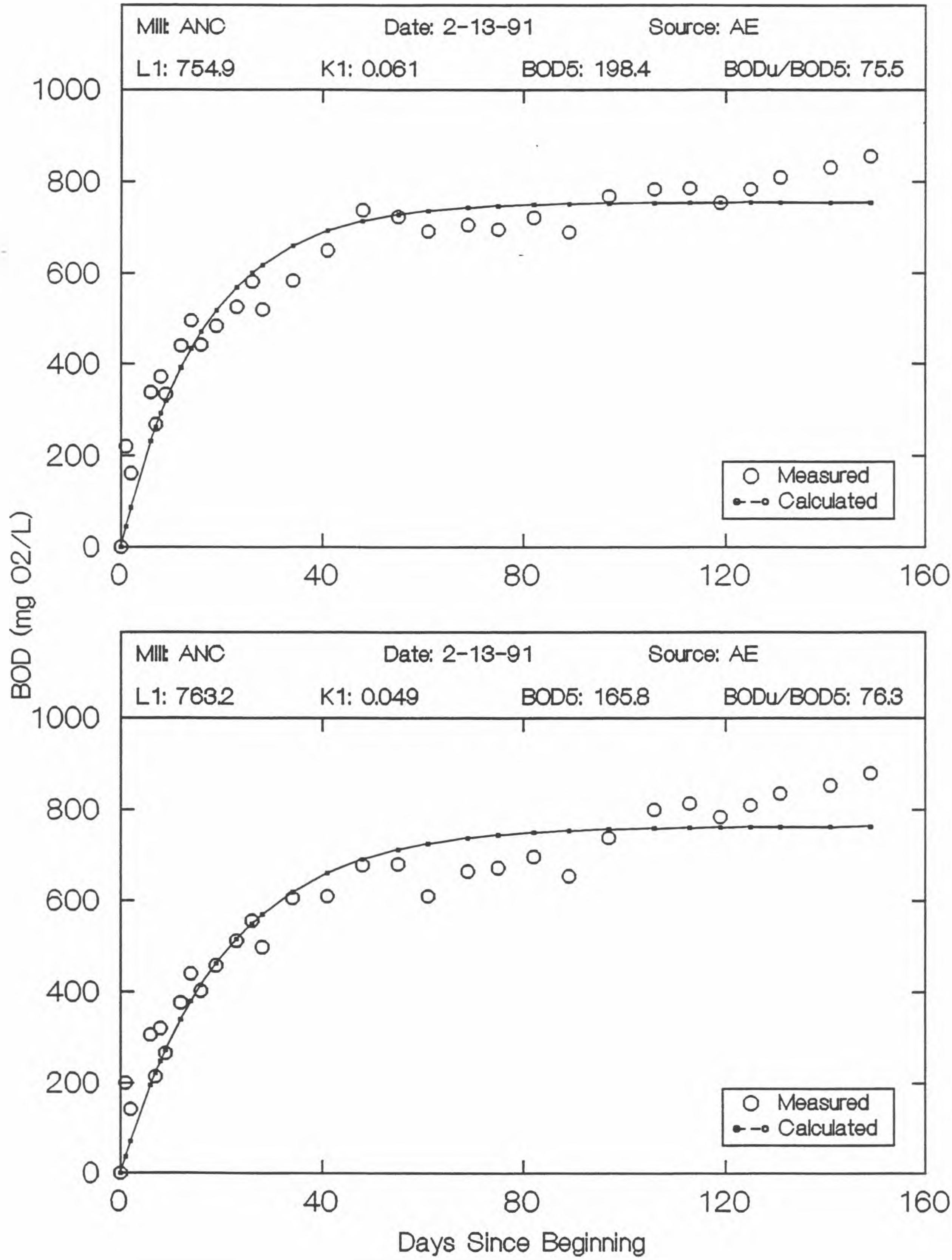


Figure A1-34 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

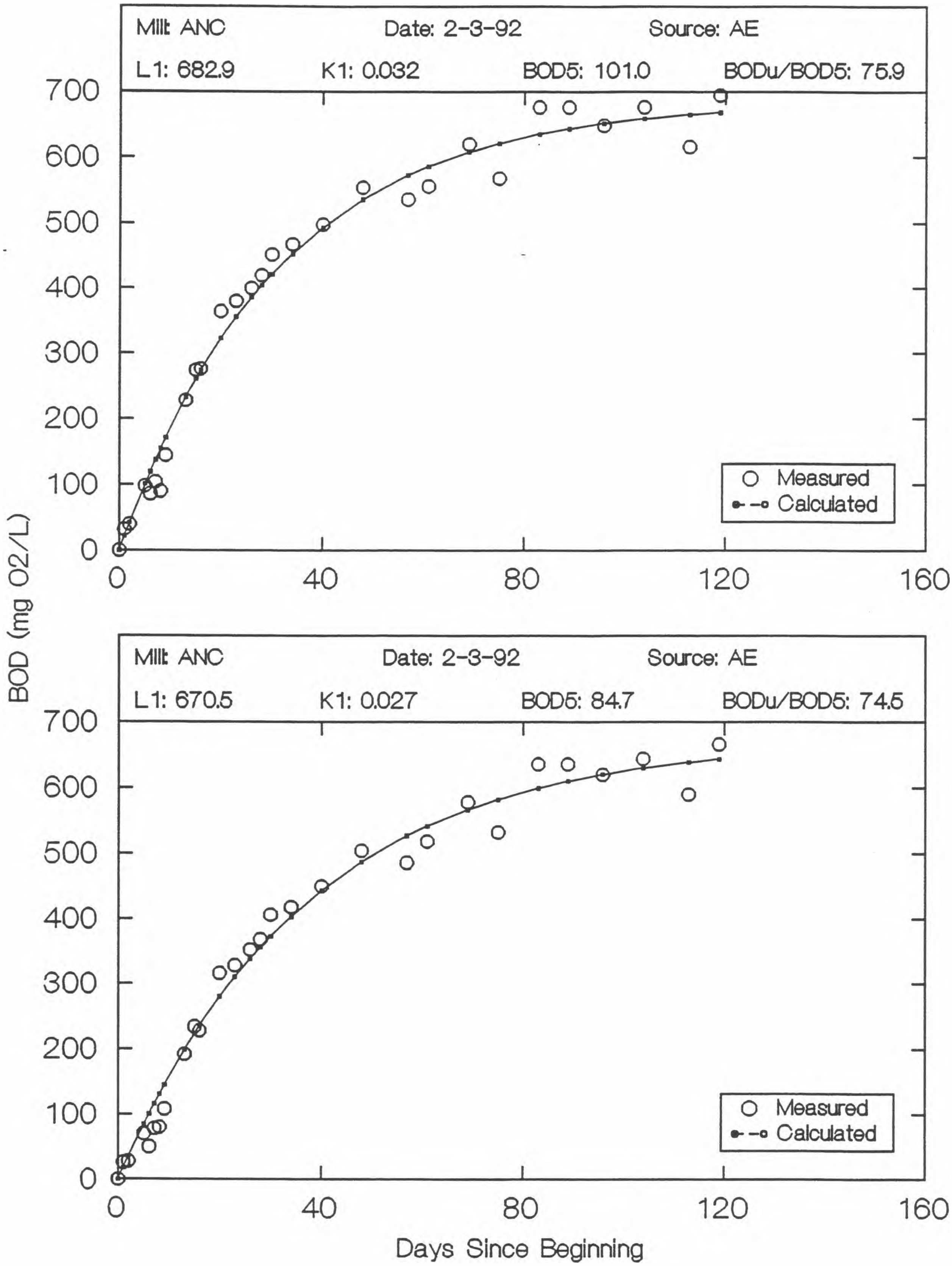


Figure A1-35 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

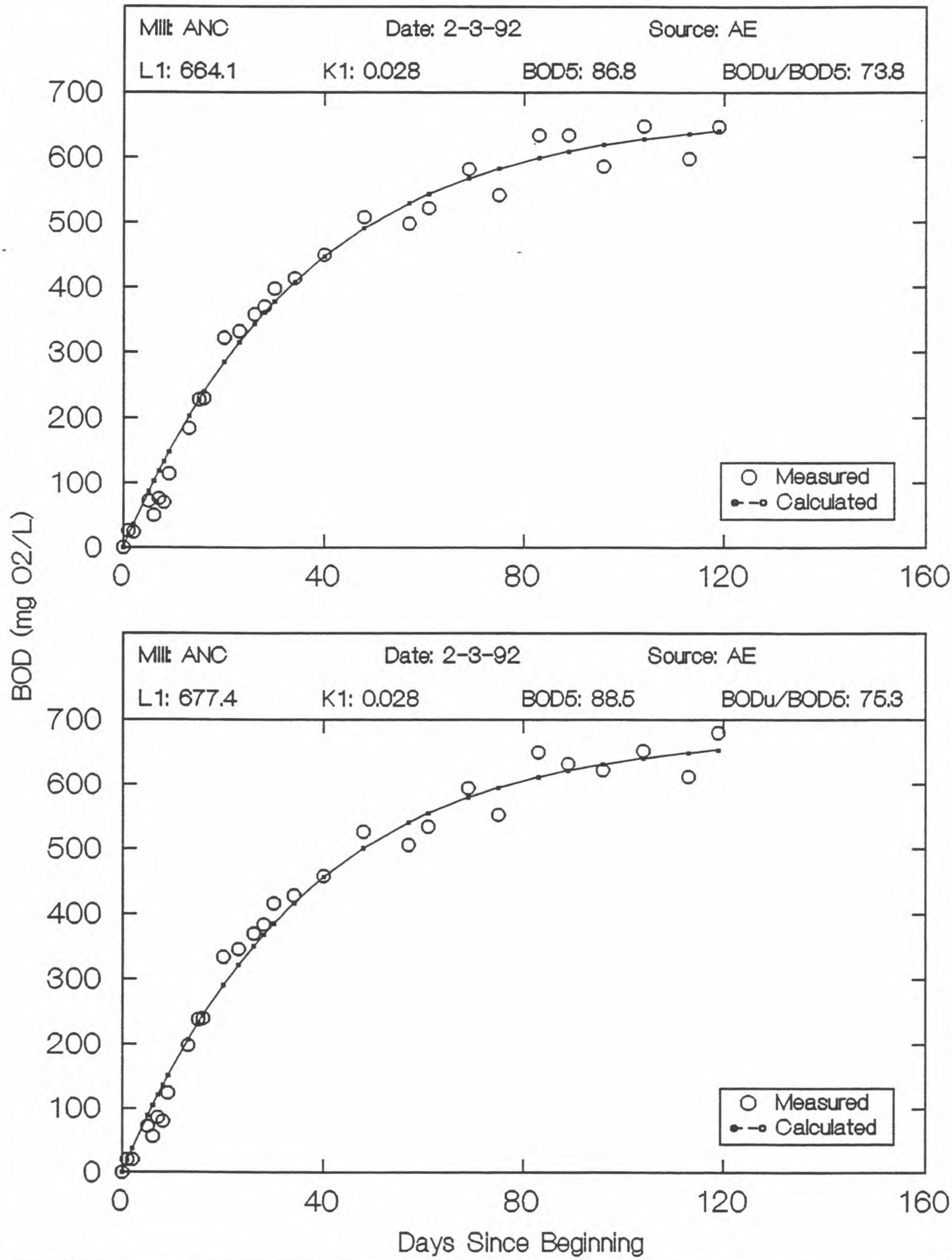


Figure A1-36 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

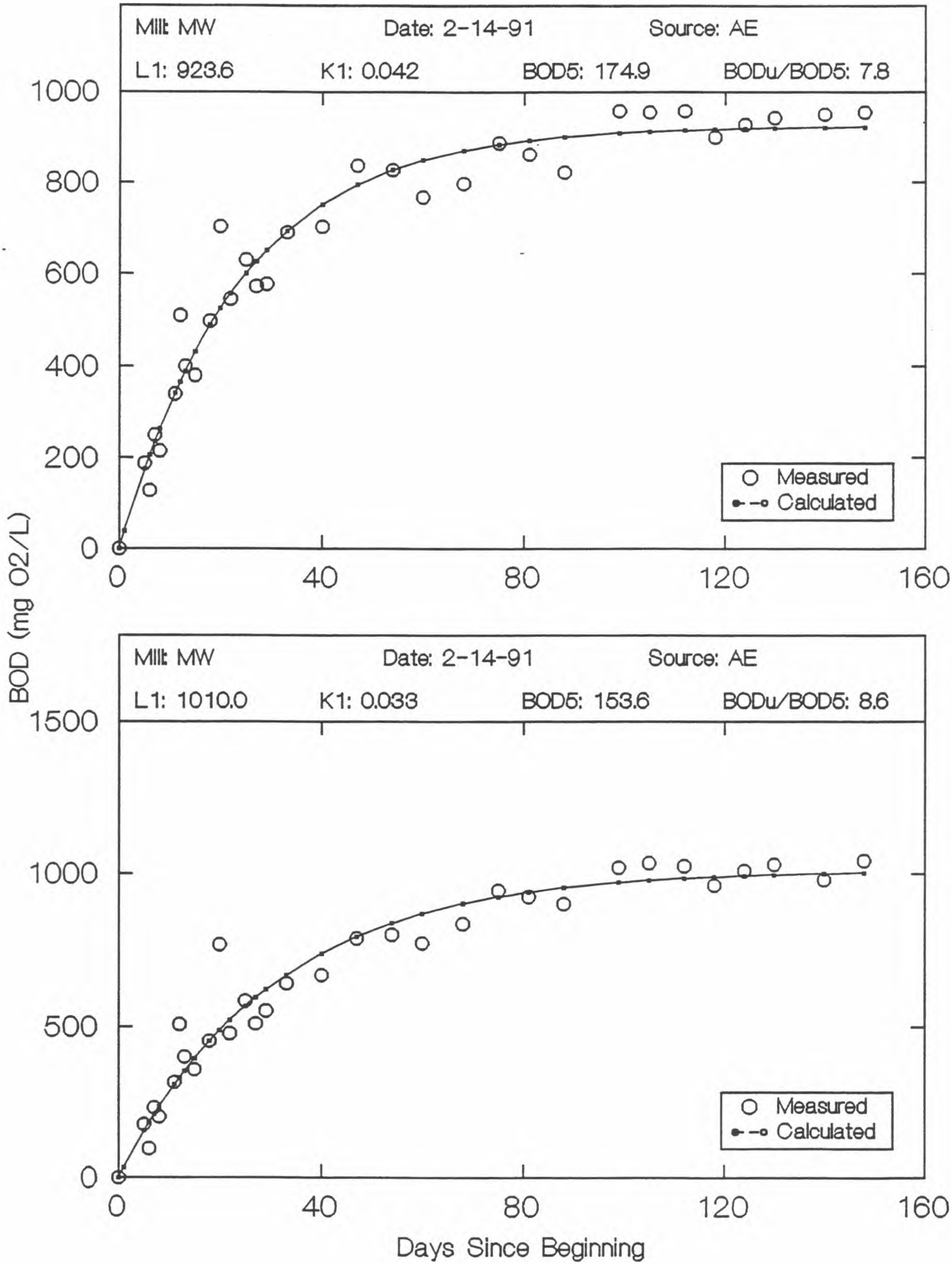


Figure A1-37 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

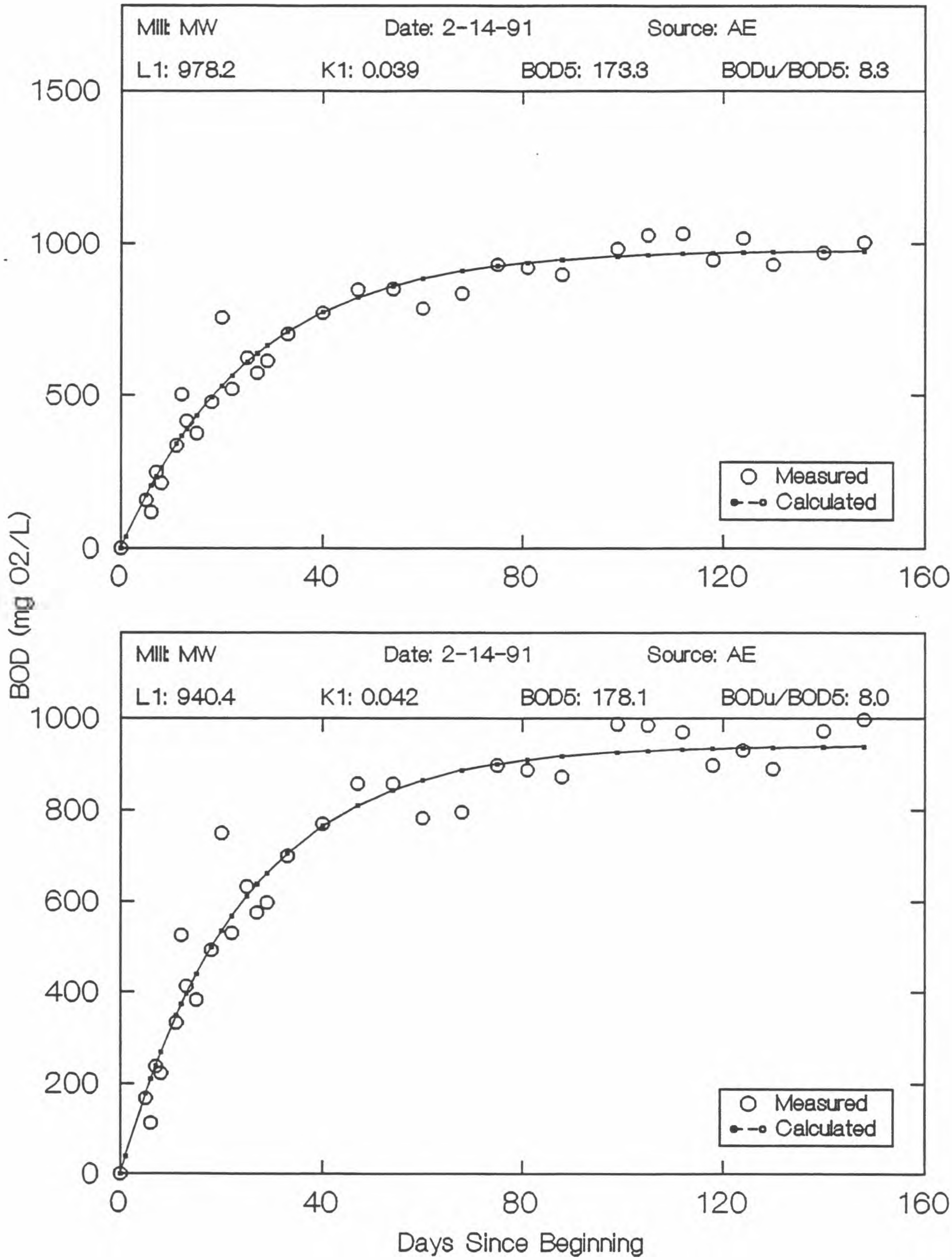


Figure A1-38 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

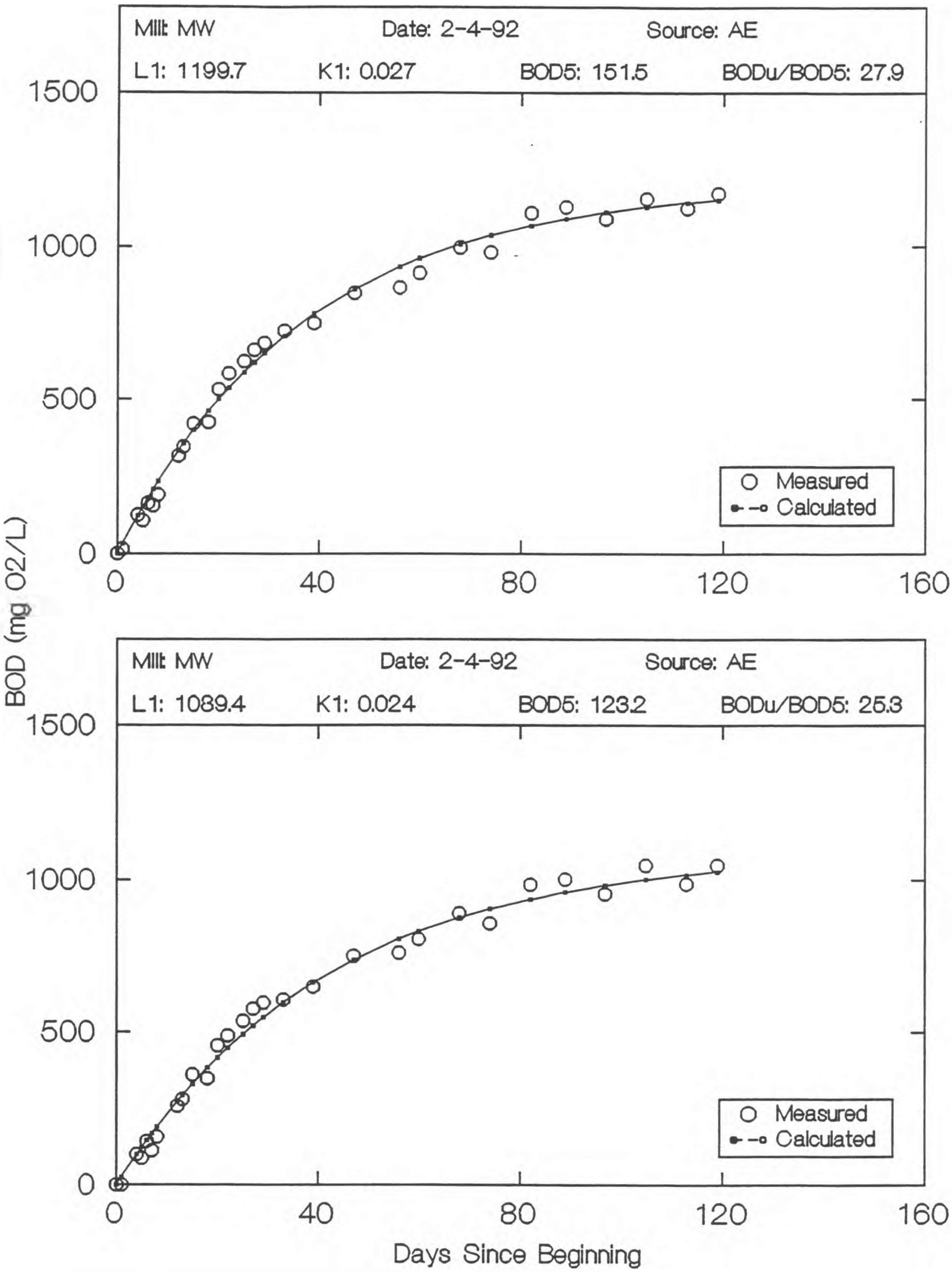


Figure A1-39 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

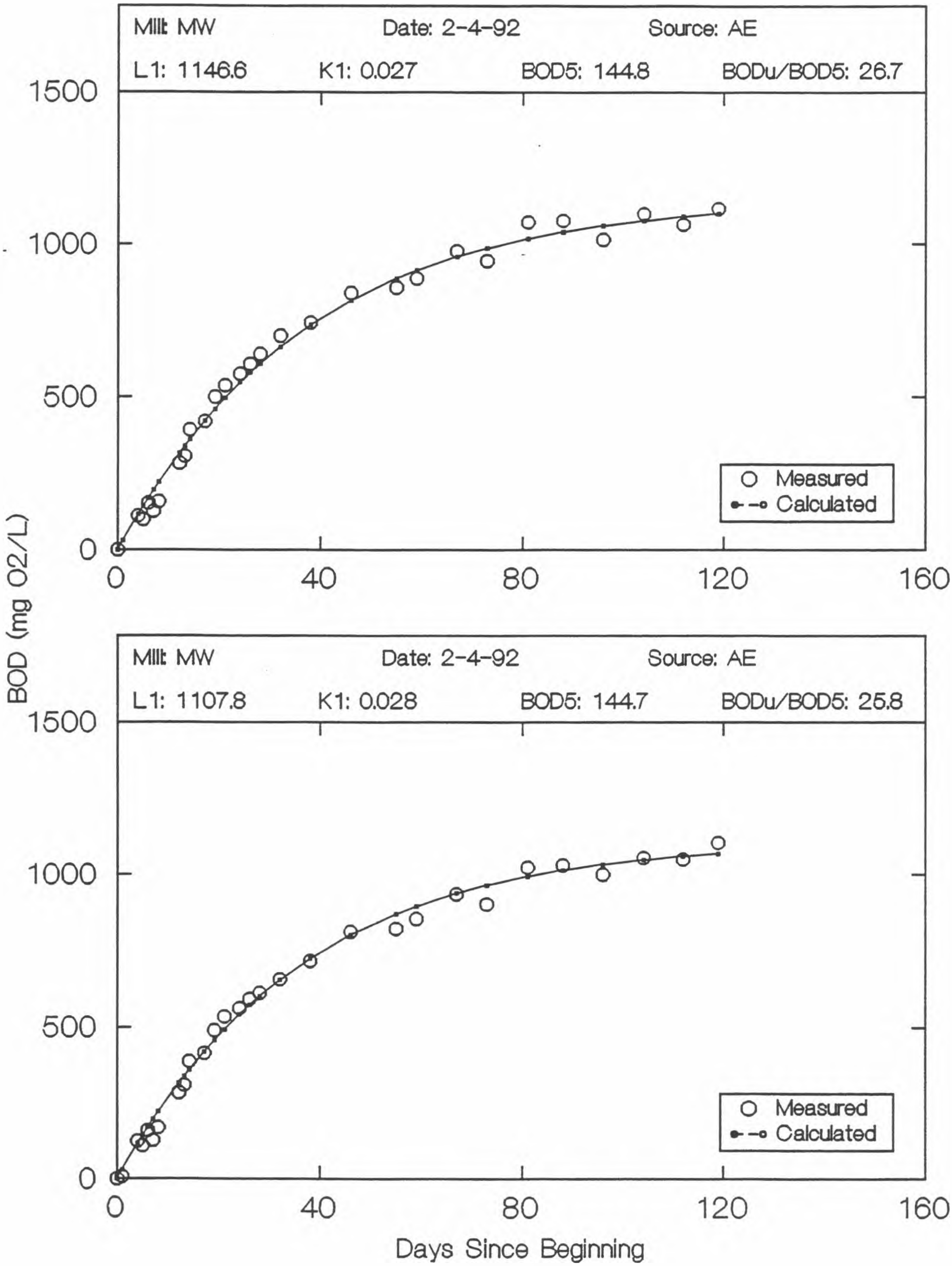


Figure A1-40 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

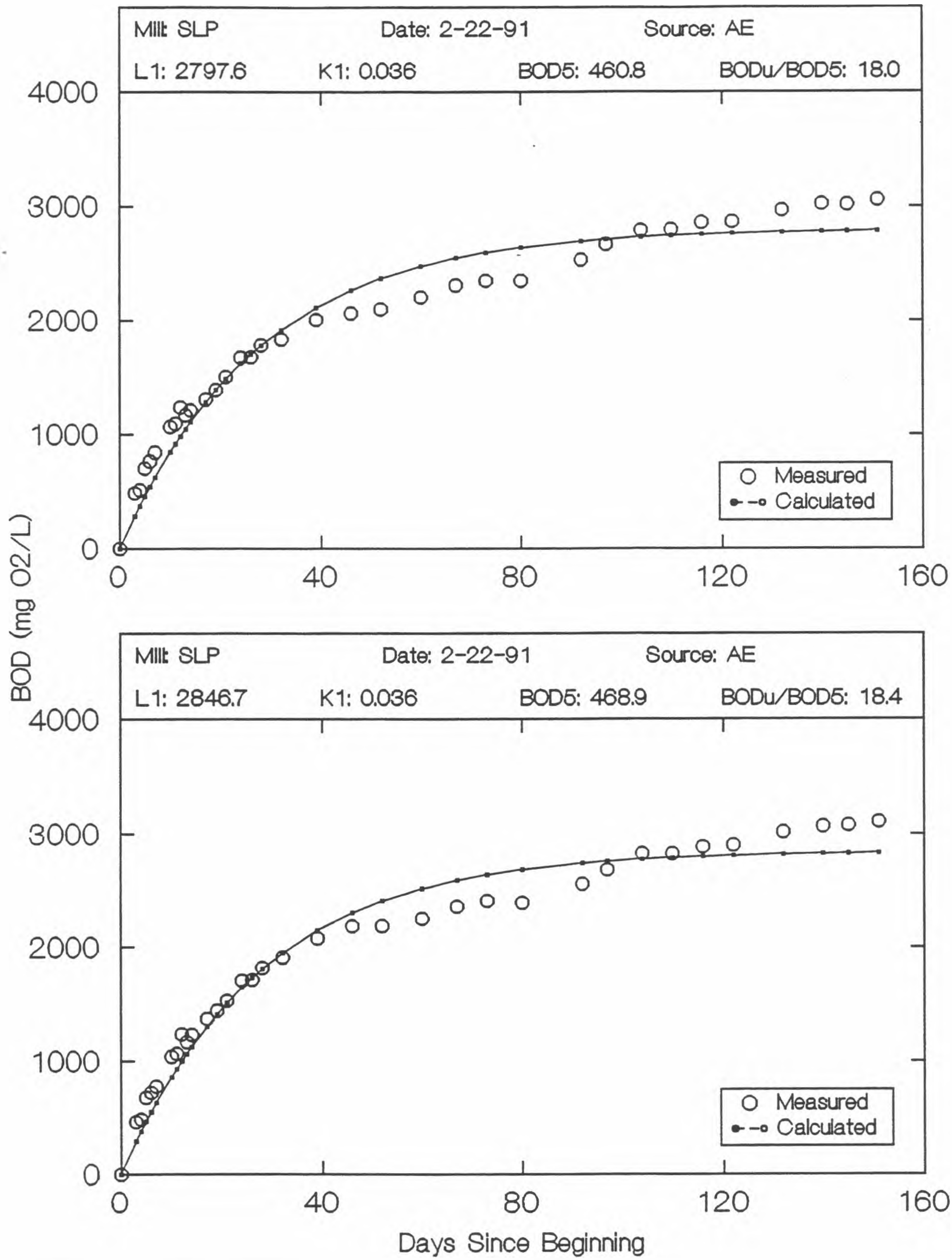


Figure A1-41 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

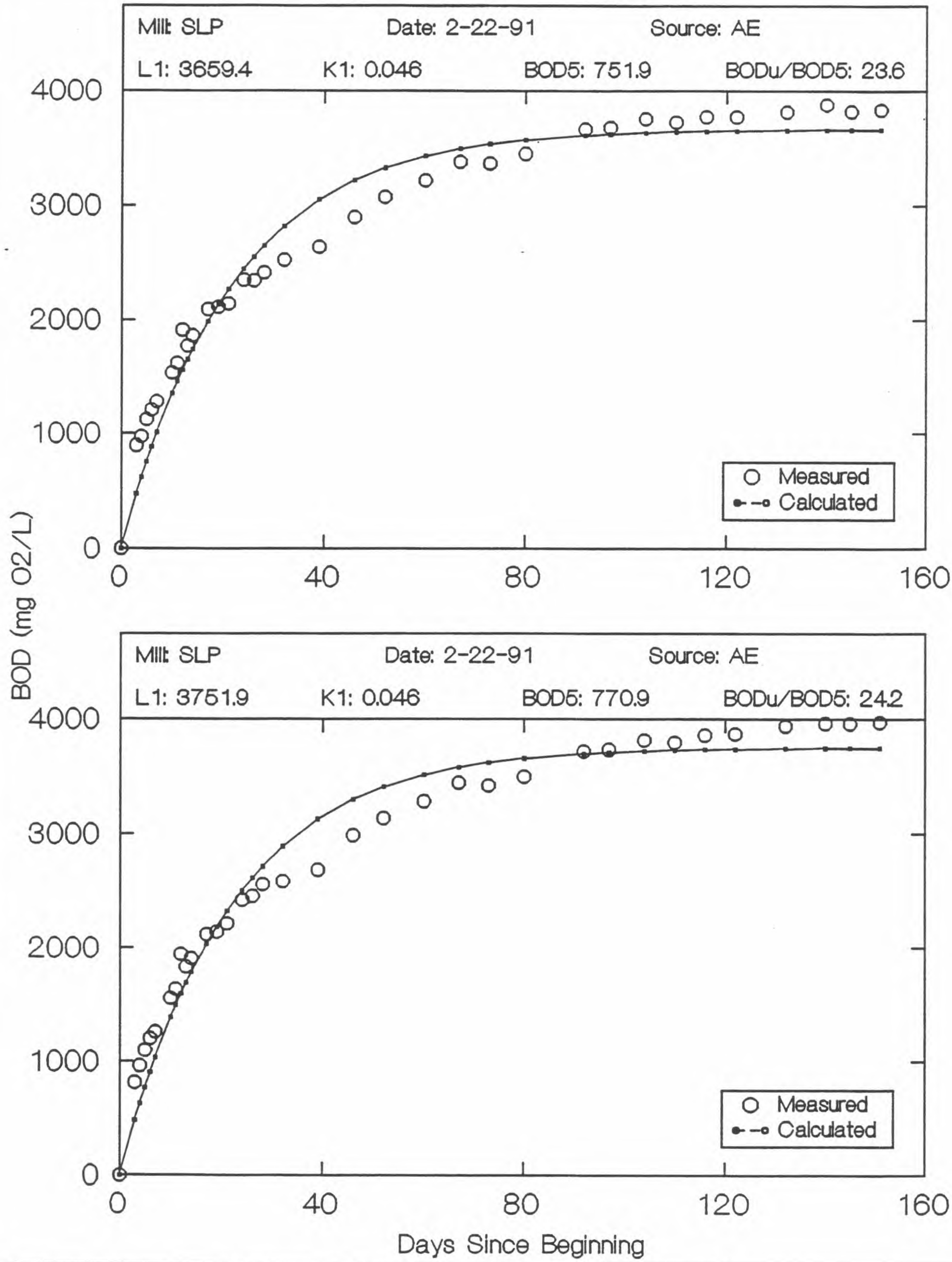


Figure A1-42 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

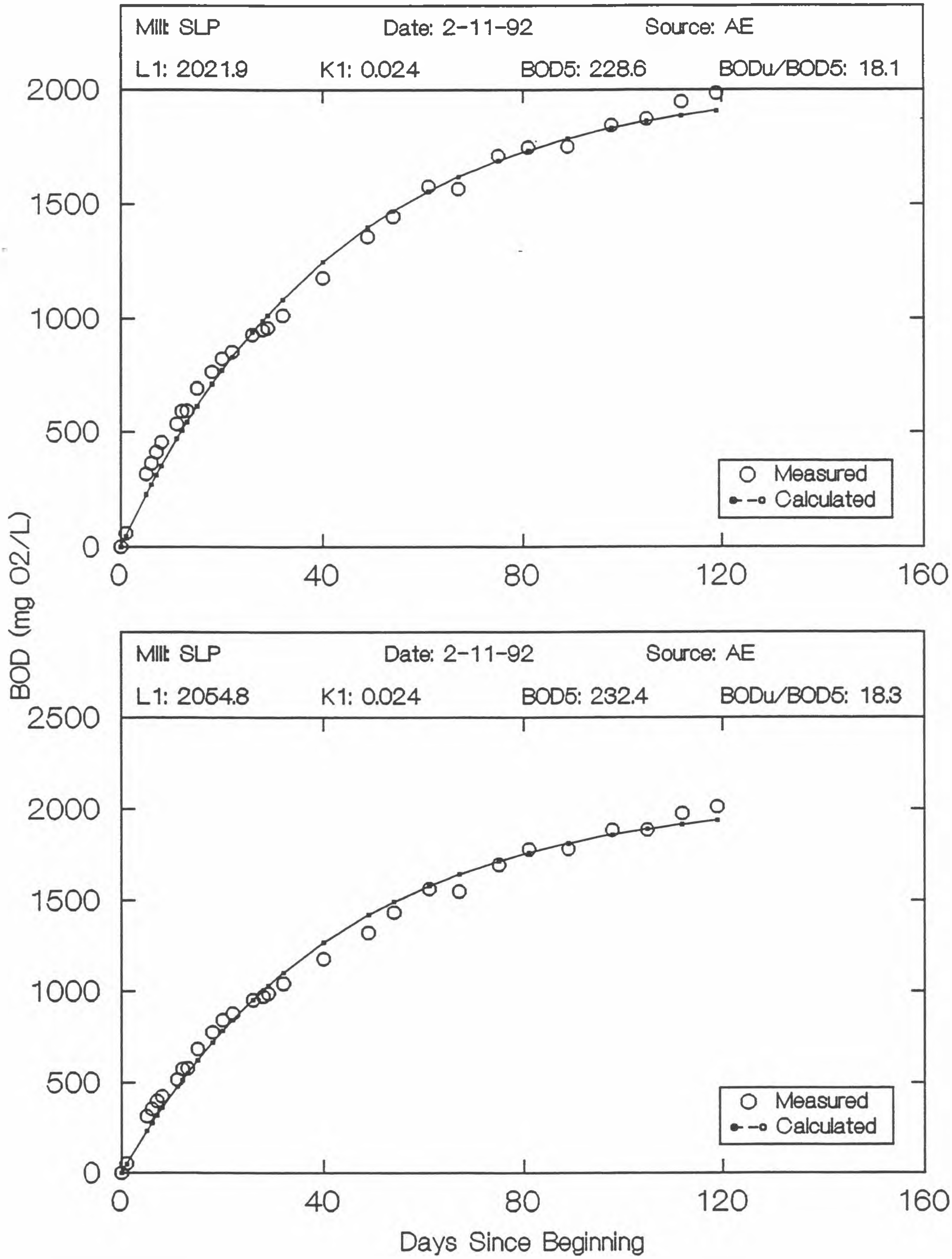


Figure A1-43 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

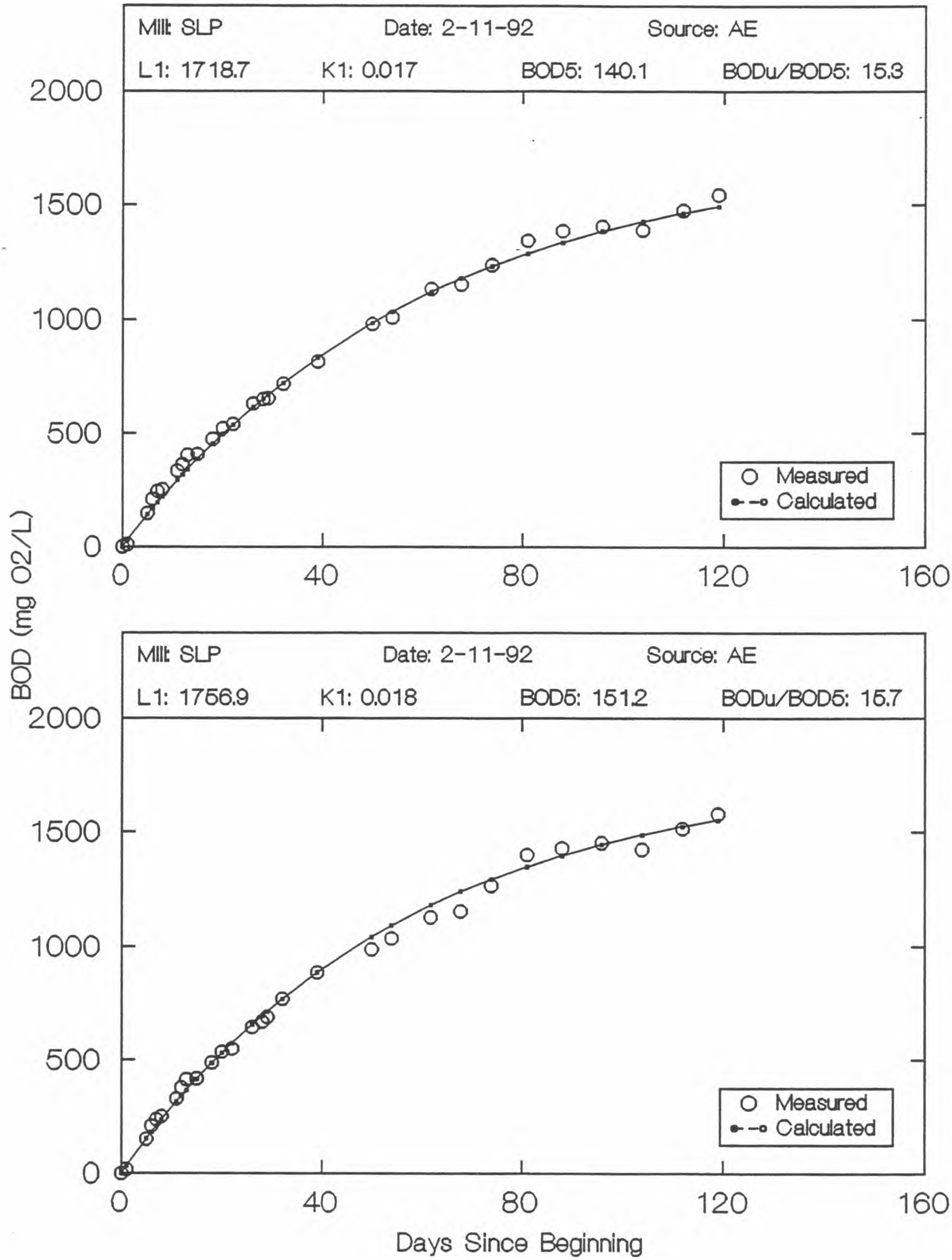


Figure A1-44 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

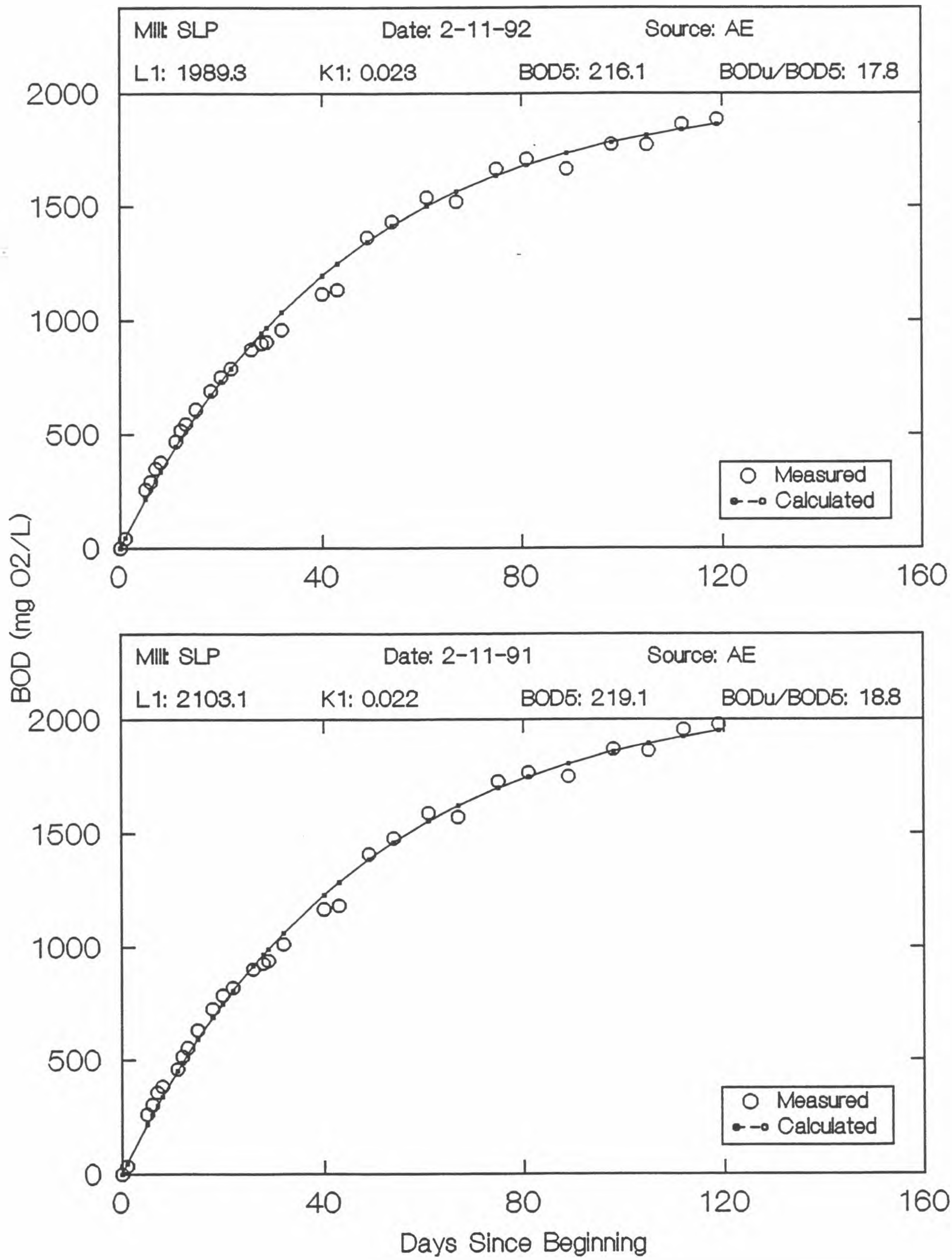


Figure A1-45 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

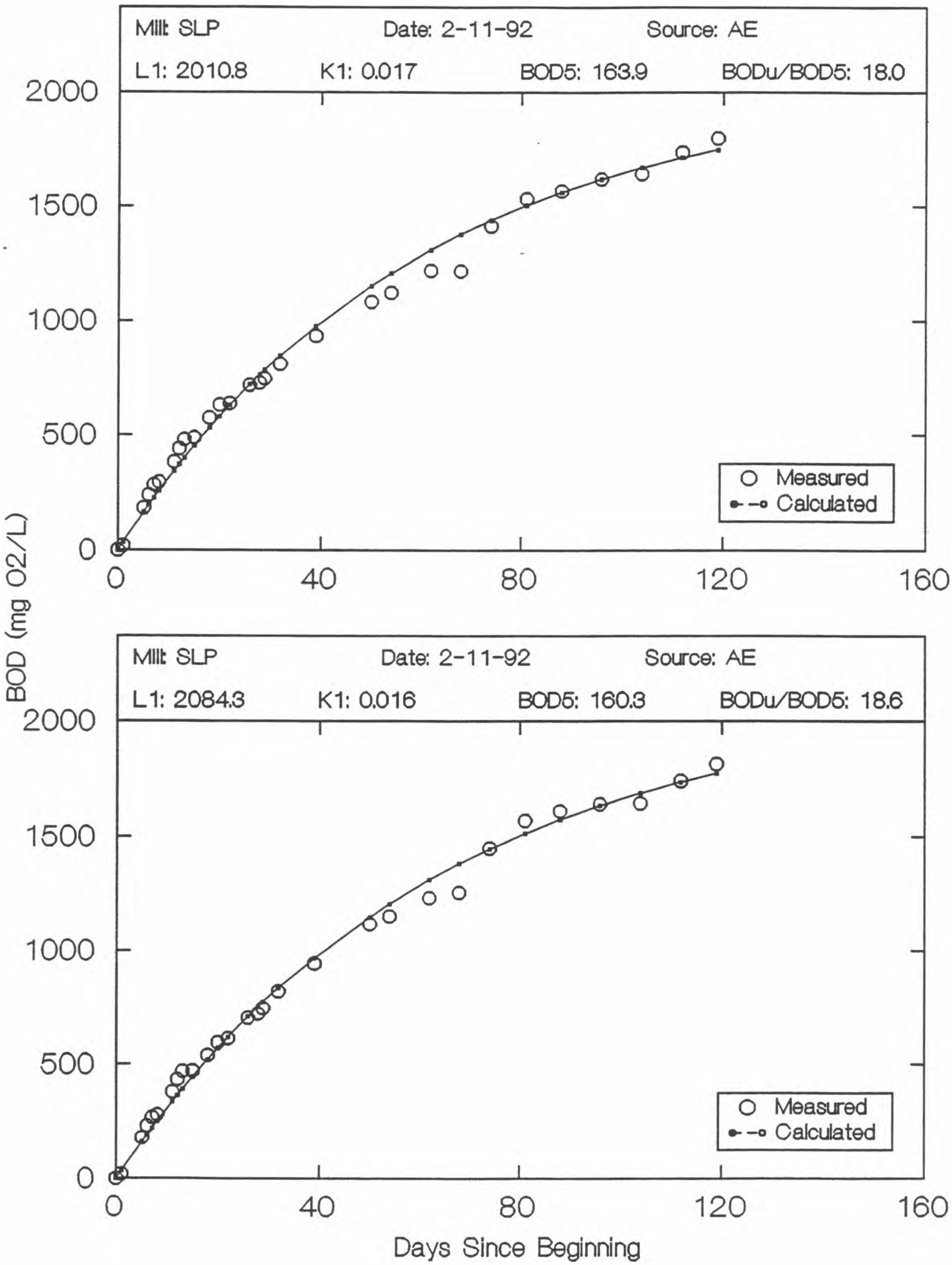


Figure A1-46 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

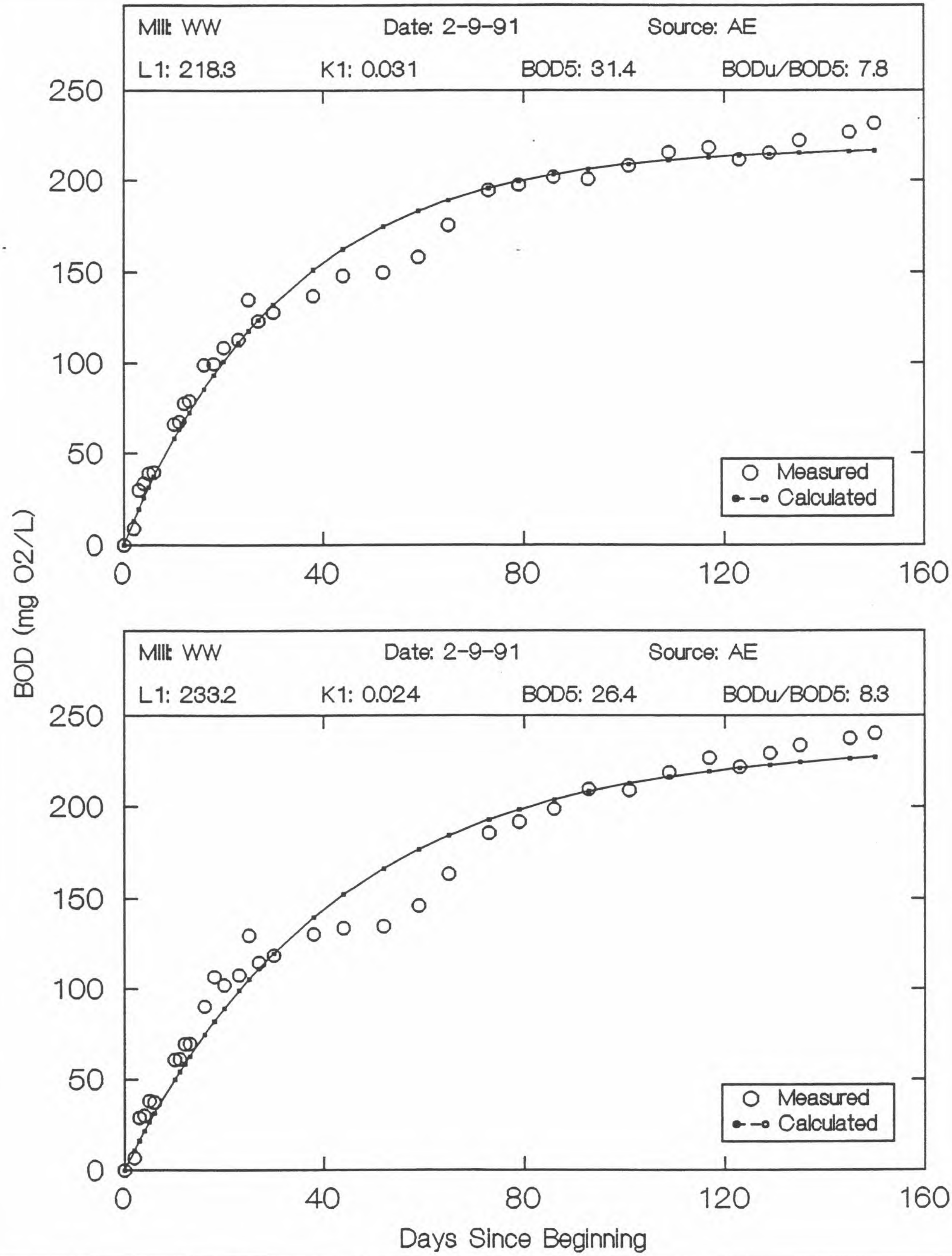


Figure A1-47 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

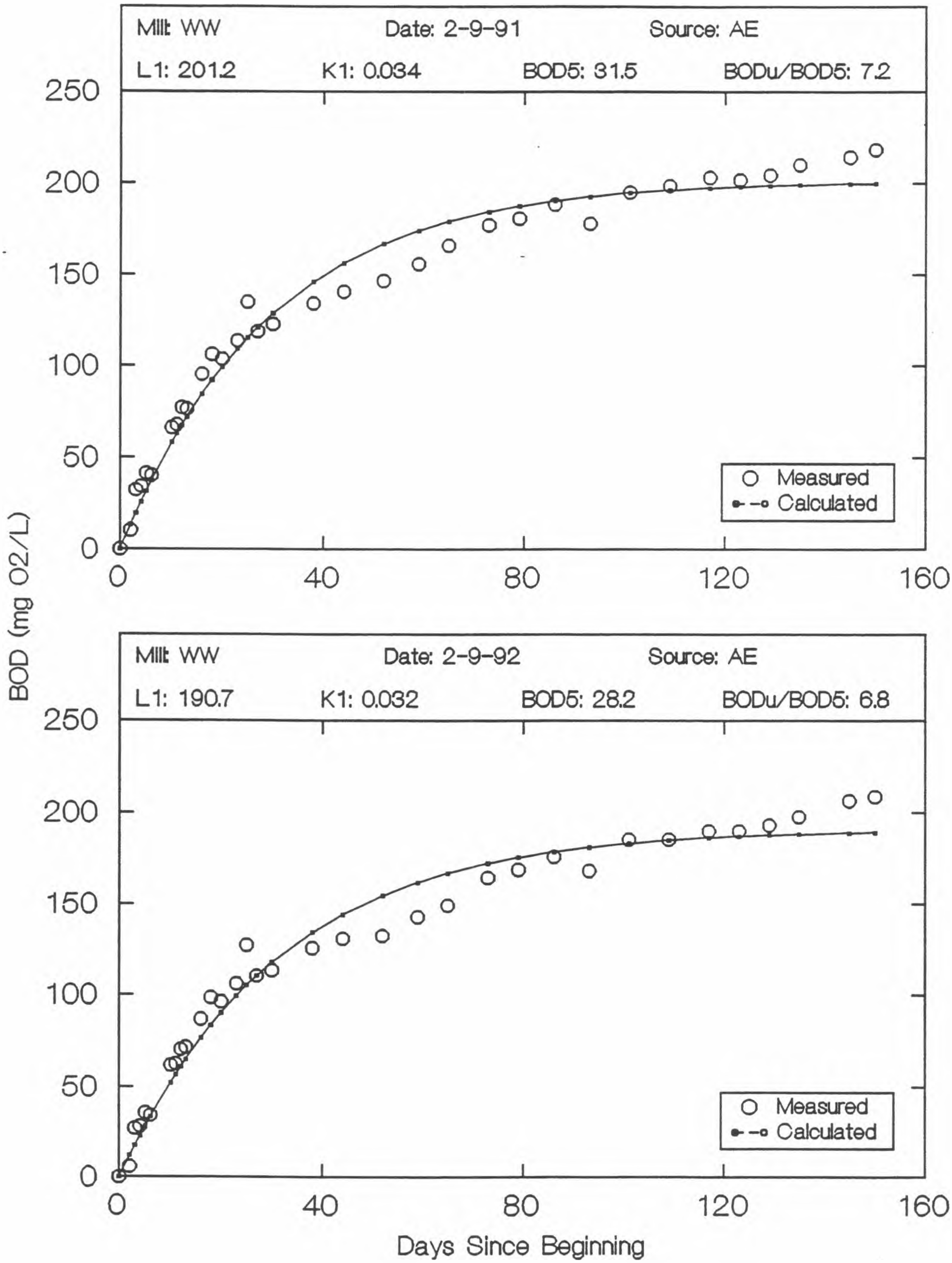


Figure A1-48 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

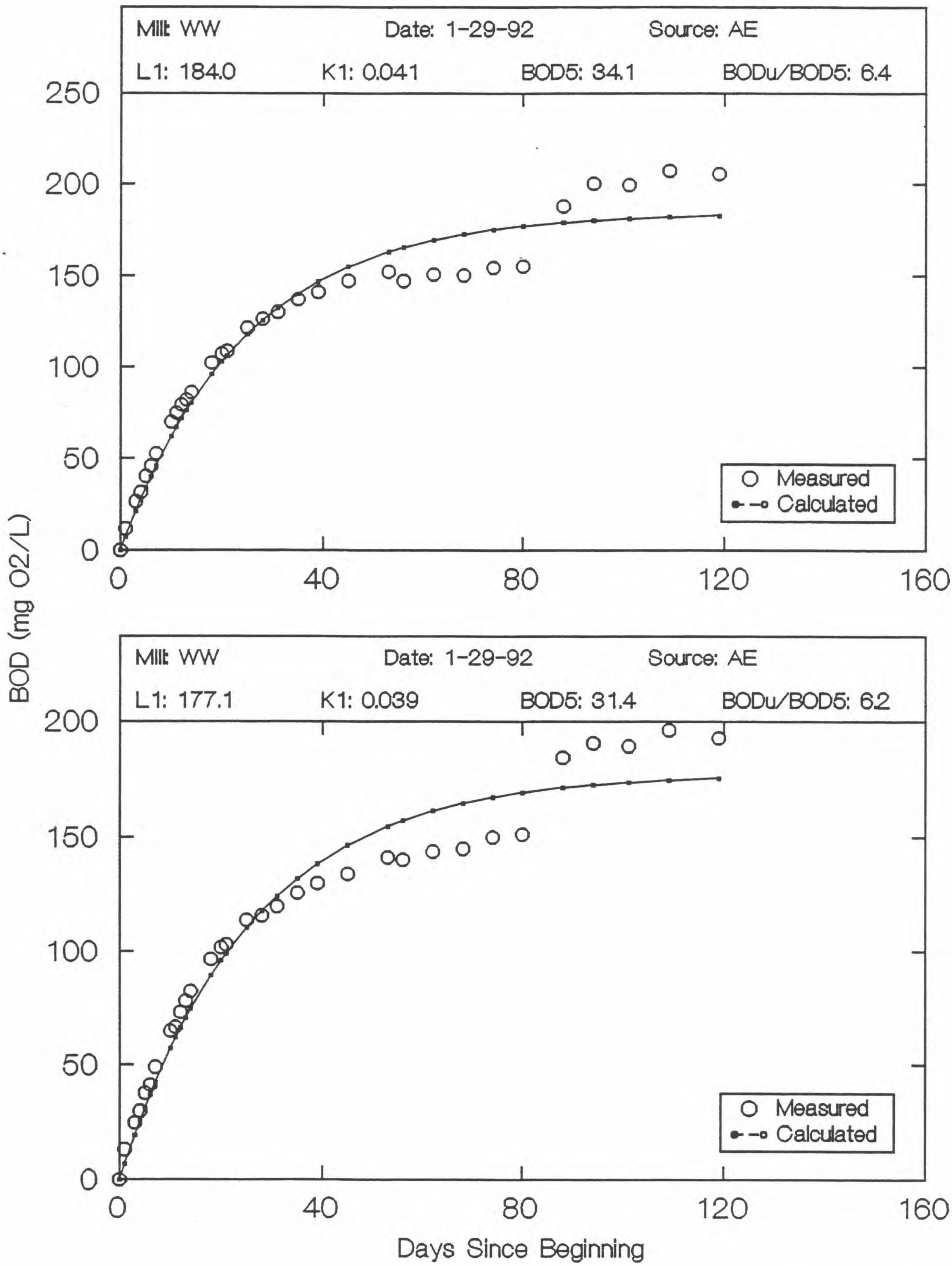


Figure A1-49 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

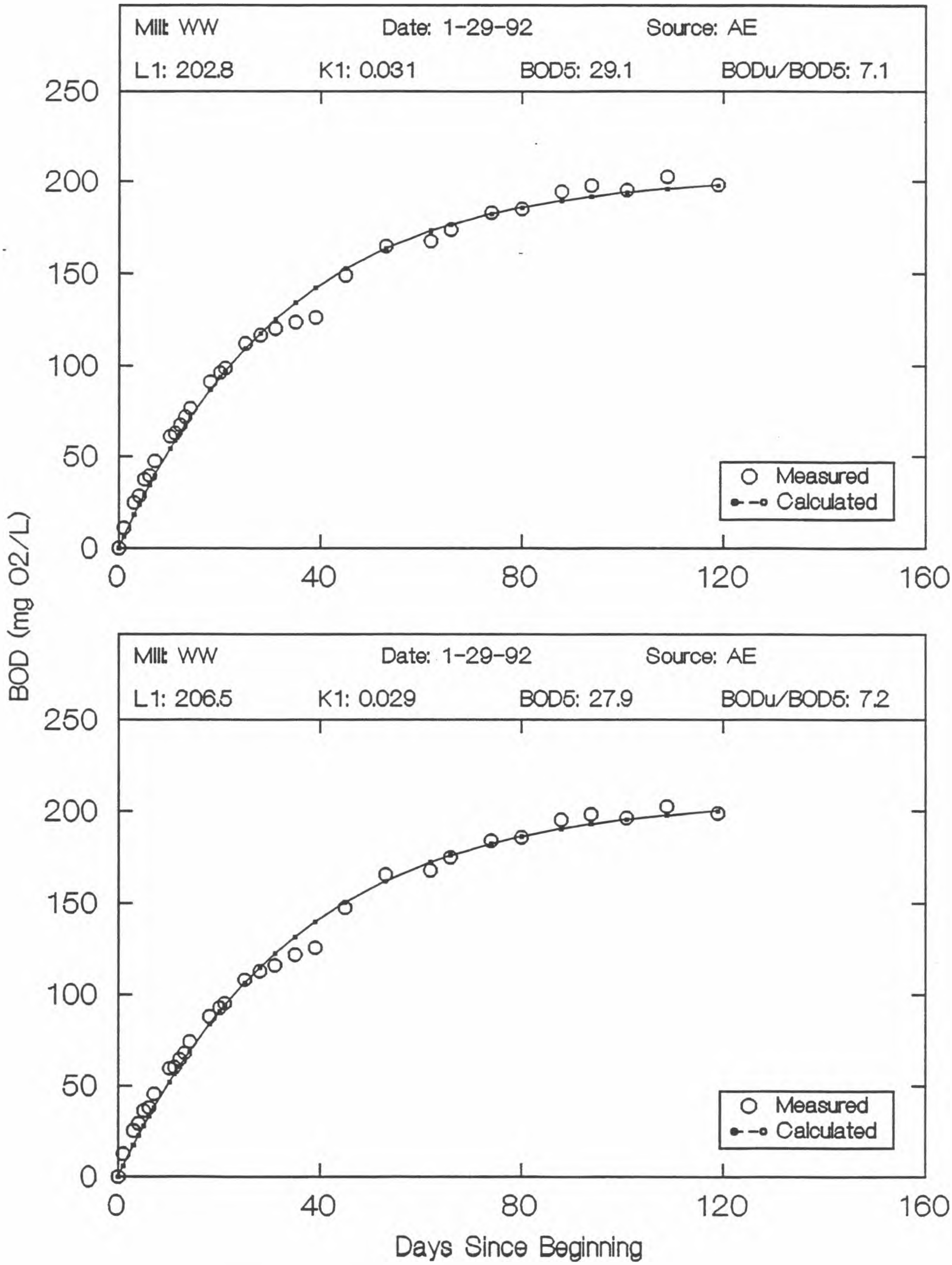


Figure A1-50 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

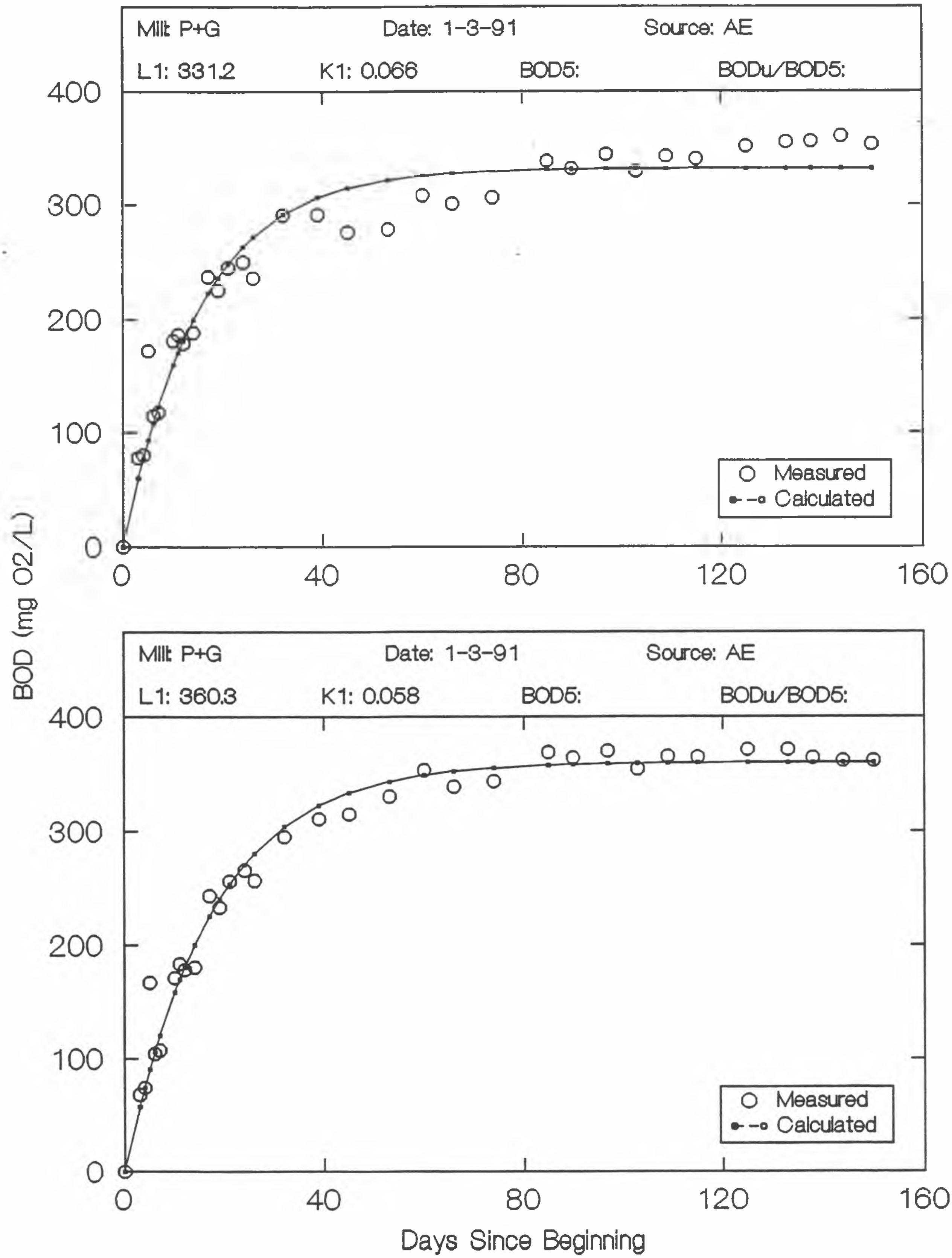


Figure A1-51 March 12, 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

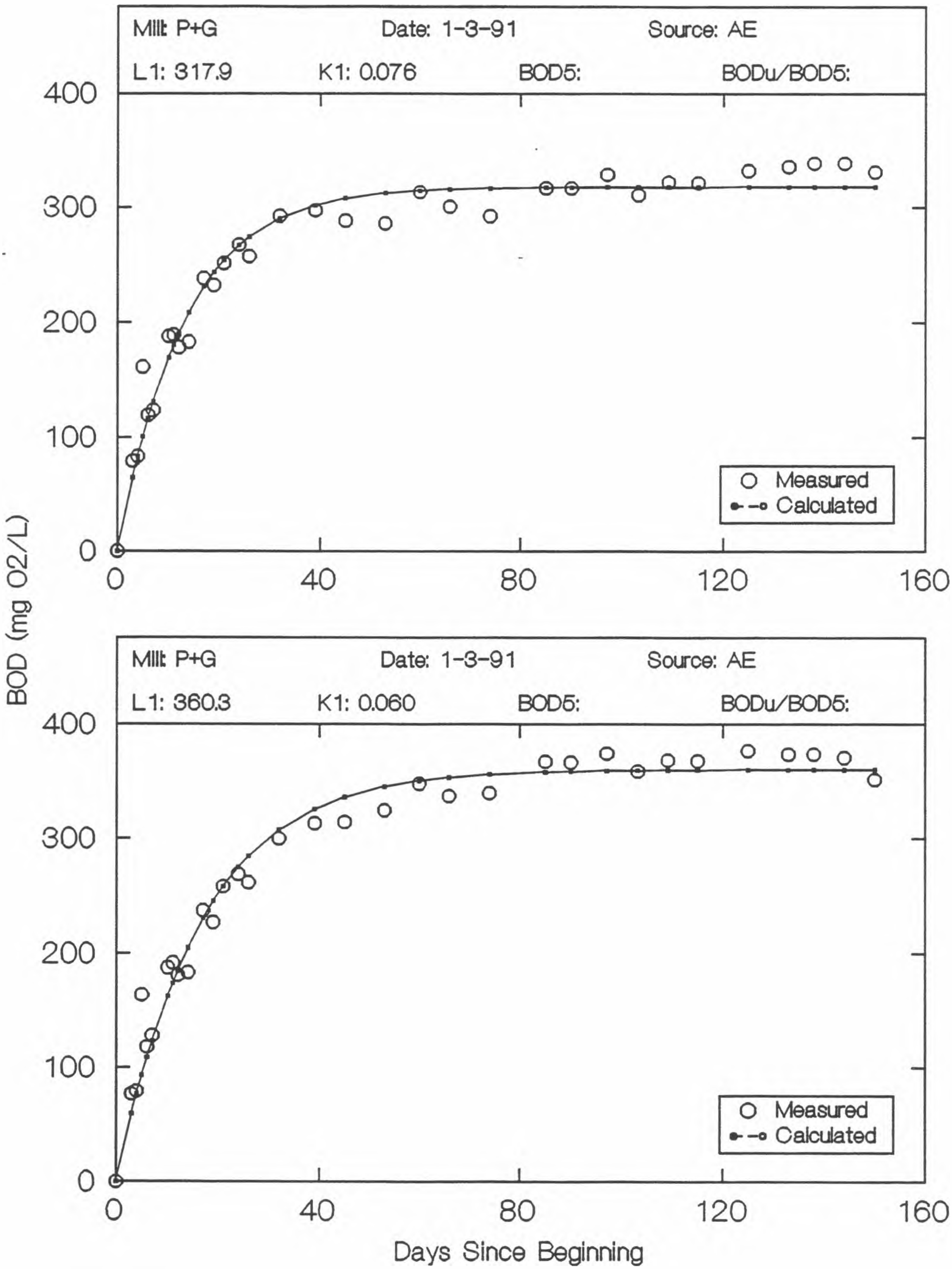
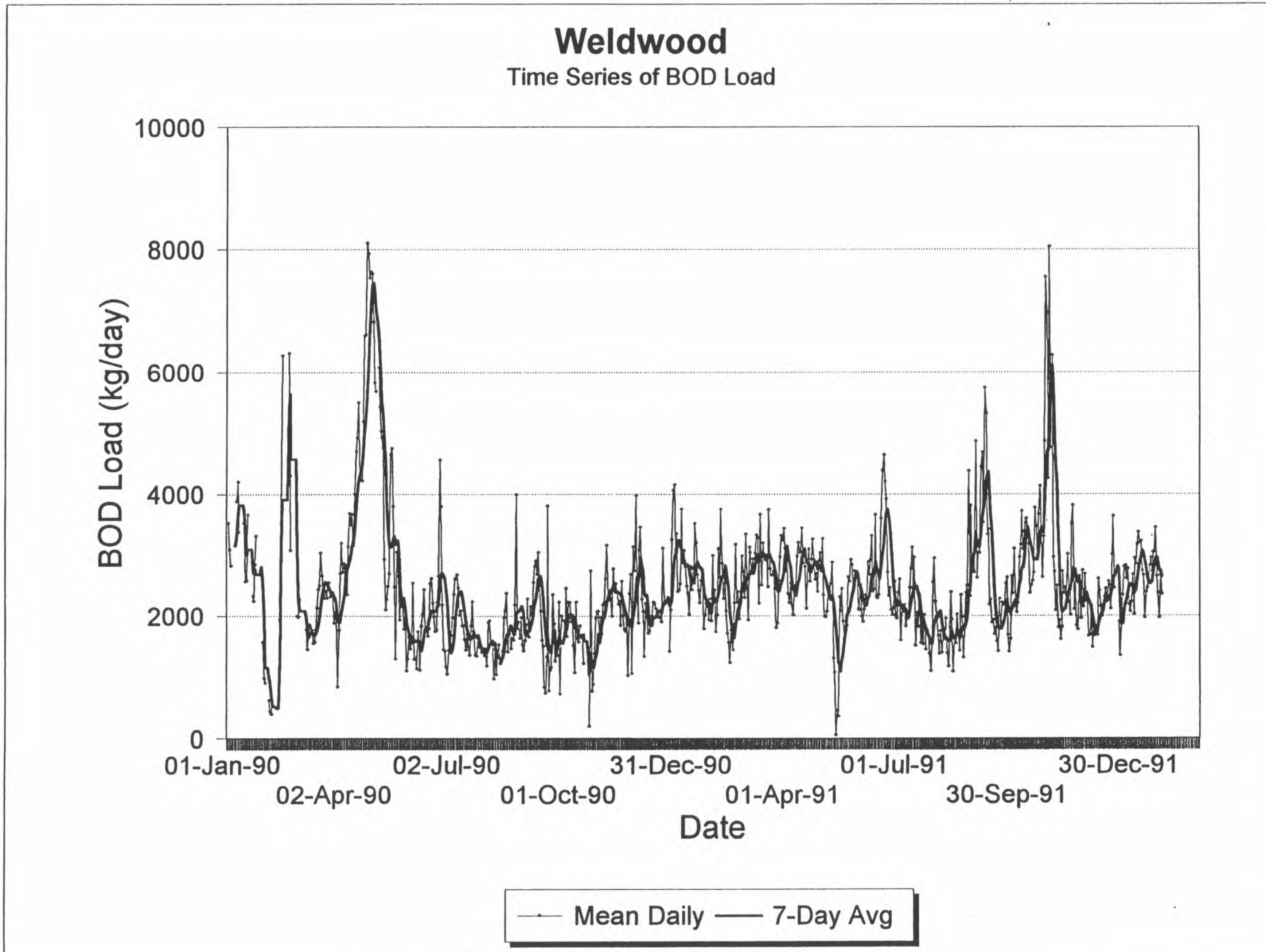
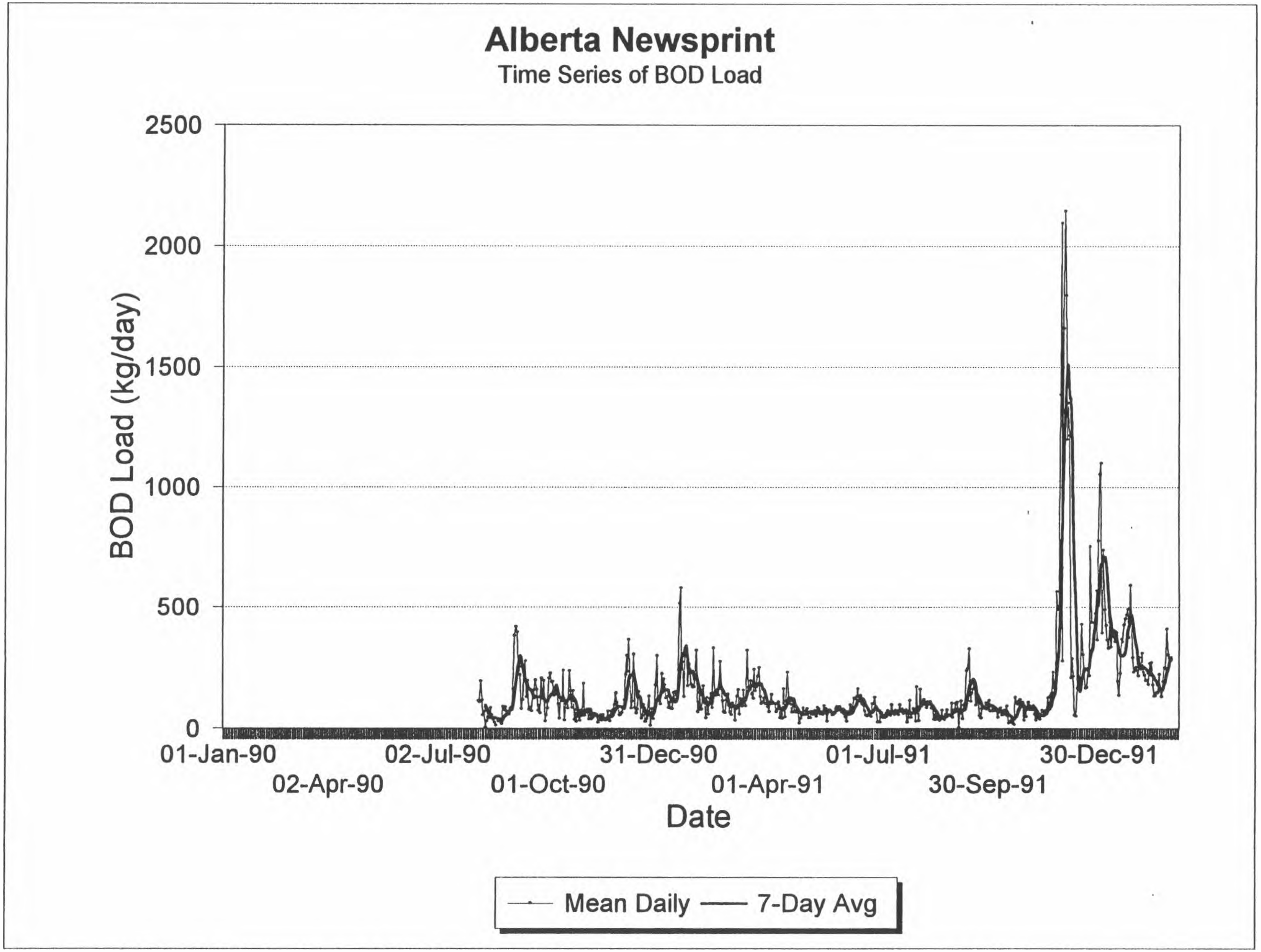


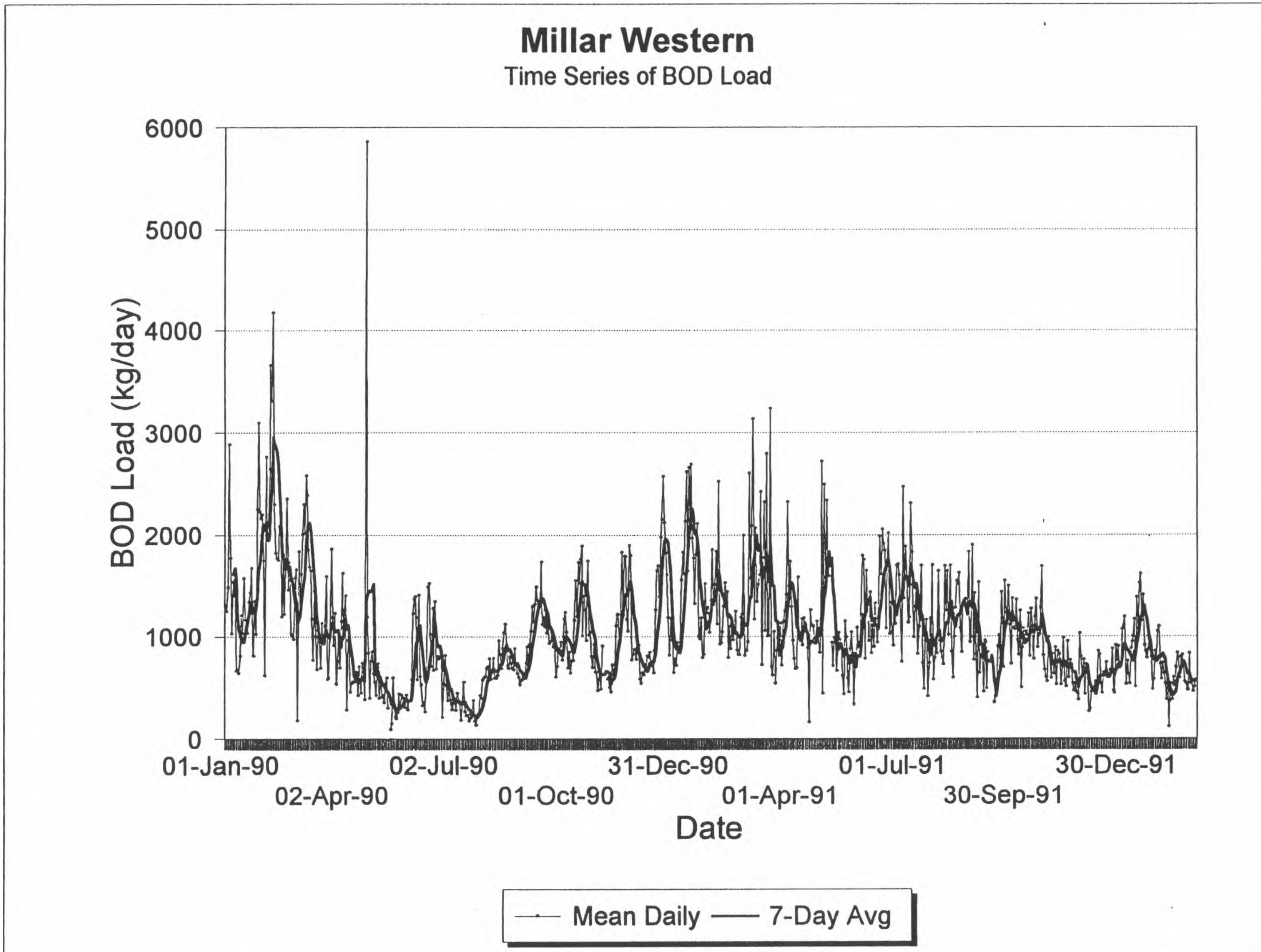
Figure A1-52 March 12. 1993	Measured and Calculated BOD versus Time	Environmental Management Associates

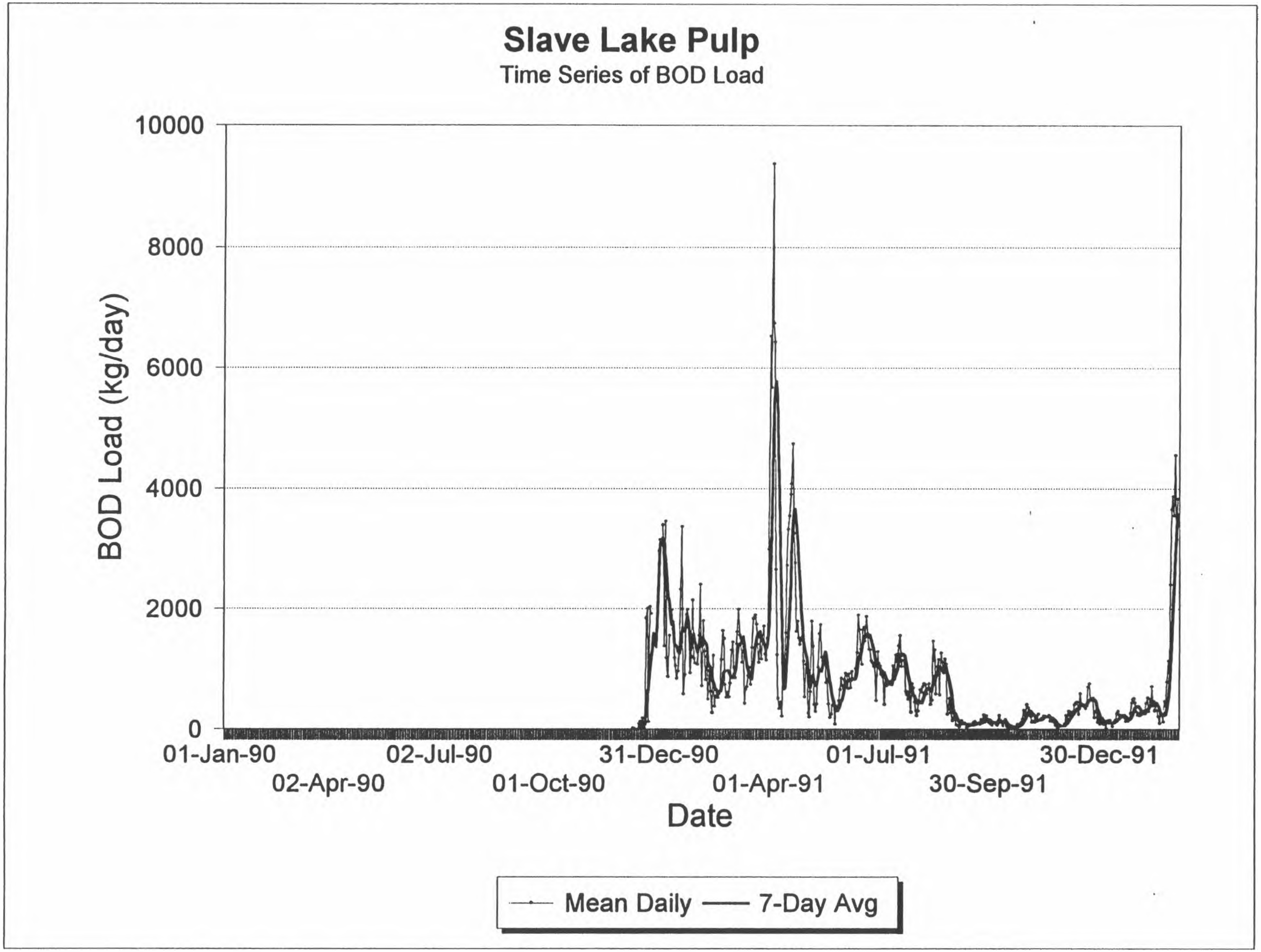
APPENDIX B

TIME SERIES BOD GRAPHS


Weldwood
Time Series of BOD Load
BOD Load (kg/day)
10000
8000
6000
4000
2000
0
01-Jan-90
02-Apr-90
02-Jul-90
01-Oct-90
31-Dec-90
01-Apr-91
01-Jul-91
30-Sep-91
30-Dec-91
Date
Mean Daily
7-Day Avg


Alberta Newsprint
Time Series of BOD Load
BOD Load (kg/day)
2500
2000
1500
1000
500
0
01-Jan-90
02-Apr-90
02-Jul-90
01-Oct-90
31-Dec-90
01-Apr-91
01-Jul-91
30-Sep-91
30-Dec-91
Date
Mean Daily
7-Day Avg

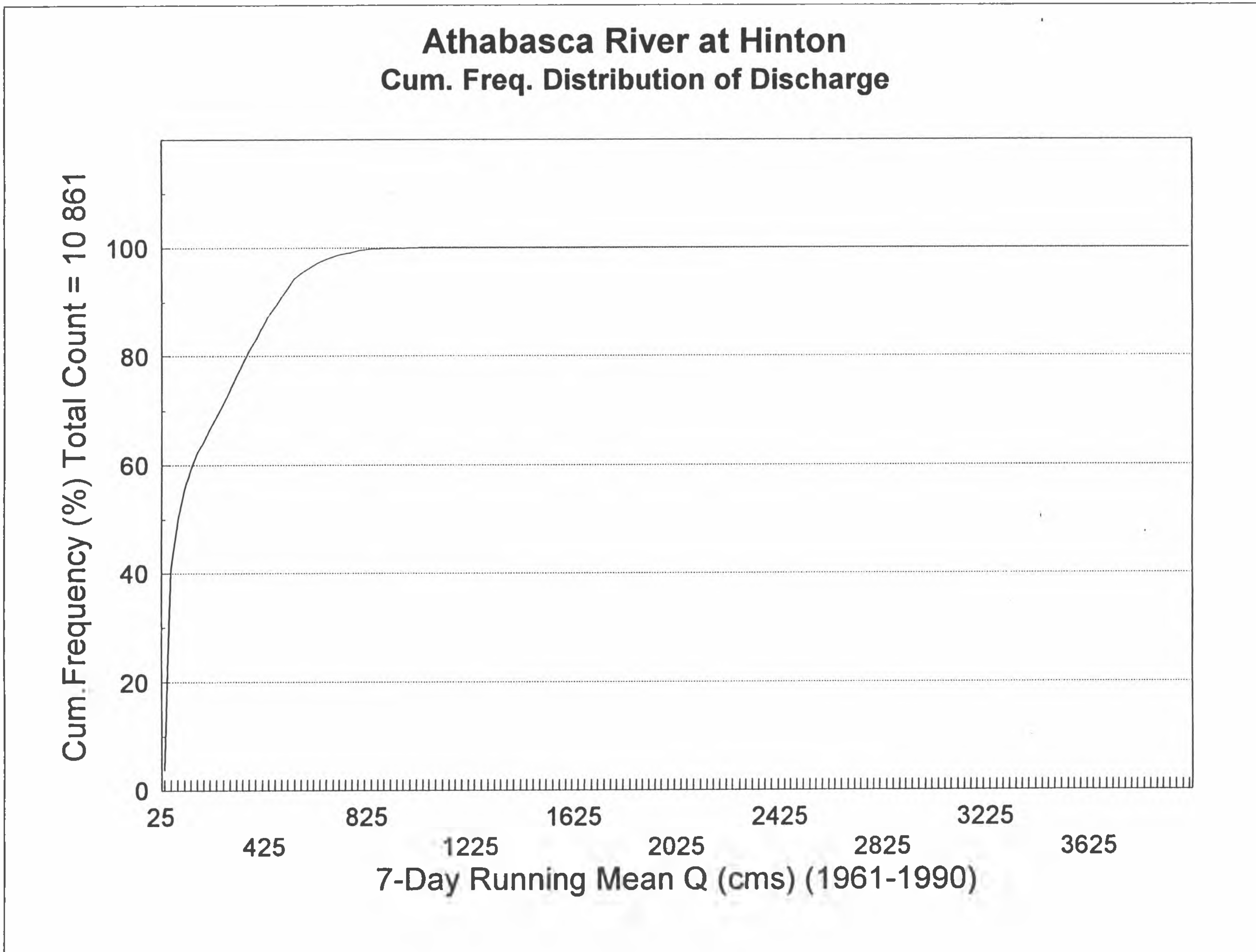

Millar Western
Time Series of BOD Load
BOD Load (kg/day)
6000
5000
4000
3000
2000
1000
0
01-Jan-90
02-Apr-90
02-Jul-90
01-Oct-90
31-Dec-90
01-Apr-91
01-Jul-91
30-Sep-91
30-Dec-91
Date
Mean Daily
7-Day Avg

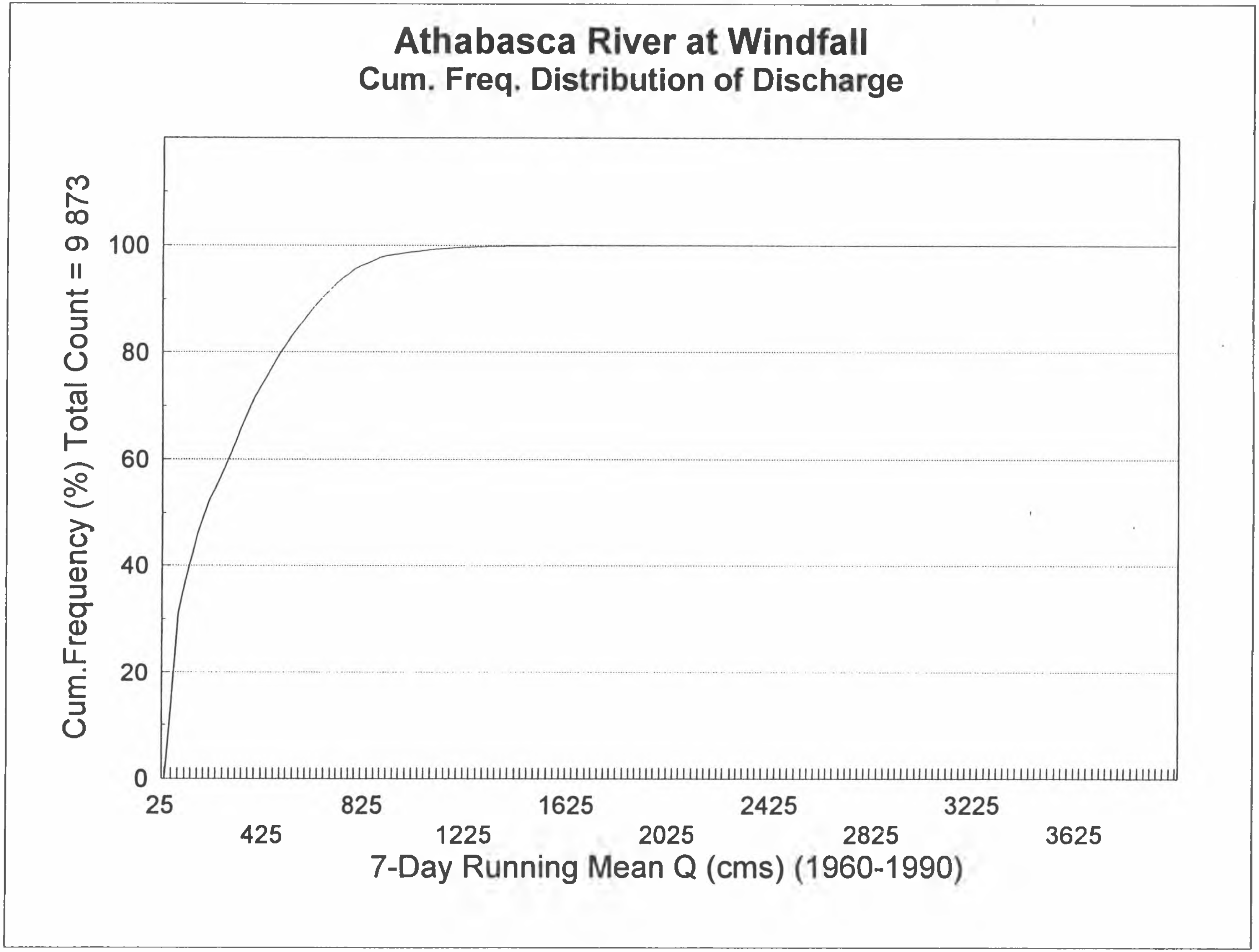


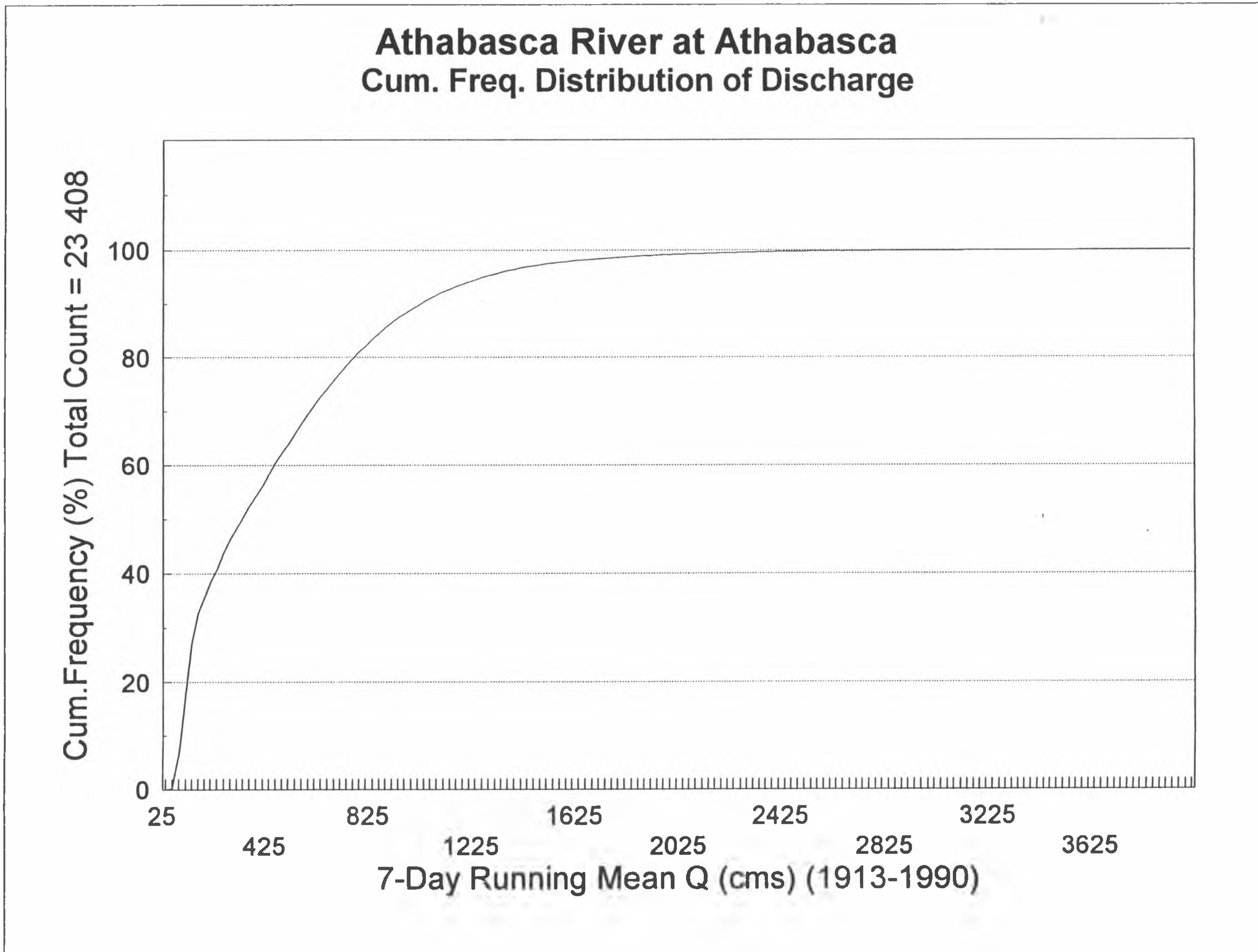
Slave Lake Pulp
Time Series of BOD Load
BOD Load (kg/day)
10000
8000
6000
4000
2000
0
01-Jan-90
02-Apr-90
02-Jul-90
01-Oct-90
31-Dec-90
01-Apr-91
01-Jul-91
30-Sep-91
30-Dec-91
Date
Mean Daily
7-Day Avg

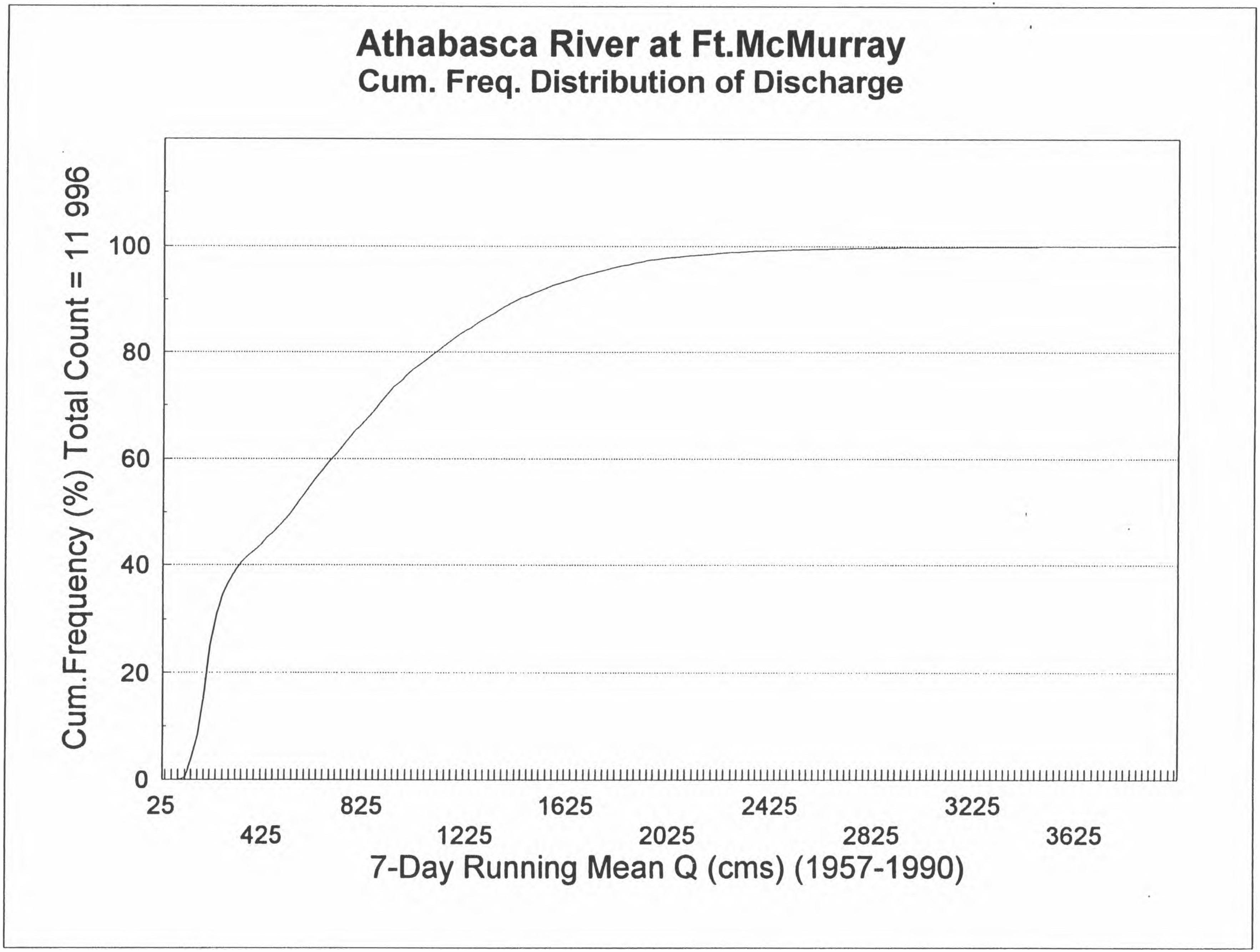
APPENDIX C

FLOW PROBABILITY GRAPHS


Athabasca River at Hinton
Cum. Freq. Distribution of Discharge
Cum.Frequency (%) Total Count = 10 861
100
80
60
40
20
0
25
425
825
1225
1625
2025
2425
2825
3225
3625
7-Day Running Mean Q (cms) (1961-1990)


Athabasca River at Windfall
Cum. Freq. Distribution of Discharge
Cum.Frequency (%) Total Count = 9 873
100
80
60
40
20
0
25
425
825
1225
1625
2025
2425
2825
3225
3625
7-Day Running Mean Q (cms) (1960-1990)


Athabasca River at Athabasca
Cum. Freq. Distribution of Discharge
Cum.Frequency (%) Total Count = 23 408
0
20
40
60
80
100
25
425
825
1225
1625
2025
2425
2825
3225
3625
7-Day Running Mean Q (cms) (1913-1990)



Athabasca River at Ft.McMurray
Cum. Freq. Distribution of Discharge
Cum.Frequency (%) Total Count = 11 996
100
80
60
40
20
0
25
425
825
1225
1625
2025
2425
2825
3225
3625
7-Day Running Mean Q (cms) (1957-1990)

APPENDIX D

SENSITIVITY ANALYSIS RESULTS

Results of sensitivity analysis using March 1989 calibration file and a 20% preturbation of variables (percent change from original).

VARIABLE	LOCATION	DISSOLVED OXYGEN	EFFLUENT BOD	BACKGROUND BOD
CALIBRATION	U/S BERLAND	0	0	0
	U/S WHITECOURT	0	0	0
	U/S SMITH	0	0	0
	U/S ATHABASCA	0	0	0
	U/S GRAND RAPIDS	0	0	0
	U/S FT. MCMURRAY	0	0	0
	END	0	0	0
INCREASE HEADWATER/TRIBUTARY FLOWS	U/S BERLAND	1.8	-12.2	0.9
	U/S WHITECOURT	1.7	-15.1	0.9
	U/S SMITH	7.0	17.1	1.6
	U/S ATHABASCA	3.6	18.6	1.8
	U/S GRAND RAPIDS	3.9	20.6	2.5
	U/S FT. MCMURRAY	-6.0	1.6	3.0
	END	-3.8	8.7	2.7
DECREASE HEADWATER/TRIBUTARY FLOWS	U/S BERLAND	-2.6	15.9	-1.3
	U/S WHITECOURT	-2.3	21.8	-1.3
	U/S SMITH	-9.6	-23.5	-2.2
	U/S ATHABASCA	-4.9	-23.9	-2.4
	U/S GRAND RAPIDS	-5.1	-25.6	-3.2
	U/S FT. MCMURRAY	10.1	0.3	-3.8
	END	5.4	-9.4	-3.0
INCREASE MILL BOD CONCENTRATIONS	U/S BERLAND	-0.5	20.0	0.0
	U/S WHITECOURT	-0.7	20.0	0.0
	U/S SMITH	-3.3	20.0	0.0
	U/S ATHABASCA	-1.8	19.8	0.0
	U/S GRAND RAPIDS	-2.1	19.4	0.0
	U/S FT. MCMURRAY	-1.3	9.4	0.0
	END	-0.9	8.7	0.0
DECREASE MILL BOD CONCENTRATIONS	U/S BERLAND	0.5	-20.0	0.0
	U/S WHITECOURT	0.7	-20.0	0.0
	U/S SMITH	3.3	-20.0	0.0
	U/S ATHABASCA	1.9	-19.4	0.0
	U/S GRAND RAPIDS	2.1	-19.4	0.0
	U/S FT. MCMURRAY	1.4	-9.4	0.0
	END	0.9	-9.4	0.0
INCREASE MILL D.O. CONCENTRATIONS	U/S BERLAND	0.3	0.0	0.0
	U/S WHITECOURT	0.3	0.0	0.0
	U/S SMITH	0.4	0.0	0.0
	U/S ATHABASCA	0.2	0.0	0.0
	U/S GRAND RAPIDS	0.2	0.0	0.0
	U/S FT. MCMURRAY	0.1	0.0	0.0
	END	0.1	0.0	0.0
DECREASE MILL D.O. CONCENTRATIONS	U/S BERLAND	-0.3	0.0	0.0
	U/S WHITECOURT	-0.3	0.0	0.0
	U/S SMITH	-0.4	0.0	0.0
	U/S ATHABASCA	-0.2	0.0	0.0
	U/S GRAND RAPIDS	-0.2	0.0	0.0
	U/S FT. MCMURRAY	-0.1	0.0	0.0
	END	-0.1	0.0	0.0
INCREASE OTHER EFFLUENT BOD CONCENTRATIONS	U/S BERLAND	0.0	0.0	0.0
	U/S WHITECOURT	0.0	0.0	0.0
	U/S SMITH	0.0	0.0	0.0
	U/S ATHABASCA	0.0	0.4	0.0
	U/S GRAND RAPIDS	0.0	0.6	0.0
	U/S FT. MCMURRAY	0.0	11.0	0.0
	END	-0.1	10.9	0.0
DECREASE OTHER EFFLUENT BOD CONCENTRATIONS	U/S BERLAND	0.0	0.0	0.0
	U/S WHITECOURT	0.0	0.0	0.0
	U/S SMITH	0.0	0.0	0.0
	U/S ATHABASCA	0.0	-0.4	0.0
	U/S GRAND RAPIDS	0.0	-0.6	0.0
	U/S FT. MCMURRAY	0.0	-10.6	0.0
	END	0.1	-11.6	0.0

Results of sensitivity analysis using March 1989 calibration file and a 20% preturbation of variables (percent change from original).

VARIABLE	LOCATION	DISSOLVED OXYGEN	EFFLUENT BOD	BACKGROUND BOD
INCREASE OTHER EFFLUENT D.O.	U/S BERLAND	0.0	0.0	0.0
	U/S WHITECOURT	0.0	0.0	0.0
	U/S SMITH	0.0	0.0	0.0
	U/S ATHABASCA	0.0	0.0	0.0
	U/S GRAND RAPIDS	0.0	0.0	0.0
	U/S FT. MCMURRAY	0.0	0.0	0.0
	END	0.0	0.0	0.0
DECREASE OTHER EFFLUENT D.O.	U/S BERLAND	0.0	0.0	0.0
	U/S WHITECOURT	0.0	0.0	0.0
	U/S SMITH	-0.0	0.0	0.0
	U/S ATHABASCA	0.0	0.0	0.0
	U/S GRAND RAPIDS	0.0	0.0	0.0
	U/S FT. MCMURRAY	-0.0	0.0	0.0
	END	-0.0	0.0	0.0
INCREASE TRIBUTARY BOD	U/S BERLAND	-0.0	0.0	1.2
	U/S WHITECOURT	-0.1	0.0	6.2
	U/S SMITH	-1.1	0.0	7.8
	U/S ATHABASCA	-1.0	0.0	7.0
	U/S GRAND RAPIDS	-1.4	0.0	7.4
	U/S FT. MCMURRAY	-1.0	0.0	7.4
	END	-1.0	0.0	12.3
DECREASE TRIBUTARY BOD	U/S BERLAND	0.0	0.0	-1.2
	U/S WHITECOURT	0.1	0.0	-6.2
	U/S SMITH	1.1	0.0	-7.9
	U/S ATHABASCA	1.0	0.0	-7.0
	U/S GRAND RAPIDS	1.4	0.0	-7.3
	U/S FT. MCMURRAY	1.0	0.0	-7.4
	END	1.0	0.0	-12.3
INCREASE TRIBUTARY D.O. LOAD	U/S BERLAND	1.6	0.0	0.0
	U/S WHITECOURT	6.1	0.0	0.0
	U/S SMITH	9.6	0.0	0.0
	U/S ATHABASCA	6.1	0.0	0.0
	U/S GRAND RAPIDS	6.6	0.0	0.0
	U/S FT. MCMURRAY	4.2	0.0	0.0
	END	11.6	0.0	0.0
DECREASE TRIBUTARY D.O. LOAD	U/S BERLAND	-1.6	0.0	0.0
	U/S WHITECOURT	-6.1	0.0	0.0
	U/S SMITH	-9.6	0.0	0.0
	U/S ATHABASCA	-6.1	0.0	0.0
	U/S GRAND RAPIDS	-6.6	0.0	0.0
	U/S FT. MCMURRAY	-4.2	0.0	0.0
	END	-11.6	0.0	0.0
INCREASE HEADWATER D.O. LOAD	U/S BERLAND	15.8	0.0	0.0
	U/S WHITECOURT	11.9	0.0	0.0
	U/S SMITH	17.2	0.0	0.0
	U/S ATHABASCA	18.6	0.0	0.0
	U/S GRAND RAPIDS	19.6	0.0	0.0
	U/S FT. MCMURRAY	12.1	0.0	0.0
	END	7.5	0.0	0.0
DECREASE HEADWATER D.O. LOAD	U/S BERLAND	-15.8	0.0	0.0
	U/S WHITECOURT	-11.9	0.0	0.0
	U/S SMITH	-17.2	0.0	0.0
	U/S ATHABASCA	-18.6	0.0	0.0
	U/S GRAND RAPIDS	-19.6	0.0	0.0
	U/S FT. MCMURRAY	-12.1	0.0	0.0
	END	-7.5	0.0	0.0

Results of sensitivity analysis using March 1989 calibration file and a 20% preturbation of variables (percent change from original).

VARIABLE	LOCATION	DISSOLVED OXYGEN	EFFLUENT BOD	BACKGROUND BOD
INCREASE HEADWATER BOD LOAD	U/S BERLAND	-0.7	0.0	18.8
	U/S WHITECOURT	-0.9	0.0	13.8
	U/S SMITH	-3.2	0.0	12.1
	U/S ATHABASCA	-2.4	0.0	13.0
	U/S GRAND RAPIDS	-3.3	0.0	12.7
	U/S FT. MCMURRAY	-2.3	0.0	12.6
	END	-1.7	0.0	7.7
DECREASE HEADWATER BOD LOAD	U/S BERLAND	0.7	0.0	-18.8
	U/S WHITECOURT	0.9	0.0	-13.8
	U/S SMITH	3.2	0.0	-12.2
	U/S ATHABASCA	2.4	0.0	-13.0
	U/S GRAND RAPIDS	3.3	0.0	-12.6
	U/S FT. MCMURRAY	2.3	0.0	-12.6
	END	1.7	0.0	-7.7
INCREASE VELOCITY	U/S BERLAND	2.4	8.6	1.2
	U/S WHITECOURT	2.4	3.1	1.8
	U/S SMITH	10.3	72.9	4.8
	U/S ATHABASCA	5.8	81.8	6.1
	U/S GRAND RAPIDS	6.4	92.8	8.6
	U/S FT. MCMURRAY	-3.9	47.7	10.3
	END	-1.2	54.3	8.7
DECREASE VELOCITY	U/S BERLAND	-2.4	-7.9	-1.2
	U/S WHITECOURT	-2.3	-2.8	-1.7
	U/S SMITH	-10.6	-43.5	-5.4
	U/S ATHABASCA	-5.8	-45.7	-6.5
	U/S GRAND RAPIDS	-6.4	-48.9	-8.5
	U/S FT. MCMURRAY	3.8	-24.5	-10.6
	END	1.2	-28.3	-8.6
INCREASE SETTLING RATE	U/S BERLAND	0.1	-6.0	0.0
	U/S WHITECOURT	0.2	-2.1	0.0
	U/S SMITH	2.4	-36.5	0.0
	U/S ATHABASCA	1.6	-35.6	0.0
	U/S GRAND RAPIDS	2.0	-36.1	0.0
	U/S FT. MCMURRAY	1.3	-16.8	0.0
	END	0.9	-16.7	0.0
DECREASE SETTLING RATE	U/S BERLAND	-0.1	6.4	0.0
	U/S WHITECOURT	-0.2	2.3	0.0
	U/S SMITH	-3.1	57.6	0.0
	U/S ATHABASCA	-2.2	56.7	0.0
	U/S GRAND RAPIDS	-2.8	56.7	0.0
	U/S FT. MCMURRAY	-1.9	26.8	0.0
	END	-1.3	25.4	0.0
INCREASE BACKGROUND BOD DECAY RATE	U/S BERLAND	-0.7	0.0	-1.2
	U/S WHITECOURT	-1.0	0.0	-1.7
	U/S SMITH	-3.7	0.0	-4.5
	U/S ATHABASCA	-2.7	0.0	-5.8
	U/S GRAND RAPIDS	-3.5	0.0	-7.8
	U/S FT. MCMURRAY	-2.4	0.0	-9.2
	END	-1.8	0.0	-7.8
DECREASE BACKGROUND BOD DECAY RATE	U/S BERLAND	0.7	0.0	1.2
	U/S WHITECOURT	1.0	0.0	1.8
	U/S SMITH	3.9	0.0	4.8
	U/S ATHABASCA	2.9	0.0	6.1
	U/S GRAND RAPIDS	3.9	0.0	8.6
	U/S FT. MCMURRAY	2.7	0.0	10.3
	END	2.1	0.0	8.7

Results of sensitivity analysis using March 1989 calibration file and a 20% preturbation of variables (percent change from original).

VARIABLE	LOCATION	DISSOLVED OXYGEN	EFFLUENT BOD	BACKGROUND BOD
INCREASE EFFLUENT BOD DECAY RATE	U/S BERLAND	-0.5	-2.0	0.0
	U/S WHITECOURT	-0.6	-0.8	0.0
	U/S SMITH	-2.8	-8.8	0.0
	U/S ATHABASCA	-1.4	-13.4	0.0
	U/S GRAND RAPIDS	-1.5	-18.9	0.0
	U/S FT. MCMURRAY	-0.9	-10.3	0.0
	END	-0.6	-15.9	0.0
DECREASE EFFLUENT BOD DECAY RATE	U/S BERLAND	0.5	2.0	0.0
	U/S WHITECOURT	0.7	0.8	0.0
	U/S SMITH	2.9	9.6	0.0
	U/S ATHABASCA	1.6	15.8	0.0
	U/S GRAND RAPIDS	1.7	23.3	0.0
	U/S FT. MCMURRAY	1.0	13.5	0.0
	END	0.7	19.6	0.0
INCREASE OPENWATER REAERATION RATE	U/S BERLAND	0.8	0.0	0.0
	U/S WHITECOURT	0.9	0.0	0.0
	U/S SMITH	1.3	0.0	0.0
	U/S ATHABASCA	0.7	0.0	0.0
	U/S GRAND RAPIDS	0.7	0.0	0.0
	U/S FT. MCMURRAY	0.4	0.0	0.0
	END	0.3	0.0	0.0
DECREASE OPENWATER REAERATION RATE	U/S BERLAND	-0.8	0.0	0.0
	U/S WHITECOURT	-0.9	0.0	0.0
	U/S SMITH	-1.4	0.0	0.0
	U/S ATHABASCA	-0.7	0.0	0.0
	U/S GRAND RAPIDS	-0.7	0.0	0.0
	U/S FT. MCMURRAY	-0.4	0.0	0.0
	END	-0.3	0.0	0.0
INCREASE ICE COVER REAERATION RATE*	U/S BERLAND	1.7	0.0	0.0
	U/S WHITECOURT	2.9	0.0	0.0
	U/S SMITH	18.0	0.6	-0.6
	U/S ATHABASCA	13.6	0.8	-0.5
	U/S GRAND RAPIDS	19.4	0.6	-0.5
	U/S FT. MCMURRAY	11.9	0.3	-0.5
	END	8.0	0.0	-0.3
INCREASE SOD RATE*	U/S BERLAND	-2.1	0.0	0.0
	U/S WHITECOURT	-2.2	0.0	0.0
	U/S SMITH	-19.3	0.0	0.0
	U/S ATHABASCA	-11.0	0.0	0.0
	U/S GRAND RAPIDS	-12.8	0.0	0.0
	U/S FT. MCMURRAY	-8.4	0.0	0.0
	END	-6.3	0.0	0.0
DECREASE SOD RATE	U/S BERLAND	2.1	0.0	0.0
	U/S WHITECOURT	1.8	0.0	0.0
	U/S SMITH	7.4	0.0	0.0
	U/S ATHABASCA	3.8	0.0	0.0
	U/S GRAND RAPIDS	4.0	0.0	0.0
	U/S FT. MCMURRAY	2.5	0.0	0.0
	END	2.5	0.0	0.0

* rates were increased from 0.001 1/day to 0.02 1/day compared with 20% for other input variables.

Results of sensitivity analysis using March 1989 calibration file and a 20% preturbation of variables (percent change from original).

VARIABLE	LOCATION	DISSOLVED OXYGEN	EFFLUENT BOD	BACKGROUND BOD
INCREASE MILL BOD AND SOD	U/S BERLAND	-2.7	20.0	0.0
	U/S WHITECOURT	-2.5	20.0	0.0
	U/S SMITH	-10.7	20.0	0.0
	U/S ATHABASCA	-5.7	19.8	0.0
	U/S GRAND RAPIDS	-6.1	19.4	0.0
	U/S FT. MCMURRAY	-3.8	9.4	0.0
	END	-3.4	8.7	0.0
DECREASE MILL BOD AND SOD	U/S BERLAND	2.7	-20.0	0.0
	U/S WHITECOURT	2.5	-20.0	0.0
	U/S SMITH	10.7	-20.0	0.0
	U/S ATHABASCA	5.7	-19.4	0.0
	U/S GRAND RAPIDS	6.1	-19.4	0.0
	U/S FT. MCMURRAY	3.8	-9.4	0.0
	END	3.4	-9.4	0.0
INCREASE WELDWOOD BOD AND SOD	U/S BERLAND	-2.7	20.0	0.0
	U/S WHITECOURT	-2.3	3.7	0.0
	U/S SMITH	-3.8	3.7	0.0
	U/S ATHABASCA	-1.9	3.6	0.0
	U/S GRAND RAPIDS	-2.0	3.3	0.0
	U/S FT. MCMURRAY	-1.3	1.9	0.0
	END	-0.8	1.4	0.0
DECREASE WELDWOOD BOD AND SOD	U/S BERLAND	2.7	-20.0	0.0
	U/S WHITECOURT	2.3	-3.7	0.0
	U/S SMITH	3.8	-3.7	0.0
	U/S ATHABASCA	1.9	-3.6	0.0
	U/S GRAND RAPIDS	2.0	-3.3	0.0
	U/S FT. MCMURRAY	1.3	-1.6	0.0
	END	0.8	-2.2	0.0
INCREASE MILLAR WESTERN BOD AND SOD	U/S BERLAND	0.0	0.0	0.0
	U/S WHITECOURT	-0.2	16.3	0.0
	U/S SMITH	-6.9	16.3	0.0
	U/S ATHABASCA	-3.6	16.2	0.0
	U/S GRAND RAPIDS	-3.9	16.1	0.0
	U/S FT. MCMURRAY	-2.5	7.7	0.0
	END	-1.6	7.2	0.0
DECREASE MILLAR WESTERN BOD AND SOD	U/S BERLAND	0.0	0.0	0.0
	U/S WHITECOURT	0.2	-16.3	0.0
	U/S SMITH	6.9	-16.3	0.0
	U/S ATHABASCA	3.6	-15.8	0.0
	U/S GRAND RAPIDS	3.9	-16.1	0.0
	U/S FT. MCMURRAY	2.5	-7.4	0.0
	END	1.6	-7.2	0.0

APPENDIX E

STUDY TERMS OF REFERENCE

NORTHERN RIVER BASINS STUDY
SCHEDULE A - TERMS OF REFERENCE

PROJECT 2512-B1 (Project # Subject to Change): DISSOLVED OXYGEN MODELLING

I. Introduction

Two of the major objectives of the Northern River Basins Study are to determine the impacts of effluent discharges on the aquatic environment and to develop predictive tools to determine the cumulative effects of such discharge. One area of concern related to effluent discharges is the effect of nutrients on the aquatic environment. A Nutrients Group has been established by the Northern River Basins Study to specifically address such concerns.

One of the goals of the group is to develop a model that will quantify the relationship between nutrients, and algal and invertebrate biomass and nutrient transport and fate in the aquatic environment, so that the consequences of controlling or note controlling nutrients can be assessed. This will be done through an iterative process involving the following components:

- Data and Information Review and Synthesis;
- Model Selection and Development;
- Model Refinement; and,
- Field Investigations.

An important component of an overall nutrients model will be the development of appropriate dissolved oxygen models for the northern river systems. Previous dissolved oxygen modelling (DOSTOC) has been carried out for the Athabasca River using 1988/90 winter dissolved oxygen data (MacDonald and Taylor 1990). This project will utilize these previously calibrated models and winter dissolved oxygen data collected in subsequent years to assess their ability to predict observed conditions and to identify field research needs for model refinement.

II. Objectives

The purposes of this project included the following:

1. to determine the ability of previously calibrated water quality models to predict observed winter dissolved oxygen conditions in the Athabasca and Wapiti/Smoky/Peace river systems; and,

2. to identify model process rates requiring refinements in existing water quality models to better predict winter dissolve oxygen conditions in the Athabasca and Wapiti/Smoky/Peace river systems.

III. Requirements

A. Modelling

1. Utilize 1990/91 and 1991/92 field data in previously calibrated water quality models to predict winter dissolved oxygen conditions in the Athabasca and Wapiti/Smoky/Peace river systems. Databases will be provided by Alberta Environment (contact Leigh Noton - 427-5893) and the Northern River Basins Study (contact Greg Wagner 0 427-1742) and are to include water column and effluent BOD and BODU, and winter hydraulic travel time in the lower Athabasca River (including the 1992 Alberta Research Council dye tests of travel time prepared for the Northern River Basins Study). River and tributary flows may have to be balanced by the Consultant.

2. In conjunction with the modelling exercise, carry out a sensitivity analysis to determine the influence of all rate coefficients, input data, model assumptions and other inputs.

3. Attach a risk assessment model to the input data deck to provide a histogram indicating the probability of a given oxygen level occurring at 7Q10, average winter flow and two intermediate flow scenarios (considering flow event probabilities in combinations with discharge probabilities) for the Athabasca River at its confluence with the Lesser Slave River (assuming a effluent loading distribution at Weldwood, Alberta Newsprint and Millar Western). Also, predict a frequency distribution of dissolved oxygen concentrations for the Athabasca River upstream of Grand Rapids, with an assumed effluent distribution of BOD for Alpac.

4. All modelling outputs are to be downloaded into a geo-referenced, electronic database (Dbase IV format).

5. Conduct a re-evaluation of model selection.

B. Reporting

1. Prepare a report outlining the results of the modelling exercise. The report will include the following:

   - a general overview of the models and the process rates and assumptions use to calibrate the models;
   - an evaluation of model selection;
   - a statistical comparison of predicted vs. observed winter dissolved oxygen conditions;
   - an interpretation of the modelling in light of previous modelling results;
   - the results of the sensitivity analysis and identification of priority input needs for model refinement;
   - the results of the risk assessment model; and,
   - an appendix of all data and calculations used in model development.

IV. Reporting Requirements

1. Submit ten copies of a draft report outlining the results of the modelling exercise to the certification officer by March 15th, 1993.

2. Three weeks after the receipt of review comments on the draft report, submit five cerlox bound copies and two unbound, camera-ready copies of the final report to the certification officer. At the same time submit and electronic copy, in Word Perfect 5.1 format and on 5¼ or 3½ inch floppy disk, of the final report to the certification officer. An electronic copy (Dbase IV format on floppy disk) of data used to develop figures, tables and appendices in the final report is also to be submitted to the certification officer. The final report is to include an executive summary.

3. Along with the final report, submit copies of geo-referenced, electronic databases (Dbase IV format on 5¼ or 3½ inch floppy disk), containing model output data, to the certification officer.

V. Literature Cited

MacDonald, G. and H. Hamilton. 1989. Model Calibration and Receiving Water Evaluation for Pulp Mill Developments on the Athabasca River: I. Dissolved Oxygen. Prepared by: Hydroqual Consultants Inc., Calgary. Prepared for: Standards and Approvals Division, Alberta Environment, Edmonton.

MacDonald, G. and A. Radermacher. 1992. Athabasca Water Quality Modelling, 1990 Update. Prepared by Environmental Management Associates, Calgary.

MacDonald, G. and B.R. Taylor. 1990. Implementation of Water Quality Models for the Wapiti, Smoky and Peace River Systems. Prepared by: Hydroqual Consultants Inc., Calgary. Prepared for: Standards and Approvals Division, Alberta Environment, Edmonton.