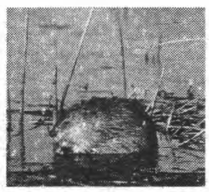
Canada Alberta Northwest Territories

Northern River Basins Study



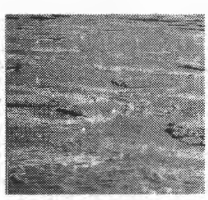






NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 136

CONTAMINANT FATE MODELLING FOR THE ATHABASCA RIVER: IMPLEMENTATION OF NEW SEDIMENT FLUX ROUTINES






Prepared for the
Northern River Basins Study
under Project 2381-E1

by

Golder Associates Ltd.

NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 136

CONTAMINANT FATE MODELLING FOR THE ATHABASCA RIVER: IMPLEMENTATION OF NEW SEDIMENT FLUX ROUTINES

Published by the
Northern River Basins Study
Edmonton, Alberta
March, 1997

CANADIAN CATALOGUING IN PUBLICATION DATA

Main entry under title :

Contaminant fate modelling for the Athabasca River :
implementation of new sediment flux routines

(Northern River Basins Study project report,
ISSN 1192-3571 ; no. 136)
Includes bibliographical references.
ISBN 0-662-24835-X
Cat. no. R71-49/3-136E

1. Sedimentation transport -- Alberta -- Athabasca
River -- Simulation methods.
2. Sedimentation and deposition -- Alberta -- Athabasca
River -- Simulation methods.
3. Organic water pollutants -- Alberta -- Athabasca
River -- Simulation methods.
I. Golder Associates.
II. Northern River Basins Study (Canada)
III. Series.

TD387.A43C66 1997 551.3'03'0971232 C96-980289-7

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.

NORTHERN RIVER BASINS STUDY
PROJECT REPORT RELEASE FORM

This publication may be cited as:

Golder Associates Ltd. 1997. ***Northern River Basins Study Project Report No. 136, Contaminant Fate Modelling for the Athabasca River: Implementation of New Sediment Flux Routines.*** **Northern River Basins Study, Edmonton, Alberta.**

Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project 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 — 14 May 96
(Dr. Fred J. Wrona, 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 — 24 May / 96
(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, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington — May 29/96
(Lucille Partington, Co-chair) — (Date)

Robert McLeod — May 21/96
(Robert McLeod, Co-chair) — (Date)

CONTAMINANT FATE MODELLING FOR THE ATHABASCA RIVER: IMPLEMENTATION OF NEW SEDIMENT FLUX ROUTINES

STUDY PERSPECTIVE

> ***Related Study Questions***
>
> *13a) What predictive tools are required to determine 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 stake holders hove the opportunity for input.*

Environments are constantly changing; that the aquatic environments contained within the Northern River Basins Study (NRBS) area were being changed as a result of development was not challenged. However, the ability to describe and predict those changes likely to arise from development continued to be a challenge to resource managers at the onset of the Study.

Typically, the change that occurs within the environment like those found in the Peace, Athabasca and Slave rivers, take place over an extended period of time. Although not as evident or dramatic, the change and its effects can be just as substantive as those occurring within a shorter time frame; the changes are so subtle as to go unnoticed. A major difficulty for aquatic scientists working with these large aquatic systems is the lack of documented information covering a long period of time. The monitoring that was underway or done prior to the onset of the NRBS Study was disparate and information gaps existed.

For large, complex, aquatic ecosystems like the Peace, Athabasca and Slave rivers, subjected to significant seasonal variation, scientists use tools like models to help them assess the consequence of changing one or many parameters. Models offer researchers and managers with the capability of being better able to understand and predict changes arising from development. NRBS undertook to investigate the potential use of models. A decision was made to utilize WASP IV, Thomann/Connolly and Gobas food chain models, to assess the fate and bioaccumulation of point-source contaminants entering the upper Athabasca River.

The modelling effort by NRBS was a multi-faceted initiative involving review and interpretation of sediment transport dynamics, contaminant distribution and concentration in sediment, water and biota and the refinement of existing models. This report describes work to improve the sediment transport simulations that could be inputted into a model, WASP 4. Many contaminants released to the aquatic environment do not remain in solution but attach themselves to fine particles suspended in the water column. Knowledge of sediment - contaminant interaction, combined with an understanding of sediment transport dynamics, better enables researchers to simulate the transport and uptake of contaminants within the aquatic environment.

Although project results revealed a need for additional work in the area of model parameters and input conditions, the new model better predicts the exchange of sediment between the bed and water column and concludes that they are more dynamic than earlier predicted. In the revised model, there is an accumulation of fine sediment on the river bed during the late fall and winter, this material is resuspended during the spring freshet, and little accumulation occurs during the summer. The model reasonably predicts a seasonally dynamic pattern of contaminant and organic carbon concentrations in the depositional areas downstream from the pulp mill at Hinton (the only bleached kraft mill input modelled on the Athabasca). The model predicts winter accumulations but overestimated late spring and fall accumulations. Further work into sampling depositional areas in winter and during open water to see if there is a difference of the magnitude predicted by the model would provide an additional test of the model's applicability.

Information from this project is being integrated with the contaminant - food chain modelling project to better enable these latter models to simulate contaminant transport and bioaccumulation within the food chain. Ultimately, the intent is to build models that will enable researchers and resource managers to predict changes likely to occur from existing and new sources of development.

Complementary work is reported in Northern River Basins Study Project Reports No. 136 (*Contaminant Fate Modelling for the Athabasca River: Implementation of New Sediment Flux Routines*), No. 137 (*A Bioenergetic Model of Food Chain Uptake and Accumulation of Organic Chemicals, Athabasca River*), No. 112 (*Contaminant Fate Modelling, Athabasca, Wapiti, and Smoky Rivers*), and No. 113 (*A Bioenergetic Model of Food Chain Uptake and Accumulation of Organic Chemicals, Athabasca River: Stochastic and Time Variable Version)*.

REPORT SUMMARY

A sediment transport algorithm for the Athabasca River, developed by Krishnappan (1995), has been incorporated into the Athabasca River contaminate fate model. The revised fate model allows predictive sediment transport simulation with the WASP4 model framework. The revised fate model predicts resuspension from hydraulic information supplied by the WASP4 model, and user supplied sediment characteristics. The new algorithm has a number of advantages over the descriptive sediment transport routines included in the original version of WASP4, including:

- The revised model predicts resuspension as well as deposition. In the original calibration only net deposition could be included in the simulations.
- The revised model can be applied to different flow conditions, without having to re-describe sediment transport rates.

Several simulations were run with the new model using the input files from the original Athabasca River Model Calibration (Golder Associates Ltd. 1995). Simulated total suspended solids (TSS) concentrations in the water column under open-water and ice-covered conditions, simulated contaminant concentrations in all media were generally comparable to the original calibration.

The main differences between the new simulations and the original calibration relate to sediment and contaminant concentrations in the bed. The new model predicts a very dynamic exchange of sediment between the water column and bed. The model predicts an accumulation of fine bed sediment over the late fall and winter, removal by resuspension during the spring freshet, and very little net accumulation during the summer. Predicted contaminant concentrations during the winter are similar to the original calibration, however late spring to late fall concentrations are much lower predicted in the original calibration.

The simulations presented in this report do not represent a complete recalibration of the model. To accomplish this a larger number of simulations would be required, evaluating a broader range of model parameters and input conditions which can affect sediment transport.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

A numerical model of the one-dimensional transport and fate of organic contaminants in the Athabasca River has been developed for the Northern River Basins Study (NRBS) using the WASP4 modelling system (Golder Associates Ltd. 1995). The model simulates contaminant concentrations in the water column and bed sediments and includes a dynamic exchange between the water and bed sediment compartments.

One limitation of WASP4 is a lack predictive sediment transport. WASP4 includes descriptive sediment transport in which WASP4 will simulate settling and resuspension of sediment based on user defined time-series of settling and resuspension velocities. Descriptive sediment transport simulation is dependent on having sufficient observed sediment data to adequately describe settling and resuspension. For the Athabasca River, sufficient data existed to adequately define net settling rates, but not resuspension events. The result was a descriptive sediment transport calibration, which included the depositional component of sediment transport, but neglected resuspension. The model simulated a continual accumulation of sediment, and no net downstream movement of bed sediment.

The lack of resuspension in the model made it impossible to attempt a realistic simulation of multi-year (i.e. long-term) bed sediment contaminant concentrations. One major recommendation of the calibration study was to consider implementation of a predictive sediment transport model to address this deficiency (Golder Associates Ltd. 1995).

Predictive sediment transport calculates settling and resuspension of sediment based on the hydrodynamic characteristics of the river and the physical characteristics of the sediment. Predictive sediment transport algorithms have been developed for the Athabasca River based on rotating flume experiments (Krishnappan 1995). Because the algorithms are based on measurable sediment properties and predictable hydrodynamic properties, they can be applied under different flow conditions.

The objective of the current projects was to develop a predictive model of sediment deposition and resuspension, which is based on readily available sediment properties and predictable hydrodynamic properties, and to incorporate this as a sub-model with the WASP4 modelling framework. The sediment transport algorithms have been developed and reported separately (Krishnappan 1995). This report documents the incorporation of the sediment transport algorithms into WASP4 and the re-simulation of contaminant transport in the Athabasca River using the enhanced WASP4 model.

The project proceeded in three distinct phases:

I. Coding of the sediment routines as a stand-alone computer program for testing and debugging.
II. Incorporation of the new sediment routines into WASP4. New subroutines and modifications to existing subroutines are listed in Appendix A.
III. Re-simulation of the existing NRBS-WASP4 model for the Athabasca River. The re-simulation included minor changes to the existing calibration as necessary. The re-simulation included simulation of suspended solids and each of the chemicals considered in the original calibration, except for phenanthrene.

2.0 WASP4 IMPLEMENTATION OF SEDIMENT TRANSPORT ALGORITHM

The Athabasca River sediment algorithm developed by Krishnappan (1995) calculates the fraction of suspended sediment deposition based on the initial suspended sediment concentration and the bed shear stress, and calculates the fraction of bed sediment resuspended based on the mass of sediment previously deposited and the bed shear stress. The sediment algorithm is written in a steady state format. To incorporate the sediment algorithm into WASP4, it must be assumed that suspended solids reach an equilibrium condition during each time-step.

Sediment transport in WASP4 is driven by user-input time-series of deposition and resuspension velocities. In this implementation, the user-input velocities will be bypassed and the sediment algorithm will directly calculate the mass of sediment resuspended and deposited in each time-step, based on hydraulic information and sediment masses (bed and suspended) supplied by WASP4. The calculated masses of sediment deposited and resuspended will be passed back to WASP4 for inclusion in the sediment mass balance calculations. The exact sequence of the calculations performed, each time interval, is outline below.

1. At the beginning of the time interval, WASP4 calculates a new sediment mass balance, including the calculation of new sediment concentrations for each cell, based on user defined inflows (upstream, tributaries, effluents) and outflows (downstream, withdrawals). WASP4 passes the following information to the sediment algorithm:

   - volumes (Vol), depth for all segments (H),
   - sediment concentrations (C_{sw}) and velocities for surface water segments (U)
   - sediment concentrations (C_{sb}) and surface areas for bed segments (BSA), and
   - concentrations of chemicals sorbed to; the bed sediment (C_{cb}), and to the suspended sediment in the water column (C_{cw})

2. The sediment algorithm uses the information to calculate the fraction of suspended sediment deposited and the fraction of bed sediment resuspended.

3. For each segment, the fractions are multiplied by the sediment concentrations and segment volumes to calculate the mass flux of sediment deposited to or resuspended from each cell. Equation 3 in Krishnappan (1995) has been rewritten as:

   $$q_{su} = C_{sw} * Vol \qquad \text{(Modified Equation 3)}$$

   where, q_{su} is the volume of sediment in the control segment rather than the volume of sediment entering the segment. The time interval has been normalized to a per day basis.

Equation 5 in Krishnappan (1995) has been rewritten as:

$$q_{sb} = C_{sb} * BSA * H + q_{su} * f_d \quad \text{(Modified Equation 5)}$$

In Modified Equation 5, $C_{sb} * H$ is substituted for P as the amount of sediment on the bed, as a mass of bed sediment per unit area.

4. The mass fluxes of sediment deposition (q_{sd} - Krishnappan, 1995, Equation 4) and resuspension (q_{sr} - Krishnappan, 1995, Equation 6) are passed back to WASP4.

5. Chemical mass fluxes associated with sediment transport are calculated by multiplying the sediment mass flux by the chemical concentration of the sediment.

   Resuspension chemical flux (q_{cr}):
   $q_{cr} = C_{cb} * q_{sr}$

   Deposition chemical flux (q_{cd}):
   $q_{cd} = C_{cw} * q_{sd}$

6. The chemical and sediment mass fluxes are included in the overall mass balance equations in WASP4 to recalculate new sediment and chemical concentrations in each cell.

A listing and discussion of code modifications that were made to WASP4 to incorporate the sediment routines are given in Appendix A.

3.0 USING THE SEDIMENT TRANSPORT ALGORITHMS IN WASP4

The sediment algorithms require that a number of parameters be specified to calibrate the algorithms to the system being simulated. These parameters have been added to the WASP4 input deck in such a way that, if the sediment transport parameters are not specified, then WASP4 will execute using the original descriptive sediment transport method.

New input fields have been added to two records in Data Group D (flows).

1. Two parameters have been added to Record 1; SEDOPT and SEDICEFC.

   - SEDOPT is a flag which, if set to 1, will activate the sediment transport algorithms. If SEDOPT is missing or set to any other value, WASP4 will execute with its default sediment transport routines. SEDOPT must be specified in columns 26 to 30 within record 1.

   - SEDICEFC is the ratio of open water to ice covered bed shear stress. Krishnappan (1995) indicates that a value of 0.50 can be assumed as a first approximation.

2. Two parameters have been added to Record 2 of Data Block D.4 (sediment transport fields); D_{65} and T_{cd}.

   - D_{65} represents the characteristic bed material diameter (m) for determining bed roughness. This parameter can be considered analogous to a Manning's coefficient.

   - T_{cd} represents the critical shear stress for deposition (N/m^2). This parameter was measured in flume experiments, but will need to be scaled up for application to the actual river system (B.G. Krishnappan, personal communication).

   Record 2 is repeated for each sediment transport field specified. Each sediment transport field consists of one or more pairs of water column and underlying sediment cells (Record 4) and an associated velocity time function (Record 6). The D65 and Tcd values set for a given transport field will be used for all cells specified in that transport field. The structure of the sediment transport fields has not been changed. The user must still specify sediment pairs, and associated velocity time function, however the sediment algorithm does not use the velocity time function. The sediment algorithm requires that, in Record 4, the water column segment be specified as JQ and the bed segments as IQ.

   The following example is an excerpt from the Athabasca River input deck showing SEDOPT and SEDICEFC, and D65 and TCD in the first sediment transport field.

Record 1

SEDOPT

D6 TCD

SEDICEF

Record 2 for the first sediment transport

```
 6 1.157e-05      1.0    1     0.50  (SS settling)
16   2.0e-3      0.500      Weldwood settling zone 1
 6.0e05    2   224   6.0e05    3   225   6.0e05    4   226   6.0e05    5   227
 6.0e05    6   228   6.0e05    7   229   6.0e05    8   230   6.0e05    9   231
 6.0e05   10   232   6.0e05   11   233   6.0e05   12   234   6.0e05   13   235
 6.0e05   14   236   6.0e05   15   237   6.0e05   16   238   6.0e05   17   238
37
    0.5          1        0.5         32        0.5         60        0.5         91
    0.1        121        0.0        152        0.0        182        0.1        213
    0.2        244        0.3        274        0.4        305        0.5        335
    0.5        366        0.5        397        0.5        425        0.5        456
    0.1        486          0        517          0        547        0.1        578
    0.2        609        0.3        639        0.4        670        0.5        700
    0.5        731        0.5        762        0.5        790        0.5        821
    0.1        851          0        882          0        912        0.1        943
    0.2        974        0.3       1004        0.4       1035        0.5       1065
    0.5       1096
```

4.0 ATHABASCA RIVER SIMULATIONS

4.1 PARAMETER SELECTION

The Athabasca River model calibration presented in Golder (1995), was revised to activate the new sediment transport algorithms and set the appropriate sediment transport parameters. The only other change made to the simulations was to set the WASP4 bed volume option from constant volume to variable volume. The variable bed volume allows simulated sediment volumes to change in response to deposition and resuspension.

Initial parameter values recommended by B.G. Krishnappan (personal communication) were:

- SEDICFC 0.50
- D65 2.00E-3 m
- Tcd 0.50 N/m^2

One set of D65 and Tcd values was applied for entire Athabasca River.

Simulation results for this initial simulation are presented in Appendix B. Phenanthrene was not simulated in this study. The time-series of phenanthrene loading information for the Athabasca River does not exist, and would be necessary to make time-series simulations with predictive sediment transport. The figure numbering is identical to the original calibration report (Golder Associates Ltd. 1995) to facilitate a direct comparison of the results. An additional plot (d) was added to Figures 4.10, 4.14, 4.18, 4.22, and 4.26, to show the simulated time-series of bed sediment chemical concentrations at additional sites.

Initial simulation results for total suspended solids (TSS) show a good agreement with measured concentrations during open-water conditions, for all stations except at the Old Fort station (Appendix A, Figure 4.6). Simulated open-water concentrations at Old-Fort are higher than measured values. Simulated ice-covered TSS concentration are less than measured values.

The over-prediction of TSS concentration at Old Fort is related to the initial sediment assumptions used in the model. For most of the river (Bed Segments 223 to 424) the distribution of fine to coarse sediment is 15% to 85%. At the bottom of the system (Bed Segment 425 to 432) the distribution is essentially reversed. This provides a much larger volume of fine sediment for resuspension which leads to the over-prediction. Setting the fine to coarse sediment ratio for the entire river to 15% to 85% eliminated this problem.

Under prediction of ice-cover TSS concentrations may be related to the value specified for the ratio of ice-covered to open water bed shear velocity (SEDICEFC). Krishnappan recommended an initial value of 0.5 be used as a first approximation. However, the WASP4 model uses different hydraulic for ice-covered and open water conditions. The ice-covered hydraulics calculate lower bed shear stresses than do the open-water hydraulics. At Hinton with a typical winter low flow of 40 m3/s, the calculated bed shear stress under ice-covered conditions is about 40% of the open water value, with using SEDICEFC. To decrease the amount of net deposition under ice-covered conditions, would require a SEDICEFC of greater than 0.5. A simulation was run with the SEDICEFC set to 1.0. This simulation failed to noticeably improve the winter calibration. It would be difficult to justify increasing SEDICEFC to a value greater than 1.0. Another option for decreasing the net sedimentation is to increase the characteristic sediment diameter (D65). At Hinton, at 40 m3/s under ice-covered conditions, a ten-fold increase in D65 (from 0.002 to 0.02 m), results in about a two-fold increase in the bed shear stress. Kellerhals *et al.* 1972 measured D65 values for the Athabasca River from Hinton to Athabasca ranging from 0.056 to 0.082 m (n=3). This information is consistent with a higher D65 value. Unlike changing SEDICEFC, changes to D65 will affect the simulation of both open-water and ice-covered condition.

A second set of simulations was run with the following modifications made:

- The 85/15 coarse to fine sediment ratio in the bed was used for the entire system
- SEDICEFC was set to 1.0
- D65 was set to 0.02 m

The adjustment of D65 will decrease the amount of deposition and increase the amount of resuspension. SEDICEFC will have the same effect but only in the winter. Simulation results for this second set of simulations are presented in Appendix C. The following is a brief discussion of the second set of simulations results by parameter.

4.2 TSS

TSS results are generally comparable between the two simulations and open water simulated concentrations are in agreement with observed values. The second set of simulations predicts higher winter TSS concentrations in the first 300 km downstream of Hinton, however both simulations underestimate measured concentrations further downstream. The original calibration also underestimated downstream TSS concentrations during the winter. During the winter, measured TSS concentrations were typically at or near the detection limit and it is difficult to determine whether net deposition in the winter is overestimated, or if there are small unaccounted watershed sources of sediment.

4.3 BED SEDIMENT

Simulated bed sediment concentrations at selected sites are shown in Figure 1. The sediment algorithm simulates an accumulation of fine sediment over the winter, nearly complete removal of fine bed sediment during the spring freshet, and no significant net accumulation of fine sediment during the late spring to late fall period. Adjustment of D65 and SEDICEFC in the second simulation, resulted in a decrease in both the amount of bed sediment accumulation and the time-period of accumulation.

There was no real data available with which to verify or refute these simulations. The modelling predicted sediment concentrations for an entire reach of river. Localised accumulations of fine sediment during the late spring to fall period would be expected in lower energy sections of the river, even if there is no significant accumulation in the reach as a whole.

4.4 CHEMICAL CONCENTRATIONS

Results for the simulation of chemical concentrations in the water column and adsorbed to TSS for both simulations presented in this report are comparable with the original calibration. Differences between the original calibration and the simulations in this report, are attributable to differences in sediment transport. Since, chemical sorption is an instantaneous equilibrium process in the model, if the model predicted similar TSS concentrations, then the chemical concentrations in the water and absorbed to TSS would also be comparable.

The main differences between the current simulations and the original calibration were expected in chemical concentrations in bed sediments. In the original calibration, only deposition was included in the model, resulting in a gradual accumulation of bed sediment and chemical mass in the bed. Concentrations varied only by accumulation of settled TSS and the concentrations of chemicals bound to the settled TSS. Consequently, sediment concentrations tended to vary slowly over time, and largely reflected the initial concentration specified.

With the sediment transport algorithm included in the model, the bed sediment behaved much more dynamically, and consequently bed sediment concentrations were also dynamic. Simulated concentrations increased in the late summer to early winter, and declined in the late winter to early spring. Concentrations remained at zero over much of the late spring and summer period reflecting the simulated removal of fine sediment from the river bed during the spring freshet.

Differences in chemistry between the simulations presented in this report and the original calibration are summarized below:

- The second simulation overestimated 2,3,7,8 TCDF concentrations in the bed in the May 1993 survey (Figure 4.9b).

- Simulated bed sediment concentrations for all chemicals declined more rapidly with distance downstream in the initial simulation, compared to the second simulation (see Figures 4.10c and 4.10d for 2,3,7,8 TCDF).

- DHA concentrations in the bed and TSS were over-estimated for the April 1992 survey by a factor of about two by both simulations in this report (Figure 4.13b). The original calibration DHA in TSS was over-estimated by a factor of three to five. Simulated bed sediment DHA concentrations in the original calibration were very close to measured values, because the initial DHA concentrations in the bed were calculated from the same measured values.

- DHA concentrations in the bed were over-estimated by a factor of two to three for the May 1993 by both simulations in this report (Figure 4.13c).

- 12,14-dichloro-DHA concentrations in the water column for the January 1992 survey were over-estimated in the second simulation, by a factor of about two (Figure 4.17a).

- 12,14-dichloro-DHA concentrations in the bed sediment for the 1992 and 1993 surveys were over-estimated by both simulations in this report.

- Simulated bed sediment 3,4,5-TCG concentrations for the January 1992 were higher by a factor of five to ten in the simulations in this report, compared to the original calibration (Figure 4.25a). There is no observed data for comparison.

- Simulated bed sediment 3,4,5-TCV concentrations for the simulations in this report were much lower than the original calibration and measured concentrations (Figures 4.29a, 4.29b and 4.29c).

- The second simulation simulated spikes in bed sediment 3,4,5-TCV concentrations in May of each year which were not present in the initial simulation.

4.5 DISCUSSION

After adjustment of model parameters, TSS concentrations simulated using the new sediment transport algorithm under open water and ice covered conditions were comparable to the original calibration. This indicates that the model predicts about the right amount of net sedimentation. The new sediment algorithm predicts a much more dynamic exchange of sediment between the water column and bed. The available data can not verify or refute to what extent the individual components of net sedimentation (i.e. deposition and resuspension) are correctly represented in the model.

Changes to initial conditions at the downstream end of the system, were necessary to calibrate the model. These changes also indicate that the sediment transport algorithm can be sensitive to the initial ratio of fine to coarse sediment. This sensitivity was not, however, tested in any systematic manner.

Another variable which may affect the simulation results is the initial depth of the bed segment. An initial depth of 10 cm was assumed for all segments. The sensitivity of simulation results to this variable was not tested.

5.0 CONCLUSIONS

The sediment transport algorithm developed by Krishnappan (1995) was successfully included in the Athabasca River WASP4 Toxics model, and a new version of the model was created.

The new sediment transport algorithm in the Athabasca River model now predicts a dynamic exchange of fine sediment between the water column and the bed based on hydraulic characteristics simulated in the model. The sediment transport algorithm also simulates a net downstream movement of fine sediment.

The Athabasca River calibration files from Golder Associates Ltd. (1995) were resimulated using the new WASP4 model. A second set of simulations provided a reasonable match between observed and measured TSS concentrations in the water column under open-water and ice-covered conditions. Simulated sediment concentrations exhibit a much different pattern compared to the original calibration. In the original calibration, there was a gradual accumulation of bed sediment due to deposition without any resuspension. Consequently, changes to sediment chemistry were relatively gradual. With the new sediment algorithms, sediment transport is much more dynamic, and the temporal pattern is very different. Simulated bed sediment concentrations exhibit a distinct seasonal pattern related to settling and resuspension patterns, which are in turn flow related. The new sediment algorithm predicts the near complete removal of fine bed sediment during the spring freschet. Unfortunately, there is no monitoring data available to refute or support the predictions.

The simulations included in this report do not represent a complete recalibration of the model. To accomplish this a larger number of simulations would be required, evaluating a broader range of model parameters and input conditions which can affect sediment transport.

Model parameters and conditions which were identified as having the potential to affect the sediment transport simulation results include:

- SEDICEFC
- D65
- Tcd
- Initial ratio of fine to coarse sediment in bed segment
- Initial bed segment thickness

6.0 REFERENCES

Leopold, L.B. and T. Maddox 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications, Professional Paper 252, U.S. Geological Survey, Washington, DC.

Golder Associates Ltd. 1995. Contaminant Fate Modelling for the Athabasca and Wapiti/Smoky Rivers. Prepared for the Northern River Basins Study, Edmonton, Alberta.

Kellerhals, R., C.R. Neill and D.I. Bray. 1972. Hydraulic and geomorphic characteristics of rivers in Alberta. Research Council of Alberta. River Engineering and Surface Hydrology Report 72-1. Edmonton, AB.

Krishnappan, B.G. 1995. A New Algorithm for Fine Sediment Transport. National Water Research Institute, Burlington, Ontario.

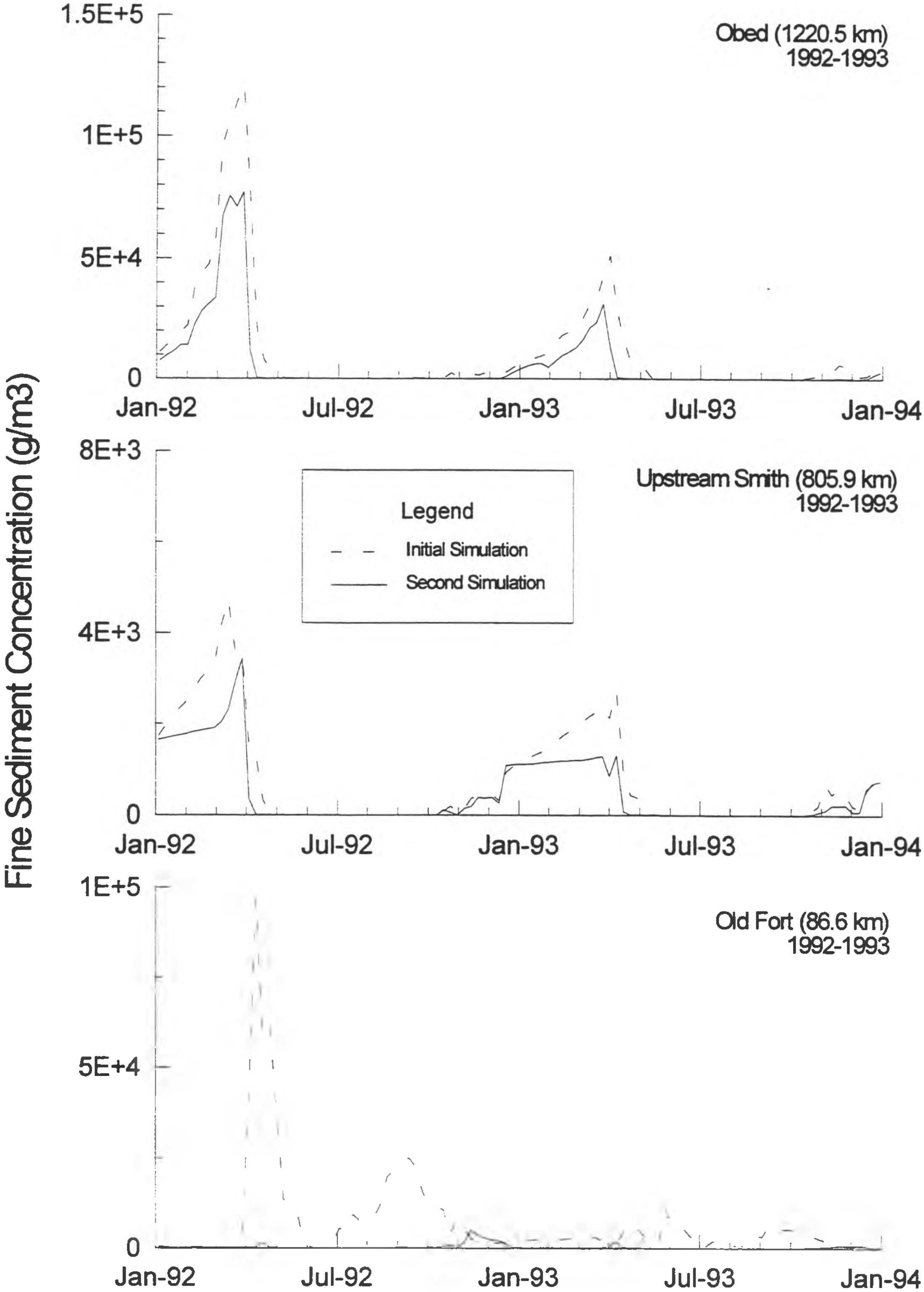


Figure 1.
Comparison of simulated bed fine sediment concentrations with different values of representative bed material size (D65) and SEDICEFC.

APPENDIX A: WASP4 CODE CHANGES

APPENDIX A: WASP4 CODE CHANGES

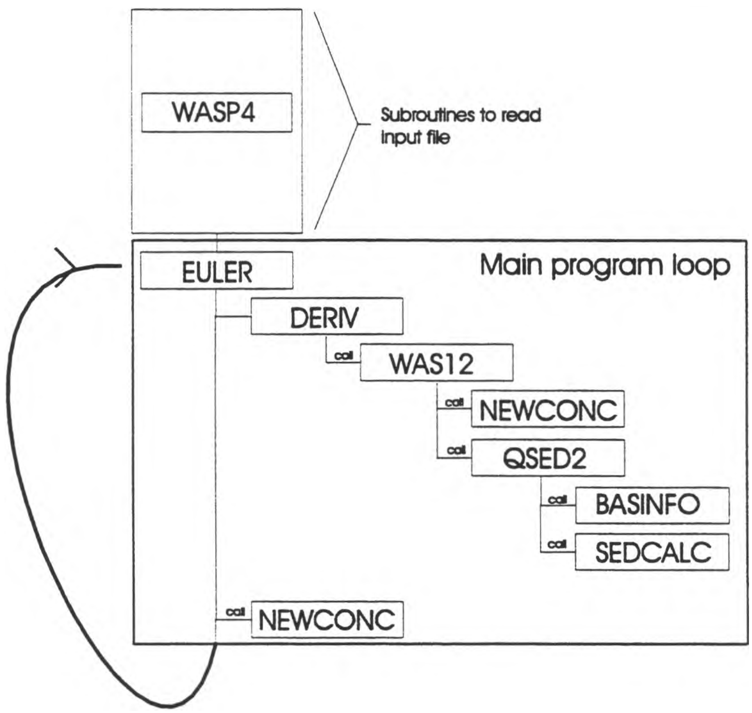
This appendix lists and discusses the modifications made to incorporate new sediment transport algorithms into the Athabasca River Model developed using the WASP4 modelling system. The main code modifications can be broken into three main steps:

- Reading sediment transport parameters
- Coding sediment transport subroutines
- Linking sediment transport subroutines with WASP4 mass balance calculations.

One additional change involved modifying the subroutine which reads volume and hydraulic information. Prior modifications were made to WASP4 to fully implement the Leopold-Maddox flow relationships which were included in the original WASP4 model. Leopold-Maddox coefficients for the Athabasca River have be calculated for ice-covered and open-water conditions. Changes have been made to allow both ice-covered and open-water Leopold-Maddox coefficients to be used in the model.

Each of these steps is discussed in turn, and a complete listing of all new and modified subroutines is included a the end of this appendix. All equation numbers listed are for equations in Krishnappan (1995).

The sub-set of the sequence of subroutine calls which were modified in or added to WASP4 are illustrated below.



Reading Sediment Transport Parameters

Subroutine WASP4 was modified to read the flag to activate the new sediment algorithms (SEDOPT), as well as three sediment transport parameters (SEDICEFC, D65(NF,NI), Tcd(NF,NI)). Each of these variables have been added to the main TOXI4 common block (WASP.CMN).

SEDOPT is an integer variable with an I5 format. A value of one activates the new sediment transport algorithm. Any other value, will not activate the new predictive algorithms and the default descriptive sediment transport algorithms will be used.

SEDICEFC is factor for adjusting the bed shear stress (Equation A2) under ice covered conditions. SEDICEFC is a single precision, real variable with an F10.0 format.

D65(NF,NI) is the character bed material diameter, which determines bed roughness in the shear velocity calculation (Equation A1). It is a single precision, real, two-dimensional array, with an F10.0 format.

Tcd(NF,NI) is the critical shear stress for deposition. It is used in the equations to calculate the fraction of suspended sediment deposited (Equation 1), and the fraction of bed sediment resuspended (Equation 2). It is a single precision, real, two-dimensional array, with an F10.0 format.

For D65(NF,NI) and Tcd(NF,NI), NF is the total number of flow fields, and NI is the number of sediment transport flow fields. NF and NI are dimensioned in WASP.CMN, but the values specified in an input deck may be less than or equal to the dimensioned values. NF is currently dimensioned to 6 and NI is currently dimensioned to 20. The sediment transport flow fields (NF) are fields 3,4 and 5, for solids 1,2 and 3, respectively.

Coding Sediment Transport Subroutines

The sediment transport algorithm described in Krishnappan (1995), with modifications discussed in Chapter 0, was implemented in two subroutines, BASINFO and SEDCALC. Variables are dimensioned in one of the following common blocks, SED2.CMN or WASP.CMN.

Subroutine BASINFO computes the bed shear velocities (Equation A1), the bed shear stress (Equation A2), the fraction of sediment deposited (Equation 1), and the fraction of sediment eroded (Equation 2) for each segment.

Subroutine SEDCALC takes the information calculated in BASINFO, and computes the mass fluxes of sediment deposited (Equation 4) and resuspended (Equation 6).

Linking Sediment Transport Subroutines with WASP4 Mass Balance Calculations.

Linking of the sediment algorithm subroutines, BASINFO and SEDCALC, into the WASP4 mass balance framework is performed in subroutine QSED2. This subroutine was modified from the default WASP4 sediment transport subroutine, QSED.

QSED2 calls BASINFO and SEDCALC, and takes the depositional fluxes (QSR(NF,J)) and erosional fluxes (qsd(NF,I) and includes them in the WASP4 mass balance framework. QSR(NF,J) represents the erosional mass flux rate for solid field NF from bed segment I to the overlying water column segment J. QSD(NF,I) represents the depositional mass flux rate for solid field NF from water column segment J to underlying bed segment I.

WASP4 tracks the net flux of each system (3 chemicals and 3 solids) out of each segment using the variable, CD(ISYS,ISEG), where ISYS is the system number and ISEG is the segment number. A negative net flux would, therefore, represent and net flux into a segment.

For solids (ISYS = 2,3,4), the net flux variable CD(ISYS,ISEG) is updated as follows:

For bed segments (J):

$$CD(ISYS,I) = CD(ISYS,I) + QSD(NF,J) - QSR(NF,J)$$

For water column segments (J):

$$CD(ISYS,J) = CD(ISYS,J) - QSD(NF,J) + QSR(NF,J)$$

For chemicals (ISYS = 1,5,6), the net flux variable CD(ISYS,ISEG) is updated as follows:

For bed segments (J):

$$CD(ISYS,I) = CD(ISYS,I) + \frac{QSD(NF,J) * C(ISYS,J) * TSF(ISYS,J)}{C(NF-1,J)} - QSR(NF,J)\frac{QSR(NF,J) * C(ISYS,I) * TSF(ISYS,I)}{C(NF-1,I)}$$

For water column segments (J):

$$CD(ISYS,J) = CD(ISYS,J) - \frac{QSD(NF,J) * C(ISYS,J) * TSF(ISYS,J)}{C(NF-1,J)} + QSR(NF,J)\frac{QSR(NF,J) * C(ISYS,I) * TSF(ISYS,I)}{C(NF-1,I)}$$

C(ISYS,J) = total concentration of chemical ISYS in water column segment J

C(ISYS,I) = total concentration of chemical ISYS in bed segment I
C(NF-1,J) = concentration of solid NF-1 in water column segment J
C(NF-1,I) = concentration of solid NF-1 in bed segment I
TSF(ISYS,J) = fraction of total chemical ISYS, which is sorbed to solid NF-1, for water column segment J

TSF(ISYS,I) = fraction of total chemical ISYS, which is sorbed to solid NF-1, for bed segment I
Note: NF-1 is the appropriate solid system for flow field NF.

The variable TSF is calculated in subroutine FRCION, where TSF is equivalent to TSOLFRAC. The current implementation requires that the fine sediment is Solid 1, and that Solids 2 and 3 do not adsorb chemicals (i.e. FOC = 0).

Variable CD(ISYS,ISEG) is updated for each system , for each sediment transport flow field, for each segment. Actual updating of concentrations in WASP4 occurs in subroutine EULER. EULER has been modified by removing the code which updates the concentrations and putting it in a separate subroutine called NEWCONC. NEWCONC was created to allow concentrations to be updated in more than one place in the program. In addition to updating concentrations in EULER, a call to NEWCONC was added to subroutine WAS12, just before the call to QSED2. This call to NEWCONC allows concentrations to be updated to reflect advective chemical and solids transport for the current time-step. Previously WASP4 accumulated net mass transfers of chemical and solids for all processes (i.e. exchanges, advection, sediment transport, mass loadings, inflows), and updated all concentrations at the end of the time-step.

Incorporating Ice-covered and Open-water hydraulics

The original model calibration (Golder Associates Ltd. 1995) utilized only ice-covered hydraulics. The reason for this was that WASP4 could not utilize more than one set of Leopold-Maddox coefficients, and the winter was the critical calibration period. Sediment transport modelling was descriptive in the original calibration, and, therefore, not sensitive to the hydraulic characteristics of the river. The new sediment algorithms are dependent on the hydraulic characteristics of the river, and it was, therefore, considered important that both open-water and ice-covered hydraulics be represented in the modelling.

Subroutine WASP3 was modified so that both ice-covered and open-water Leopold Maddox coefficients can be included in the input file in Data Group C, Record 3. A second set of Leopold-Maddox coefficients are read for each cell. The format is the same as for the first set:

A1 is VMULT2(ISEG), the hydraulic coefficient for velocity (Format F10.0)
B2 is VEXP2(ISEG), the hydraulic exponent for velocity (Format F10.0)
C2 is DMULT2(ISEG), the hydraulic coefficient for depth (Format F10.0)
D2 is DXP2(ISEG), the hydraulic exponent for depth (Format F10.0)
ISEG is the number of segments.

Subroutine Q2UPDATE was modified so that WASP4 will use the first set of Leopold-Maddox coefficients if the river temperature (TEMPFN(1)) is less than or equal to zero, and the second set if the river temperature is greater than or equal to zero. TEMPFN(1) is the first of four time-variable temperature functions allowed in WASP4. A pointer to the time function must be specified in Data Group G (Environmental Parameters). The actual time function is specified in Data Group I (Kinetic Time Functions). The time function was specified in the original calibration and it has not been changed. The only change is the use of this time function to determine whether ice-covered or open-water Leopold-Maddox coefficients will be used.

```
SUBROUTINE WASP4
C=======================================================================
C  Last Revised:  Date: Thursday, 1 February 1990.  Time: 16:26:12.
C  READ FLOWS (GROUP D)
C
C  Correction History:
C                        -- Added Evaporation
C
C-----------------------------------------------------------
C
      INCLUDE 'WASP.CMN'
C***  MONTE CARLO ROUTINE COMMON BLOCK -MD- JULY 12/92
      INCLUDE 'RISK.CMN'
C
      INTEGER SEGJUN, SEACHN
      character hydrofil*12,files(5)*15
C
      COMMON /SWFLW/ SCALQ, SCALV, NJ, NC, JUNSEG (SG), SEGJUN (SG),
     1   NSEA, JSEA (5), SIGN (5), SEACHN (5), NBC, NUPS
C
C*** -BZ- 15-Apr-1993 17:00:57
      LLLFFIEL = 0
C
      IF (MFLAG .EQ. 0) CALL GETMES (10,0)
C
      READ (IN, 5000, ERR = 1000) IQOPT, NFIELD, hydrofil
 5000 FORMAT(2I5,a12)
      WRITE (OUT, 6000) IQOPT
 6000 FORMAT(////37X,'FLOWS'/,37X,5('~')//,29X,'Flow Option',I3,' Used')
C
      WRITE (OUT, 6010) NFIELD
 6010 FORMAT(26X,'Number of Flow Fields = ',I3)
C
C*************************************************************************
C            IF NFIELD = 0, Skip Flow Computations
C*************************************************************************
C
      IF (NFIELD .EQ. 0) THEN
        NFIELD = 1
        NINQ (1) = 0
        GO TO 1010
      END IF
C
C*************************************************************************
C       Check if NFIELD is greater than the maximum allowed
C       check for sediment transport fields if IBEDV=1
C*************************************************************************
C
      IF (NFIELD .GT. MNF) THEN
        WRITE (OUT, 6020) MNF
 6020   FORMAT(/20X,'The Number of Flow Fields is Greater than ',
     1        /20X,'the Maximum of ',I5,2X,'Set in the Common Block',
     2        /20X,'** EXECUTION TERMINATED')
        CALL WEXIT('Dimension Error See the Output File',1)
      END IF
      IF (NFIELD .LT. 3 .AND. IBEDV .GE. 1) THEN
        WRITE (OUT, 6030)
 6030   FORMAT(/10X,'*** Solids Transport Fields are Required for ***',
     1        /10X,'Variable Bed Volume Option ',
     2        /10X,'Specify Field 3 Flows or Change Bed Option IBEDV')
        CALL WEXIT('Dimension Error See the Output File',1)
      END IF
      NDISS = 2
C
C                   LOOP THROUGH FIELDS
C
C
```

```
C     *********************************************************
C     * FIELD 1 = Total Water Transport, BQ is continuity array, *
C     *         QT contains flows for time function             *
C     * FIELD 2 = Dissolved transport only                      *
C     * FIELDS 3 or greater are solids fields, BQ is array of   *
C     *         areas, QT contains settling and scour velocities*
C     *********************************************************
C
   DO 1020 NF = 1, NFIELD
C
C*********************************************************************
C       IF IQOPT =3 Field 1 flows are input from a
C       link-node hydrodynamic model
C*********************************************************************
C
      IF (IQOPT .GE. 3 .AND. NF .EQ. 1) THEN
       if (hydrofil .eq. '          ')then
c         CALL COLOR ('white', 'blue')
c         CALL HIGHLT ('blue', 'white')
         n = 30
         call OSDIRI (' ','*.hyd',FILES, n)
        if ( n .eq. 0)then
         CALL ATTRIB(' ')
         CALL COLOR('W','red')
         CALL WNOPEN(0,20,70,3)
         CALL WNOUST('No Hydrodynamic linkage file exists in the '
     1  //'WASP4 directory!!  You need to run the hydrodyamic program'
     2  //' first and copy the linkage file to the WASP directory.')
       call wexit('Error Finding Hydrodynamic Linkage File',1)
        endif
        CALL ATTRIB('bold')
        CALL COLOR('cyan','blue')
        CALL WNOPEN(0,21,70,3)
        CALL WNOUST('Please select the hydrodynamic linkage file '
     1 //'to use.  NOTE:  The hydrodynamic file must be copied from '
     2 //'the DYNHYD directory to the WASP directory.')
c       call color ('WHITE', 'blue')
       iopt = mnscrl (files, n, 0, 0, 'Hydro-Link File', 10, 1, 1)
       hydrofil = files (iopt)
      endif
      DO 1111 ISEG = 1, NOSEG
C . QSEG is determined in the QCALC program or read in by the HYDROIN
C   routine, or restart file.  In general, at this point in the program
C   QSEG has not yet been determined.
C
       IF (QSEG (ISEG) .GT. 0.0 .AND. NOQ .NE. 0) THEN
        QSEG (ISEG) = QSEG (ISEG)/86400.
        VELOCG (ISEG) = VMULT (ISEG)*QSEG (ISEG)**VEXP (ISEG)
        DEPTHG (ISEG) = DMULT (ISEG)*QSEG (ISEG)**DXP (ISEG)
       ELSE
        DEPTHG (ISEG) = DMULT (ISEG)
        velocg (iseg) = vmult (iseg)
       END IF
c***  calculate segment depth based on volume and area of the cell, assuming
c***  a rectangular box shape -MD- Feb 11/92
C***   FEB 16/92 ADDED LINEAR DEPTH-VOL OPTION -MD-
C**** -BZ- JAN 28/93 Changed logic slightly
C        IF( IVOPT.GT.1) THEN
C          IF( IDOPT(ISEG).EQ.1 ) THEN
C            DEPTHG (ISEG) = MVOL (ISEG)/ xarea(ISEG)
C          ELSE IF( IDOPT(ISEG).EQ.2 ) THEN
C            DEPTHG (ISEG) = MVOL (ISEG)*VDSLOPE(ISEG)+VDCONST(ISEG)
C         ENDIF
C        ENDIF
c***
 1111  CONTINUE
      CALL WAS4A (hydrofil)
```

```
      NINQ (1) = 1.0
      GO TO 1030
    END IF
C
c... Added SEDOPT flag to invoke Krish's Sediment Transport Algorithms Nov 95 MD
c... Added SEDICEFC         to scale bed shear stress under ice covered conditions MD Jan 96
       IF (NF .GE. 3 .AND. NF .LE. 5) THEN
c         READ (IN, 5110, ERR = 1000) NINQ (NF), SCALQ, CONVQ, SEDOPT
         READ (IN, 5110) NINQ (NF), SCALQ, CONVQ, SEDOPT, SEDICEFC
       ELSE
         READ (IN, 5010, ERR = 1000) NINQ (NF), SCALQ, CONVQ
       END IF
C
c        READ (IN, 5010, ERR = 1000) NINQ (NF), SCALQ, CONVQ
C
C**** MONTE-CARLO STUFF --- CHANGE FLOWS SCALE VALUES -MD- JULY 16/92
C        IRISK = 1
     IF (FFIELD.GT.0 .AND. IRISK.EQ.1) THEN
       JJCOUNT = EFIELD+ISCALV+1+LLLFFIEL
       DO I=1,FFIELD
         IF (FNO(I).EQ.NF) THEN
           SCALQ = SCALQ * RISKV(JJCOUNT)
           JJCOUNT = JJCOUNT + 1
           LLLFFIEL = LLLFFIEL + 1
         END IF
       END DO
     END IF
C
     WRITE (OUT, 6040) NF, NINQ (NF), SCALQ, CONVQ
c... Added SEDOPT flag to invoke Krish's Sediment Transport Algorithms
c    Nov 95 MD
 5110 FORMAT(I5,2F10.0,I5,F10.0)
 5010 FORMAT(I5,2F10.0)
 6040 FORMAT(//,23X,' Field',I3,1X,'has',1X,I3,1X,'Inflows',6X,/,
    1    23X,' SCALQ =',E10.3,2X,'CONVQ =',E10.3,/)
     NINQX = NINQ (NF)
C
C**********************************************************************
C       If no Inflows for field NF, skip to next flow field
C**********************************************************************
C
       IF (NINQX .EQ. 0) GO TO 1030
C
C          Check if number of inflows is greater than the maximum
C
       IF (NINQX .GT. MNI) THEN
         WRITE (OUT, 6050) MNI
 6050     FORMAT(///20X,'The Number of Inflows is Greater Than',
    1          /20X,'The Maximum of ',I5,2X,'Set in the Common ',
    2          'Block',/20X,'**** EXECUTION TERMINATED ****')
       CALL WEXIT('Dimension Error See the Output File',1)
       END IF
C
       IF (CONVQ .EQ. 0.0) CONVQ = 1.0
       SCALQ = SCALQ*CONVQ
C
C                  LOOP THROUGH INFLOWS
C
       DO 1040 NI = 1, NINQX
         WRITE (OUT, 6060) NI
 6060     FORMAT(//31X,'Inflow Number',I3/,31X,16('-'))
c... Added D65 and Tcd for Krish's Sediment Transport Algorithms
         IF (NF .GE. 3 .AND. NF .LE. 5 .and. SEDOPT .EQ. 1) THEN
           READ (IN, 5120, ERR = 1000) NOQS (NF, NI),
    +          D65(NF,NI),Tcd(NF,NI)
         ELSE
           READ (IN, 5020, ERR = 1000) NOQS (NF, NI)
```

```
      ENDIF
c      READ (IN, 5020, ERR = 1000) NOQS (NF, NI)
 5020  FORMAT(I5)
 5120  FORMAT(I5,2f10.0)
C
C************************************************************************
C          Read in continuity array
C************************************************************************
C
      NOQ = NOQS (NF, NI)
      IF (NOQ .GT. S2) GO TO 1050
      READ (IN, 5030, ERR = 1000) (BQ (NF, NI,
   1    NQ), JQ (NF, NI, NQ),
   2    IQ (NF, NI, NQ), NQ = 1, NOQ)
 5030  FORMAT(4(F10.0,2I5))
      IF (NF .LE. NDISS) WRITE (OUT, 6070)
      IF (NF .GT. NDISS) THEN
        IF (NF .LE. 5) WRITE (OUT, 6080)
        IF (NF .EQ. 6) WRITE (OUT, 6090)
      END IF
6070    FORMAT(5X,'Continuity Array:'//,3(8X,'Flow   From  To'),
   1     /,80('~'),/)
6080    FORMAT(5X,'Solids Transport:'//,3(8X,'Area   From  To'),
   1     /,80('~'),/)
6090    FORMAT(5X,'Evap. or Precip.:'//,3(8X,'Area   From  To'),
   1     /,80('~'),/)
      WRITE (OUT, 6100) (BQ (NF, NI, NQ), JQ (NF,
   1    NI, NQ), IQ (NF, NI, NQ),
   2    NQ = 1, NOQ)
6100    FORMAT(3(5x,E10.3,2I5))
C
C************************************************************************
C     Check for illegal solids transport flows to lower beds
C     (variable bed volume option IBEdV=1)
C************************************************************************
C
      DO 1060 NQ = 1, NOQ
        IF (IBEDV .GE. 1 .AND. NF .NE. 2) THEN
          I1 = IQ (NF, NI, NQ)
          J1 = JQ (NF, NI, NQ)
          if (i1 .eq. 0 .or. j1 .eq. 0) goto 1060
            IF (ITYPE (I1) .EQ. 4 .OR. ITYPE (J1) .EQ. 4) THEN
              WRITE (OUT, 6110) NF, NI, I1, J1
6110              FORMAT(///20X,'Flow For Field',I3,2X,'Inflow',
   1            I3,2X,'Between Segments',I3,2X,'and',I3,2X,
   2            /20X,'is Not Allowed When IBEDV =1',
   3            10X,'** RUN DISCONTINUED **')
              CALL WEXIT('Error with Bed Option and Flows',1)
            END IF
          END IF
1060    CONTINUE
C
C************************************************************************
C            Read in time functions.
C************************************************************************
C
      READ (IN, 5040, ERR = 1000) NBRKQ (NF, NI)
5040   FORMAT(I5)
      NOBRK = NBRKQ (NF, NI)
      IF (NOBRK .GT. MB) CALL BRKERR (NOBRK)
      WRITE (OUT, 6120) NOBRK
6120   FORMAT(//5X,'Number of Breaks in Time Function = ',I5,///)
      READ (IN, 5050, ERR = 1000) (QT (NF, NI, NB),
   1    TQ (NF, NI, NB), NB = 1, NOBRK)
5050   FORMAT(4(2F10.0))
      IF (NF .LE. NDISS) WRITE (OUT, 6130)
      IF (NF .GT. NDISS) WRITE (OUT, 6140)
```

```
 6130     FORMAT(3(8X,'Flow     Time   '),/,1X,78('~'),/)
 6140     FORMAT(3(6X,'Velocity    Time   '),/1X,78('~'),/)
C
C*** -BZ- 06-May-1993 09:38:36
C Now scaling QT directly instead of BQ (below).
C
        DO NB = 1, NOBRK
          QT (NF, NI, NB) = QT (NF, NI, NB)* SCALQ
        ENDDO

        WRITE (OUT, 6150) (QT (NF, NI, NB), TQ (NF,
   1      NI, NB), NB = 1, NOBRK)
 6150     FORMAT(3(5x,2(E10.3)))
C
C************************************************************************
C    Multiply flows by scale and conversion factor (cms to m**3/day)
C************************************************************************
C
        DO 1070 NQ = 1, NOQ
          IF (IQ (NF, NI, NQ) .GT. SG .OR.
   1        JQ (NF, NI, NQ) .GT. SG)
   2        CALL WERR (4, IQ (NF, NI, NQ), JQ (NF, NI, NQ))
C
C*** -BZ- 06-May-1993 09:36:17
C Changed SCALQ from BQ to QT directly.  This effects the way the
C TRSMIX modification operates.
C
C           BQ (NF, NI, NQ) = BQ (NF, NI, NQ)*SCALQ*86400.
          BQ (NF, NI, NQ) = BQ (NF, NI, NQ)*86400.
c
 1070     CONTINUE
 1040   CONTINUE
C
 1030   CONTINUE
 1020 CONTINUE
C
C************************************************************************
C      Mass balance check for advective flows (FIELD 1)
C************************************************************************
C
c** May 20/93 Adding code to allow individual flow values within any
C  time function to be varied individually -MD-
c
     IF (KTOTAL .GT. 0 .AND. IRISK .EQ. 1) THEN
c       JJCOUNT = EFIELD+ISCALV+FFIELD+NSYSB+NSYSL+NSYSN+
c    +    NSCAL+NOPAR+NOCON+NSYSC*2+NQINT+1+NOBOUND+NINIT+
c    +    NOLTF
      JJCOUNT = EFIELD+ISCALV+FFIELD+NSYSB+NSYSL+NSYSN+NSCAL+
   +    NOPAR+NOCON+NSYSC*2+NQINT+NOBOUND+NINIT+NOLTF
c
      DO JJ=1,NITOTAL
        DO IJ=1,KNO(JJ)
          JJCOUNT = JJCOUNT + 1
          QT(NFRISK(JJ),NIRISK(JJ),KRISK(JJ,IJ)) =
   +        QT(NFRISK(JJ),NIRISK(JJ),KRISK(JJ,IJ)) * RISKV(JJCOUNT)
        END DO
      END DO
     END IF
c
C
     IF (IQOPT .LT. 2 .AND. NINQ (1) .GT. 0) THEN
       DO 1080 ISEG = 1, NOSEG
         DO 1090 NI = 1, NINQ (1)
           QSUMX = 0.0
           DO 1100 NQ = 1, NOQS (1, NI)
             IF (IQ (1, NI, NQ) .EQ. ISEG) QSUMX =
   1           QSUMX + BQ (1, NI, NQ)
```

```
            IF (JQ (1, NI, NQ) .EQ. ISEG) QSUMX =
  1           QSUMX - BQ (1, NI, NQ)
 1100       CONTINUE
          IF (QSUMX .GT. 1.0E-09) WRITE (OUT, 6160) ISEG, NI
 6160     FORMAT(//10X,40('*'),/10X,'Advective Flows in Segment',I5,
  1         /10X,'Do Not Balance For Inflow',I5,
  2         /10X,'Check Continuity Matrix',/10X,40('*')//)
 1090     CONTINUE
 1080   CONTINUE
    ELSE
    END IF
c
c
C       SEGMENT LOOP
    nf=1
    do 1920 ni=1,ninq(nf)
        DO 1930 NQ = 1, NOQ
          Q = BQ (NF, NI, NQ)*QINT (NF, NI)
          IF (Q .GE. 0.) THEN
            I = IQ (NF, NI, NQ)
            J = JQ (NF, NI, NQ)
          ELSE
            J = IQ (NF, NI, NQ)
            I = JQ (NF, NI, NQ)
            Q = - Q
          END IF
C
C     Sum Segment Flows
C
          IF (J .GT. 0) QSEG (J) = QSEG (J) + 0.5*Q/86400.
          IF (I .GT. 0) QSEG (I) = QSEG (I) + 0.5*Q/86400.
 1930     CONTINUE
 1920     continue
    DO 1110 ISEG = 1, NOSEG
      IF (QSEG (ISEG) .GT. 0.0 .AND. NOQ .NE. 0) THEN
        QSEG (ISEG) = QSEG (ISEG)/86400.
        VELOCG (ISEG) = VMULT (ISEG)*QSEG (ISEG)**VEXP (ISEG)
        DEPTHG (ISEG) = DMULT (ISEG)*QSEG (ISEG)**DXP (ISEG)
      ELSE
        DEPTHG (ISEG) = DMULT (ISEG)
        velocg (iseg) = vmult (iseg)
      END IF
c***
c***  calculate segment depth based on volume and area of the cell, assuming
c***  a rectangular box shape -MD- Feb 11/92
C***  FEB 16/92 ADDED LINEAR DEPTH-VOL OPTION -MD-
C**** -BZ- JAN 28/93 Changed logic slightly
C         IF( IVOPT.GT.1) THEN
C           IF( IDOPT(ISEG).EQ.1 ) THEN
C             DEPTHG (ISEG) = MVOL (ISEG)/ xarea(ISEG)
C           ELSE IF( IDOPT(ISEG).EQ.2 ) THEN
C             DEPTHG (ISEG) = MVOL (ISEG)*VDSLOPE(ISEG)+VDCONST(ISEG)
C           ENDIF
C         ENDIF
c***
 1110 CONTINUE
C*************************************************************************
C                  BYPASS OPTIONS
C*************************************************************************
C
    READ (IN, 5060, ERR = 1000) (QBY (I), I = 1, NOSYS)
 5060 FORMAT(16I5)
    DO 1120 ISYS = 1, NOSYS
      QBY (ISYS) = QBY (ISYS) + SYSBY (ISYS)
 1120 CONTINUE
    WRITE (OUT, 6170) NOSYS, (QBY (I), I = 1, NOSYS)
 6170 FORMAT(//10X,'Q Bypass Options for Systems 1 to',I3,' are',20I3/)
```

```
      WRITE(OUT,6181)
 6181 FORMAT('1')
      RETURN
C
C****************************************************************************
C        OPTION 0 - NO FLOWS
C****************************************************************************
C
 1010 CONTINUE
      DO 1130 ISYS = 1, NOSYS
        QBY (ISYS) = 1
 1130 CONTINUE
      IQOPT = 1
      WRITE (OUT, 6180)
 6180 FORMAT(///25X,'NO FLOWS'//)
      RETURN
C
 1050 CONTINUE
      WRITE (OUT, 6190) NOQ, S2
 6190 FORMAT(///10X,'The Number of Flows ',
     1  'Specified is ',I5/10X,
     2  'The Maximum Dimensioned for This Version of WASP',
     3  ' is ',I3/10X,'Respecify Flows or Redimension Parameter "S2"',
     4  'in the Common',/,10X,'Block and Recompile.')
        CALL WEXIT('Dimension Error See the Output File',1)
 1000 CONTINUE
      CALL WEXIT('Error Reading Card Group D',1)
c
      END
```

```
      subroutine BASINFO (J,I,NF,NI)
C=========================================================================
C  CALCULATE BASIC INFORMATION
C=========================================================================

c     MAIN COMMON BLOCK
      INCLUDE 'WASP.CMN'
      include 'sed2.cmn'
      include 'environ.cmn'

c     BED SHEAR VELOCITY (Ustarr) AND BED SHEAR STRESS (TNOT)
      Ustarr = Velocg(j)/(2.5*log(11.0*Depthg(j)/(2.5*D65(NF,ni))))

c     ICE COVER CORRECTION FOR TNOT
c     Water temp linear time function 1 <=0 for ice covered conditions
      if (TEMPN(1) .le. 0.0) Ustarr = Ustarr*SEDICEFC
      Tnot(NF,j) = 1000.0 * Ustarr**2

c     CALCULATE FRACTIONS DEPOSITED (fd) AND ERODED (fe)
      if (Tnot(NF,j)/Tcd(NF,NI) .le. 1.0) then
        fd(NF,j) = 1.0
      elseif (Tnot(NF,j)/Tcd(NF,NI) .gt. 1.0 .and. Tnot(NF,j)/Tcd(NF,NI)
     +       .lt. 6) then
        fd(NF,j) = 1.0-0.32*(Tnot(NF,j)/Tcd(NF,NI)-1.0)**0.70
      else
        fd(NF,j) = 0.0
      end if

      if (Tnot(NF,j)/Tcd(NF,NI) .le. 2.0) then
        fe(NF,j) = 0.0
      elseif (Tnot(NF,j)/Tcd(NF,NI) .gt. 2.0 .and. Tnot(NF,j)/Tcd(NF,NI)
     +       .lt.12) then
        fe(NF,j) = 0.32*(Tnot(NF,j)/Tcd(NF,NI)-2.0)**0.50
      else
        fe(NF,j) = 1.0
      end if

      RETURN
      END
C
      subroutine SEDCALC (J,I,NF,NI)
C=========================================================================
C  DO SEDIMENT TRANSPORT CALCULATIONS
C=========================================================================

c     MAIN COMMON BLOCK
      INCLUDE 'WASP.CMN'
      include 'sed2.cmn'

C     qsd = AMOUNT OF SEDIMENT THAT WOULD DEPOSIT UNDER CURRENT FLOW CONDITION (kg/day)
c Note: for sediment transport (NF = 3,4, and 5) NF-1 = ISYS
c CHANGED KRISH'S ALGORITHM TO USE MASS IN CELL RATHER THAN MASS ENTERING
      qsd(NF,j) = C(NF-1,J) * MVOL(J) * fd(NF,j)

C     qsb = TOTAL SEDIMENT ON THE BED OF CONTROL SEGMENT (kg/day)
      qsb(NF,j) = C(NF-1,I) * BSA(j) * DEPTHG(I) + qsd(NF,j)

C     qsr = AMOUNT OF SEDIMENT RESUSPENDED UNDER THE CURRENT FLOW CONDITION (kg/day)
      qsr(NF,j) = qsb(NF,j) * fe(NF,j)

c NOT NEEDED BUT LEFT IN FOR POSSIBLE CHECKING LATER
C     qabn = AMOUNT OF SEDIMENT LEFT BEHIND AFTER RESUSPENSION (kg/day)
c     qabn(NF,j) = qsb(NF,j) * (1 - fe(NF,j))
C     qss = AMOUNT OF SEDIMENT COMING INTO SUSPENSION (kg/day)
c     qss(NF,j) = qsu(NF,j) * (1 - fd(NF,j)) + qsr(NF,j)
c     Css = SUSPENDED SEDIMENT CONCENTRATION IN THE CONTROL SEGMENT (mg/L)
c     Css(NF,j) = ((qsu(NF,j)/Q(j)) * (1-fd(NF,j)) + (qsb(NF,j)/Q(j))*fe(NF,j))/1000
```

```
RETURN
END
```

```
      SUBROUTINE QSED2
C=====================================================================
C  Last Revised:  Date: Thursday, 1 February 1990.  Time: 16:24:09.
C
C
C  Correction History:
C  The original QSED was modified to only calculate Settling and
c  resuspension using Krishappan's algorithm's
c  Modification made by Mark Digel of Golder Associates,
c  November 11, 1995
C
C--------------------------------------------------------
C
      INCLUDE 'WASP.CMN'
      include 'sed2.cmn'
C
C*** -MD- MAY 20/93 ADDED NFIELDN TO PREVENT EVAP (FIELD 6) FROM
C***              BEING COMPUTED AGAIN HERE.....
      IF (NFIELD .EQ. 6) THEN
       NFIELDN = 5
      ELSE
       NFIELDN = NFIELD
      END IF
C     DO 1000 NF = 3, NFIELD
      DO 1000 NF = 3, NFIELDN
        NINQX = NINQ (NF)
        IF (NINQX .GT. 0) THEN
C
C   LOOP THROUGH INFLOWS
C
          DO 1010 NI = 1, NINQX
           NOQ = NOQS (NF, NI)
C
C    SEGMENT LOOP
C
c  Simplify by having J as water column cell and I as sediment cell
           DO 1020 NQ = 1, NOQ
            I = IQ (NF, NI, NQ)
            J = JQ (NF, NI, NQ)
            BSA(J) = BQ(NF,NI,NQ)/86400
C
C    ADVECT SYSTEM(ISYS)
C
c   Call Sediment Transport subroutines
            call BASINFO (J,I,NF,NI)
            call SEDCALC (J,I,NF,NI)

c Change logic for sediment transport where NF-1 = ISYS
c              ISYS = NF-1
            do 1030 isys = 1,nosys
            IF (QBY (ISYS) .EQ. 0) THEN
c               CALL WA12A (I, J, NOBC (ISYS),
c    1           CONC1, CONC2, ADVECT, IERR)
C                IF (IERR .GT. 0) GO TO 1040
c... Calculate CSTAR equivelents for deposition and erosion
c... qsd / c = (g/day) / (g/m3) = m3/day
C... MD JAN 30/96 TSOLFRAC IS THE SOLIDS SORBED FRACTION FOR CHEM "isys" TO SOLIDS NF-1
C...             IN SEGMENT "j"
               if (c(nf-1,j) .gt. 0.0 ) then
                IF(ISYS .GE. 2 .AND. ISYS .LE. 4) THEN
                  CSTARR1 = qsd(NF,j)
                ELSE
                  CSTARR1 = (qsd(NF,j) / c(nf-1,j)) * c(isys,j)
c    +                     * TSOLFRAC(NF-1,isys,j)
     +                    * TSOLFRAC(isys,j)
                END IF
               else
```

```
              CSTARR1 = 0.0
            end if
            if (c(nf-1,i) .gt. 0.0 ) then
              IF(ISYS .GE. 2 .AND. ISYS .LE. 4) THEN
                CSTARR2 = qsr(NF,j)
              ELSE
                CSTARR2 = (qsr(NF,j) / c(nf-1,i)) * c(isys,i)
     +                   * TSOLFRAC(isys,i)
c    +                    * TSOLFRAC(NF-1,isys,i)
              END IF
            else
              CSTARR2 = 0.0
            end if
c... Calculate deposition loss (qsd) and erosion gain in WC layer (I)
          IF (J .GT. 0) THEN
            CSTARR = -1.0*CSTARR1 + CSTARR2
            CD (ISYS, J) = CD (ISYS, J) + CSTARR
            SUMM (ISYS, J) = SUMM (ISYS, J) - CSTARR
          END IF
c... Calculate deposition (qsd) and erosion (qsr) in Bed layer (J)
          IF (I .GT. 0) then
            CSTARR = CSTARR1 - CSTARR2
c             CSTARR = qsd(NF,j) / c(nf,j) * c(isys,j) - qsr(NF,j)
c    +                    / c(nf,i) * c(isys,i)
            CD (ISYS, I) = CD (ISYS, I) + CSTARR
          END IF
C
C    MASS BALANCE
C
          IF (ISYS .EQ. JMASS) THEN
            IF (I .EQ. 0) AOFLUX =
   1          AOFLUX + (CSTARR2-CSTARR1)/1000.
            IF (J .EQ. 0) AIFLUX =
   1          AIFLUX + (CSTARR1-CSTARR2)/1000.
          END IF
         END IF
 1030      CONTINUE
 1020     CONTINUE
 1010    CONTINUE
      END IF
 1000 CONTINUE
    RETURN
C
 1040 CONTINUE
    CALL WERR (IERR, I, J)
    CALL WEXIT
    END
```

```
C==========================================================================
C         *-*-*-*-  SEDMODL MAIN COMMON BLOCK  -*-*-*-*
C==========================================================================
C   Created October 20, 1995 by Mark Digel
C-----------------------------------------------------------
c    INPUT VARIABLES
c    D65=representative bed material diameter for river segment (m) In WASP.CMN
c    ICECVR = Ice cover indicator (1 = yes, 0 = no)
c    Tcd = Critical shear stress for deposition (N/m2) In WASP.CMN
c    fd = fraction deposited
c    fe = fraction eroded
c    Pinit = Initial mass of deposited sediment per unit area (kg/m2)

c    MODEL VARIABLES
c    Tnot = Bed shear stress (N/m2)
C     qsd = AMOUNT OF SEDIMENT THAT WOULD DEPOSIT UNDER CURRENT FLOW CONDITION (kg/tstep)
C     qsb = TOTAL SEDIMENT ON THE BED OF CONTROL SEGMENT (kg/tstep)
C     qsr = AMOUNT OF SEDIMENT RESUSPENDED UNDER THE CURRENT FLOW CONDITION (kg/tstep)

C     qabn = AMOUNT OF SEDIMENT LEFT BEHIND AFTER RESUSPENSION (kg/tstep)
C     qss = AMOUNT OF SEDIMENT COMING INTO SUSPENSION (kg/tstep)
c    Css = SUSPENDED SEDIMENT CONCENTRATION IN THE CONTROL SEGMENT (mg/L)

      INTEGER sg2

c    SET FILE NUMBERS
      PARAMETER (mnf2=6,mni2=65,sg2=920)

      REAL BSA,Tnot,fd,fe,
     +    qsb,qsd,qsr
c    +    qabn,qss

      COMMON /BASICVAR/ BSA(sg2),Tnot(mnf2,sg2),fd(mnf2,sg2),
     +              fe(mnf2,sg2)

      COMMON /SEDCAVAR/ qsd(mnf2,sg2),qsb(mnf2,sg2),qsr(mnf2,sg2)
c     + qabn(mnf2,sg2),qss(mnf2,sg2),Css(mnf2,sg2)
```

```
      SUBROUTINE FRCION (ICHM, DISTRIB, PIDOC)
C======================================================================
C  Last Revised:  Date: Thursday, 1 February 1990.  Time: 16:32:15.
C
C  Correction History:
C
C
C
C----------------------------------------------------
C  Function:
C                   This routine computes the fraction of total chem
C           dissolved, doc sorbed and solids sorbed molecular and
C           ionic species JS = # of the system for the chemical being
C           considered.
C----------------------------------------------------
C
      INCLUDE 'WASP.CMN'
C
      INCLUDE 'ENVIRON.CMN'
C
      INCLUDE 'PHYSCHM.CMN'
C
      INCLUDE 'CONC.CMN'
C
C
      DIMENSION FRAC (25), DISTRIB (4), PIDOC (4), DISFCT (25)
C
C   I. COMPUTE DISTRIBUTION FACTORS FOR EACH PHASE AND SPECIE
C      Distribution factor is the ratio of component concentration
C      to dissolved parent compound concentration
C
C       A) SORBED TO SOLIDS:
C
      IF (ICHM .EQ. 1) JS = 1
      IF (ICHM .EQ. 2) JS = 5
      IF (ICHM .EQ. 3) JS = 6
      DO 1000 J = 1, 3
        JJ = 5*(J - 1)
         SLD = C(J+1,ISEG)*1.0E-06
C
C          1) parent compound

        DISFCT (1 + JJ) = PART (J, 1)*SLD
C
C          2) singly charged cation
        DISFCT (2 + JJ) = PART (J, 2)*SLD*DISTRIB (1)
C
C          3) doubly charged cation
        DISFCT (3 + JJ) = PART (J, 3)*SLD*DISTRIB (2)
C
C          4) singly charged anion
        DISFCT (4 + JJ) = PART (J, 4)*SLD*DISTRIB (3)
C
C          5) doubly charged anion
        DISFCT (5 + JJ) = PART (J, 5)*SLD*DISTRIB (4)
C
 1000 CONTINUE
C
C       B) SORBED TO DOC:
C
      DOCKGL = SDOC*1.E-06
C
C          1) parent compound
      DISFCT (16) = KOC*DOCKGL
C
C          2) singly charged cation
      DISFCT (17) = PIDOC (1)*DOCKGL*DISTRIB (1)
```

```
C
C          3) doubly charged cation
      DISFCT (18) = PIDOC (2)*DOCKGL*DISTRIB (2)
C
C          4) singly charged anion
      DISFCT (19) = PIDOC (3)*DOCKGL*DISTRIB (3)
C
C          5) doubly charged anion
      DISFCT (20) = PIDOC (4)*DOCKGL*DISTRIB (4)
C
C       C) DISSOLVED:
C
C          1) parent compound
      DISFCT (21) = 1  * PORE
C
C          2) singly charged cation
      DISFCT (22) = DISTRIB (1) * PORE
C
C          3) doubly charged cation
      DISFCT (23) = DISTRIB (2) * PORE
C
C          4) singly charged anion
      DISFCT (24) = DISTRIB (3) * PORE
C
C          5) doubly charged anion
      DISFCT (25) = DISTRIB (4) * PORE
C
C
C   II. COMPUTE FRACTION OF TOTAL CHEMICAL FOR EACH COMPONENT
C
C       A) SUM DISTRIBUTION FACTORS
C
      DENOM = 0.0
      DO 1010 K = 1, 25
C
C         For doc sorbed & dissolved components multiply by
C         porosity to convert water volume to total volume
C
        DENOM = DENOM + DISFCT (K)
 1010 CONTINUE
C
C       B) COMPUTE FRACTIONS
C
c... MD Store solids sorbed fractions for use in sediment transport
c...    subroutine QSED2.FOR - January 30, 1996 - TSOLFRAC(JS,ISEG)
      TSOLFRAC(JS,ISEG) = 0.0
DO 1020 K = 1, 25
        FRAC (K) = DISFCT (K)/DENOM
        IF (FRAC (K) .LT. 1 00E-10) FRAC (K) = 0.0
        IF (K .LE. 15) TSOLFRAC(JS,ISEG) = TSOLFRAC(JS,ISEG) + FRAC(K)
1020 CONTINUE
C
C       C) COMPUTE COMPONENT CONCENTRATIONS
C
C          1) solids sorbed components
      k=0
      DO 1030 J = 1, 3
        DO 1040 ION = 1, 5
          K = K + 1
          PARTOX (ICHM, J, ION) = FRAC (K)*C (JS, ISEG)
          IF (PARTOX (ICHM, J, ION) .LT. 1.0E-30)
     1       PARTOX (ICHM, J, ION) = 0.0
 1040   CONTINUE
 1030 CONTINUE
C
C          2) doc sorbed components
      DO 1050 K = 16, 20
```

```
      DOCTOX (ICHM, K - 15) = FRAC (K)*C (JS, ISEG)
      IF (DOCTOX (ICHM, K - 15) .LT. 1.0E-30)
   1     DOCTOX (ICHM, K - 15) = 0.0
 1050 CONTINUE
C
C           3) dissolved components
     DO 1060 K = 21, 25
      DISTOX (ICHM, K - 20) = FRAC (K)*C (JS, ISEG)
      IF (DISTOX (ICHM, K - 20) .LT. 1.0E-30)
   1     DISTOX (ICHM, K - 20) = 0.0
 1060 CONTINUE
C
C
C
C        D) EQUATE FRACTIONS TO F ARRAY FOR PROPER TRANSPORT
C           NOTE: The transport (exchange & flow) fields must
C                be as follows:
C                 field #1 applies to total chemical
C                 field #2 applies to dissolved & doc sorbed chemic
C                 field #3 to field N applies to particulate chemic
C
     F (1, JS, ISEG) = 1.0
     F (2, JS, ISEG) = 0.0
     DO 1070 K = 16, 25
      F (2, JS, ISEG) = F (2, JS, ISEG) + FRAC (K)
 1070 CONTINUE
     K=0
     DO 1080 J = 1, 3
      F (J + 2, JS, ISEG) = 0.0
      DO 1090 ION = 1, 5
        K = K + 1
        F (J + 2, JS, ISEG) = F (J + 2, JS, ISEG) + FRAC (K)
 1090   CONTINUE
 1080 CONTINUE
C
     RETURN
     END
```

```
      SUBROUTINE EULER
C======================================================================
C  Last Revised:  Date: Thursday, 1 February 1990.  Time: 16:24:41.
C
C  Correction History:
C  Feb 1993:   -BZ-
C     Added TRSMIX routines to determine average geometry
C     of the river over the cell reach.
C  March 8,1993 -BZ-
C     Added Steady State self checking routine.  This system limits
C     key parameters and wits for steady state conditions in the river
C     then resumes normal operation.
C-----------------------------------------------------
C
      INCLUDE 'WASP.CMN'
      INCLUDE 'RISK.CMN'
C**** -BZ-  flow/velocity variable flow distribution common block
      INCLUDE 'TRSMIX.CMN'
C
      REAL*8 MASS, MDER, VOLOLD, VOLNEW
      CHARACTER*1 PROP(6)
c
C  Function declarations
      INTEGER CELLNUM
      INTEGER STSTATE
c
C
      COMMON /W19/ ISKPLT
      INTEGER HDEPVEL
      COMMON /DYNHYD/ ICYCLE, itcyc, ITOTCYC, HDEPVEL, NSEG, NFLOW
      EQUIVALENCE (TIME, T)
c      DATA PROP /[illegible]/
      DATA PROP /'|','/','-','|','\','-'/
C======================================================================
C   Controls computation and output, Version 2:mass derivatives,
c   corrected for time variable volumes: in this version,
c   mass is constituent mass,  mder is the mass derivative,
c   BVOl(ISEG) is the OLD VOLUME, and MVOL(ISEG) is the NEW VOLUME
C======================================================================
C
      ITRAK = 1
      T = 0.0
      NDEVL = 0.0
      DTS2 = DT
      TMARKS = TZERO + TDINTS
c
C**** -BZ- JAN 28/93 OPTIMIZATION
C     IF (TZERO .EQ. 0.) GO TO 1000
C     CALL TINIT
C     TIME = TZERO
C     TNEXT = TZERO
C 1000 CONTINUE
C
      IF (TZERO .NE. 0.) THEN
        CALL TINIT
        TIME = TZERO
        TNEXT = TZERO
      ENDIF
C
      DAY = TZERO
      NEWDAY = 1

C**** -BZ- need to initialize QINT() for call to QUPDATE
C        READ NEW FLOWS AND VOLUMES
C
C  UPDATE FLOWS AND EXCHANGES FOR CURRENT TIME STEP.
C  IF IQOPT IS 2 OR 3, FIELD 1 FLOWS WILL BE UPDATED IN
```

```
C  HYDRAULIC SUBROUTINES (I.E. QINT(1,1)=1.0).
C
      CALL WAS8B
c
C
C**** -BZ- JAN 28/93 ADDED TRSMIX MODEL
C..set initial volumes etc
      IF( ITRSMIX.NE.0) THEN
        CALL QUPDATE
C..Initialize the first layer volumes
        DO ISG=1,NSEGS
          DO ITUB = 1,NTUBES(ISG)
            ICELL = CELLNUM(ISG,ITUB)
            IF(ITYPE(ICELL).EQ.1) THEN
              BVOL(ICELL) = MVOL(ICELL)
C..Reset cell volumes for all layers below the
C  water column.  Types should be type.ne.1 (assumed)
              ICELLB = IBOTSG(ICELL)
              WHILE(ICELLB.NE.0) DO
                BVOL(ICELLB) = MVOL(ICELLB)
                ICELLB = IBOTSG(ICELLB)
              ENDWHILE
            ENDIF
          ENDDO
        ENDDO
      ENDIF
c
C**** -BZ- Mar 5/93
C..Turn off dispersion and turn down the flow rate
      IF( ISSOPT .NE. 0) THEN
C       DO NF = 1, NRFLD
        DO NF = 1, 1
          DO NT = 1, NTEX(NF)
            BRINT(NF,NT) = 0.0
          ENDDO
        ENDDO
C       DO NF = 1, NFIELD
        DO NF = 1, 1
          DO NI = 1, NINQ(NF)
C             QINT(NF,NI)  = 1.0
            QINT(1,1)  = 1.0
          ENDDO
        ENDDO
      ENDIF

C..Output initial conditions
      CALL WAS13
c
c
C====================================================================
C                 Evaluate Derivatives
C====================================================================
C
      CALL DERIV
C
C====================================================================
C                 Update Volumes
C====================================================================
      IDISK = 0
C
C====================================================================
C           Check for FATAL Input ERROR Condition
C====================================================================
C
      IF (INPERR .GT. 0) CALL WERR (10, I, J)
C
C====================================================================
```

```
C===================== MAIN LOOP =====================================
C====================================================================
C====================================================================
C====================================================================
C              Integrate using Euler Scheme
C        for Mass Derivatives, then Find NEW Concentrations
C====================================================================
C
 1020 CONTINUE
      CALL COLOR ('BLUE','BLACK')
c Starting here put this into subroutine NEWCONC -MD- November 24, 1995
c_____________________________________________________________________
c     DO 1030 ISYS = 1, NOSYS
c       IF (SYSBY (ISYS) .GT. 0) GO TO 1030
c       DO 1040 ISEG = 1, NOSEG
c         IF (IPROP .GT. 5)IPROP=0
c         IPROP=IPROP + 1
cC**** MONTE CARLO WASP STUFF - ADDING LOOP TO TURN SCREEN CALLS ON OR OFF
cC**** -MD-  NOV 4/92
c         IF (IIFLAG.EQ.0) THEN
c           if (mflag .lt. 2)CALL OUTSXY (72,7,PROP(IPROP))
c         END IF
c         VOLOLD = BVOL (ISEG)
c         VOLNEW = MVOL (ISEG)
c         MASS = C (ISYS, ISEG)*VOLOLD
c         MDER = CD (ISYS, ISEG)
c         C (ISYS, ISEG) = (MASS + DT*MDER)/VOLNEW
c         CD (ISYS, ISEG) = 0.0
c         IF (NEGSLN .EQ. 1) GO TO 1050
cC
cC====================================================================
cC         Protect Against Underflows or Negative Solutions
cC====================================================================
cC
cC
cC   CHANGED BY R. SHAW NOV 29, 1991
cC
cC          IF (C (ISYS, ISEG) .LT. 1.0E-25) C (ISYS,
cC    1        ISEG) = 1.0E-25
cC
cC
c          IF (C (ISYS, ISEG) .LT. 1.0E-25) C (ISYS,
c    1        ISEG) = 0.0
c 1050      CONTINUE
c 1040    CONTINUE
c 1030 CONTINUE
c_____________________________________________________________________
      CALL NEWCONC
c Ending here
C
C====================================================================
C                 Update Volumes
C====================================================================
C
    IF (IVOPT .LT. 10)THEN
      DO ISEG = 1, NOSEG
        BVOL (ISEG) = MVOL (ISEG)
      ENDDO
    ENDIF
C
C====================================================================
C                 Increment Time
C====================================================================
    T = T + DT
C
    LDAY = DAY
    NDAY = T
```

```
      NEWDAY = NDAY - LDAY
      IF (NEWDAY .GE. 1) DAY = FLOAT (NDAY)
c
C..Check for steady state conditioning flags
      IF(ISSOPT.NE.0) THEN
C#######       TPRINT = 1.E30
c
C..Has steady state been achieved
        IF(STSTATE().EQ.1) THEN
c
C..If ISSOPT=2 then print results then quit
          IF(ISSOPT.EQ.2) THEN
            CALL WAS13
            GOTO 1080
          ENDIF
C..If ISSOPT=1 then print results and resume
          IF(ISSOPT.EQ.1) THEN
            ISSOPT = 0
            TPRINT = TIME
          ENDIF
        ENDIF
      ENDIF
c
C..print intermediate results
C
      IF( ISSOPT.EQ.0) THEN
        IF (TIME .GE. TPRINT) CALL WAS13
      ENDIF
c
c
C..evaluate derivatives
C
      IF (T .LT. TEND - .00001) CALL DERIV
c
C
C
C**** -BZ- JAN 28/93 OPTIMIZATION
C     IF (IDISK .NE. 1) GO TO 1070
C     IDISK = 0
C 1070 CONTINUE
C
      IF (IDISK .EQ. 1) THEN
        IDISK = 0
      ENDIF
C
C======================================================================
C          Check to See if Simulation Finished
C======================================================================
C
      IF (T .LT. TEND - .00001) GO TO 1020
C
C        Check for New Time Step, New Simulation Segment
C
      ITRAK = ITRAK + 1
      IF (TEND .GT. 0.) CALL WAS14 (ITRAK)
      DTS2 = DT/2.0
      IF (ITRAK .GT. 0) GO TO 1020
C======================================================================
C===================== END MAIN LOOP ==================================
C======================================================================
C======================================================================
C
C======================================================================
C            Simulation Finished ... WRAP UP
C======================================================================
 1080 CONTINUE
c
```

```
      IREC = IREC + 1
      T = T + DTS2
      IDISK = 1
      DO 1090 ISEG = 1, NOSEG
C        DVOL (IREC, ISEG) = BVOL (ISEG)
 1090 CONTINUE
C
      CALL WASPB
C
C=====================================================================
C       Storing Final Conditions in Simulation Restart File
C=====================================================================
C
      IF (ICFL .GE. 1) THEN
        OPEN (UNIT = RESTRT, STATUS = 'UNKNOWN', ACCESS = 'SEQUENTIAL',
     1     FILE = 'RESTART.OUT')
        WRITE (RESTRT, 6000) (ISEG, IBOTSG (ISEG),
     1      ITYPE (ISEG), MVOL (ISEG),
     2     VMULT (ISEG), VEXP (ISEG), DMULT (ISEG), DXP (ISEG),
     3     ISEG = 1, NOSEG)
C
        DO 1100 ISYS = 1, NOSYS
          DENS = DSED (ISYS)/1.E+06
          WRITE (RESTRT, 6010) CHEML (ISYS), IFIELD (ISYS), DENS,
     1                    cmax(isys)
          WRITE (RESTRT, 6020) (C (ISYS, ISEG), F (2, ISYS, ISEG),
     1       ISEG = 1, NOSEG)
6000  FORMAT(3I10,E10.3,4F10.4)
6010  FORMAT(A40,I5,F5.2,e10.3)
6020  FORMAT(3(5X,E10.3,E10.3))
1100   CONTINUE
      END IF
      call was13
      if (mflag .lt. 2)
     1 call prompt('Simulation Completed--Press Return to Exit',0)
      RETURN
      END
```

```
      SUBROUTINE NEWCONC
C=======================================================================
C This code was extracted out of Euler so that Concentrations could be updated
C in more than one place
C-----------------------------------------------
C
      INCLUDE 'WASP.CMN'
      INCLUDE 'RISK.CMN'
      INCLUDE 'TRSMIX.CMN'
C
      REAL*8 MASS, MDER, VOLOLD, VOLNEW
      CHARACTER*1 PROP(6)
C
      EQUIVALENCE (TIME, T)
      DATA PROP /'|','/','-','|','\','-'/
C=======================================================================
      DO 1030 ISYS = 1, NOSYS
        IF (SYSBY (ISYS) .GT. 0) GO TO 1030
        DO 1040 ISEG = 1, NOSEG
          IF (IPROP .GT. 5)IPROP=0
          IPROP=IPROP + 1
C**** MONTE CARLO WASP STUFF - ADDING LOOP TO TURN SCREEN CALLS ON OR OFF
C**** -MD-  NOV 4/92
          IF (IIFLAG.EQ.0) THEN
            if (mflag .lt. 2)CALL OUTSXY (72,7,PROP(IPROP))
          END IF
          VOLOLD = BVOL (ISEG)
          VOLNEW = MVOL (ISEG)
          MASS = C (ISYS, ISEG)*VOLOLD
          MDER = CD (ISYS, ISEG)
          C (ISYS, ISEG) = (MASS + DT*MDER)/VOLNEW
          CD (ISYS, ISEG) = 0.0
          IF (NEGSLN .EQ. 1) GO TO 1050
C
C=======================================================================
C         Protect Against Underflows or Negative Solutions
C=======================================================================
C
C
C  CHANGED BY R. SHAW NOV 29, 1991
C
C           IF (C (ISYS, ISEG) .LT. 1.0E-25) C (ISYS,
C    1          ISEG) = 1.0E-25
C
C
          IF (C (ISYS, ISEG) .LT. 1.0E-25) C (ISYS,
     1          ISEG) = 0.0
 1050     CONTINUE
 1040   CONTINUE
 1030 CONTINUE

      RETURN
      END
```

```
SUBROUTINE WAS12
C=====================================================================
C  Last Revised:  Date: Thursday, 1 February 1990.  Time: 16:26:05.
C
C
C  Correction History: Added qsum array, 9/9/87, rba
C
C
C-----------------------------------------------
C      WAS12 COMPUTES THE PORTION OF THE DERIVATIVE DUE TO TRANSPORT
C      AND LOADS, AND ADJUSTS VOLUMES FOR CONTINUITY (IF IVOPT=2)
C
C
      REAL LOAD
C
      INCLUDE 'WASP.CMN'
      INCLUDE 'RISK.CMN'
C
      EQUIVALENCE (TIME, T)
C
C      FLOW AND EXCHANGE CONVENTION
C        (I,J) --- (TO,FROM)
C
C        IF I=0 THEN DOWNSTREAM B.C.
C        IF J=0 THEN UPSTREAM B.C.
C
C      TRANSPORT DUE TO FLOW
C
C*********************************************************************
C               Update Boundary Conditions
C*********************************************************************
C
      AIFLUX = 0.
      AOFLUX = 0.
      RIFLUX = 0.
      ROFLUX = 0.
      XLFLUX = 0.
      DO 1000 ISYS = 1, NOSYS
        IF (SYSBY (ISYS) .EQ. 0 .AND. NOBC (ISYS) .GT. 0) THEN
          IF (TIME .GE. NTB (ISYS)) CALL WAS8A (30)
        END IF
        DO 1010 ISEG = 1, NOSEG
          SUMM (ISYS, ISEG) = - CD (ISYS, ISEG)
 1010   CONTINUE
 1000 CONTINUE
C
C*********************************************************************
C      Compute Advective Derivative and Adjust Segment Volumes
C                  Loop Through Systems
C*********************************************************************
C
C  FIRST DO SURFACE WATER FLOW FIELD
C
      IF (IQOPT .LE. 2) THEN
        IF (IQOPT .EQ. 1) CALL QSURF1
        IF (IQOPT .EQ. 2) CALL QSURF2
      ELSE
        CALL QHYDRO
      END IF
      IF (NINQ (2) .GT. 0) CALL QPORE
c... Changed to include QSED2 for Krish's Sed Trans Algorithms
C  Time Optimization
C... MD CALL TOPT HERE 1ST TIME THROUGH
C...    JAN 29,96
      IF (INTYP .EQ. 1 .AND. TIME. EQ. TZERO) CALL TOPT
      IF (NFIELD .GE. 3 .and. sedopt .eq. 1) THEN
        CALL NEWCONC
```

```
      CALL QSED2
     ELSEIF (NFIELD .GE. 3) THEN
      CALL QSED
     END IF
c     IF (NFIELD .GE. 3) CALL QSED
c
     IF (NINQ (6) .GT. 0) CALL QEVAP
C
C**********************************************************************
C       TRANSPORT DUE TO EXCHANGE
C**********************************************************************
C
C  LOOP THROUGH SYSTEMS
C
     DO 1020 ISYS = 1, NOSYS
       IF (RBY (ISYS) .NE. 0) GO TO 1020
C
C  LOOP THROUGH FIELDS
C
       DO 1030 NF = 1, NRFLD
C
C   LOOP THROUGH TIME FUNCTIONS
C
         IF (NTEX (NF) .EQ. 0) GO TO 1030
         DO 1040 NT = 1, NTEX (NF)
C
C    SEGMENT LOOP
C
           DO 1050 K = 1, NORS (NF, NT)
             I = IR (NF, NT, K)
             J = JR (NF, NT, K)
             AVPOR = 0.0
             BNUM = 0.0
c
C.. JY MAY 30/94 CALCULATE LONGITUDINAL NUMERICAL DISPERSION FOR EACH CELL
c  (FIELD 3)
C.. AND THEN SUBTRACT IT FROM LONG. DISPERSION COEFF. GIVEN IN THE INPUT DECK.
C.. NUMERICAL COFF IS DENOTED AS ENUMER (NF, NT, K)
C
             IF (NF .EQ. 3) THEN
              FACMM = 1. - 2.0*ADFAC
              VAVGG = (VELOCG (I) + VELOCG (J))/2.0
              AVGLNGTH = (LENGTH (I) + LENGTH (J))/2.0
              ENUMER (NF, NT, K) = VAVGG/2.0*(FACMM*AVGLNGTH -
    1                        VAVGG*DT*86400.)
              BBBB = BRINT (NF, NT) - ENUMER (NF, NT, K)
              IF (BBBB .LT. 0.0) BBBB = 0.0
              BLKR = BR (NF, NT, K)*BBBB
             ELSE
              BLKR = BR (NF, NT, K)*BRINT (NF, NT)
             END IF
C
C             BLKR = BR (NF, NT, K)*BRINT (NF, NT)
             CALL WA12A (I, J, NOBC (ISYS), CONC1, CONC2,
    1         ADVECT, IERR)
             IF (IERR .GT. 0) GO TO 1060
             IF (I .GT. 0) THEN
C...  JY MAY 26/94 DON'T SCALE CONC1 IF NF = 3 (LONGITUDINAL DISPERSION)
C                CONC1 = CONC1*F (NF, ISYS, I)
               IF (NF .LT. 3) CONC1 = CONC1*F (NF, ISYS, I)
               IF (NF .EQ. 2) THEN
                 CONC1 = CONC1/FRW (I)
                 AVPOR = FRW (I)
                 BNUM = 1.0
               END IF
             END IF
             IF (J .GT. 0) THEN
```

```
C... JY MAY 26/94 DON'T SCALE CONC2 IF NF = 3 (LONGITUDINAL DISPERSION)
C                 CONC2 = CONC2*F (NF, ISYS, J)
                IF (NF .LT. 3) CONC2 = CONC2*F (NF, ISYS, J)
                IF (NF .EQ. 2) THEN
                  CONC2 = CONC2/FRW (J)
                  AVPOR = AVPOR + FRW (J)
                  BNUM = BNUM + 1.0
                END IF
              END IF
C
C    CORRECT BLKR FOR POROSITY IF PORE WATER EXCHANGE
C
              IF (BNUM .GT. 0.0) THEN
                AVPOR = AVPOR/BNUM
                BLKR = BLKR*AVPOR*AVPOR
              END IF
C
C     TRANSPORT SYSTEM ISYS:
C
              RTERM = BLKR*(CONC2 - CONC1)
              IF (I .GT. 0) THEN
                CD (ISYS, I) = CD (ISYS, I) + RTERM
                IF (RTERM .LT. 0.) SUMM (ISYS, I) =
   1                         SUMM (ISYS, I) - RTERM
              ELSE
                IF (ISYS .EQ. JMASS)
   1               ROFLUX = ROFLUX + RTERM/1000.
              END IF
              IF (J .GT. 0) THEN
                CD (ISYS, J) = CD (ISYS, J) - RTERM
                IF (RTERM .GT. 0.) SUMM (ISYS, J) =
   1                         SUMM (ISYS, J) + RTERM
              ELSE
                IF (ISYS .EQ. JMASS)
   1               RIFLUX = RIFLUX + RTERM/1000.
              END IF
C
 1050         CONTINUE
 1040       CONTINUE
 1030     CONTINUE
 1020 CONTINUE
C
C      ADD IN FORCING FUNCTIONS
C
      DO 1070 ISYS = 1, NOSYS
        IF (SYSBY (ISYS) .EQ. 0 .AND. NOWK (ISYS) .GT. 0) THEN
          NWK = NOWK (ISYS)
          IF (TIME .GE. NTW (ISYS)) CALL WAS8A (50)
          DO 1080 J = 1, NWK
            DWKTIM = TIME - NWKT (ISYS, J)
            I = IWK (ISYS, J)
            IF (I .LE. 0) GO TO 1090
            LOAD = (MWK (ISYS, J)*DWKTIM + BWK (ISYS, J))*1000.
            CD (ISYS, I) = CD (ISYS, I) + LOAD
            IF (ISYS .EQ. JMASS) XLFLUX =
   1           XLFLUX + LOAD/1000.
 1080     CONTINUE
        END IF
 1070 CONTINUE
C
C        ADD IN NPS LOADS
C
      IF (LOPT .EQ. 0) GO TO 1100
      IF (NEWDAY .GE. 1) READ (AUX, END = 1100) ((NPSWK (I,
     1  J), I = 1, NOSYS), J = 1, NWKS)
      DO 1110 J = 1, NOWKS
        I = INPS (J)
```

```
      DO 1120 ISYS = 1, NOSYS
        LOAD = NPSWK (ISYS, J)*1000.
        CD (ISYS, I) = CD (ISYS, I) + LOAD
        IF (ISYS .EQ. JMASS) XLFLUX = XLFLUX + LOAD/1000.
 1120   CONTINUE
 1110 CONTINUE
 1100 CONTINUE
C
C
C       BED VOLUME COMPUTATIONS
C
      CALL BEDSED
C
C Time Optimization
C... MD DO NOT CALL TOPT HERE 1ST TIME THROUGH
C...    JAN 29,96
C      IF (INTYP .EQ. 1) CALL TOPT
      IF (INTYP .EQ. 1 .AND. TIME. NE. TZERO) CALL TOPT

C**** MONTE CARLO WASP STUFF -ADDING LOOP TO TURN SCREEN CALLS ON OR OFF
C**** -MD-  NOV 4/92
      IF (IIFLAG.EQ.0) THEN
        call color ('yellow','black')
        if (mflag .lt. 2)call outrxy(18,7,dt,'(f8.4)')
        if (mflag .lt. 2)call outixy(48,7,limseg,4)
      END IF
C
C  Accumulate Fluxes for current time step
C
      AIMASS = AIMASS + AIFLUX*DT
      AOMASS = AOMASS + AOFLUX*DT
      RIMASS = RIMASS + RIFLUX*DT
      ROMASS = ROMASS + ROFLUX*DT
      XLMASS = XLMASS + XLFLUX*DT
      XKMASS = XKMASS + XKFLUX*DT
C      XBMASS = XBMASS + XBFLUX * DT
      RETURN
C
 1090 CONTINUE
      IERR = 3
C
 1060 CONTINUE
      CALL WERR (IERR, I, J)
      CALL WEXIT
      END
```

```
 SUBROUTINE WASP3
C=====================================================================
C  Last Revised:  Date: Thursday, 1 February 1990.  Time: 16:26:12.
C
C
C  Correction History:
C
C
C----------------------------------------------------
C       SUBROUTINE TO READ VOLUMES  (GROUP C)
C
      INCLUDE 'WASP.CMN'
C***  MONTE CARLO ROUTINE COMMON BLOCK -MD- JULY 12/92
      INCLUDE 'RISK.CMN'
C*** -BZ-  flow/velocity variable flow distribution common block
      INCLUDE 'TRSMIX.CMN'
C
C
      INTEGER SEGJUN, SEACHN
      character*80 dummy
      COMMON /SWFLW/ SCALQ, SCALV, NJ, NC, JUNSEG (SG), SEGJUN (SG),
     1   NSEA, JSEA (5), SIGN (5), SEACHN (5), NBC, NUPS
C
C**********************************************************************
C              READ VOLUME OPTION AND NO. VOLUMES
C**********************************************************************
C
      IF (MFLAG .EQ. 0) CALL GETMES (8, 0)
C
      READ (IN, 5000, ERR = 1000) IVOPT, IBEDV, TDINTS
 5000 FORMAT(2I5,F10.0)
      WRITE (OUT, 6000)
 6000 FORMAT(////33X,'VOLUMES'/,33X,7('~'),/)
c
c
c**** -BZ- Jan 26,1993 added new volume control options.
c        IVOPT=4  volumes are adjusted by flowrate using the
c        auxillary input file TRSMIX
c**** -BZ- Mar 5,1993
      IXOPT  = 0
      IF(IVOPT.EQ.4) THEN
       IVOPT = 1
       ITRSMIX = 1
      ENDIF
c
c*** -BZ- Sep 29, 1993 If IVOPt =5 then read extra file containing
c    configuration information, currently hardwired to be
c    wasp.cfg
      ILEOMAD = 0
      ILEOMADF = 0
      IF(IVOPT.EQ.5) THEN
C BWZ JUNE 6, 1995 changed to WINout instead of print
C       WRITE(*,*)
C    &  'Reading dispersion file for Leopold-Maddox configuration'
C       CALL WINOUT('Reading dispersion file for Leopold-Maddox',1,0)
        call WINSIN( 'Reading dispersion file for Leopold-Maddox' )
        IVOPT = 1
        ILEOMAD = 1
c... Set ILEOMADF to 1 indicatinq Q2UPDATE has not been called yet
c   -MD- Dec 8/93
        ILEOMADF = 1
        OPEN (UNIT = iCFG, STATUS = 'OLD', ACCESS = 'SEQUENTIAL',
     1    FILE = 'WASP.CFG',iostat=istat)
        READ(iCFG, 5101) NCFGR
 5101   FORMAT(100I5)
c...    ADDED IBRNCHH make sure downstream segment is on the same stream
C       -MD- 12/10/93
```

```
      DO iNCFGR=1,NCFGR
        READ(iCFG, 5101) iXFLOW(iNCFGR), IBRNCHH(iNCFGR),
   &         (CFGNO(i,iNCFGR),i=1,iXFLOW(iNCFGR))
      END DO
      CLOSE(iCFG)
     ENDIF
c
C..User Supplied Input Dataset
C  Transverse Mixing Flow Statistics
C  The filename MIXFIL is prespecified in WASP1 subroutine
C  If the tranverse mixing model was NOT actually read or unavailable
C  then READFLOW() resets the iTRSMIX flag =0 automatically
     IF(iTRSMIX.NE.0) THEN
C       CALL WINOUT('Reading Trsmix input file ',1,0)
c
C -BZ- June 10, 1995
C  Replaced with WINSIN() sub below
C       CALL ATTRIB ('b')
C       call color ('white','blue')
C       CALL WNOPEN(0,21,70,3)
C       CALL WNOUST('Reading Trsmix input file ')
C       CALL WNCLOS(0)
      call WINSIN('Reading Trsmix input file ')
c
      CALL READFLOW(MIXFIL)
c
      WRITE (OUT, 6004) MIXFIL
 6004  FORMAT(18X,'Version: Variable Xsection/Flow, input file :',
   &      A12,//)
     ENDIF
c
c
c
C
C*******************************************************************
C  READ IN BED VOLUME OPTIONS:  IBEDV = 0, BED SEDIMENT CONCENTRATION
C                          = 1, CONSTANT CONCENTRATION,
C                            VARIABLE VOLUMES.
C                     TDINTS = TIME STEP FOR BED CALCULATIONS
C*******************************************************************
C
     WRITE (OUT, 6010) IBEDV, TDINTS
 6010 FORMAT(10X,'Bed Volume Option = ',I5,2X,
   &  'Bed Time Step = ',E10.3/)
C
C*******************************************************************
C   READ IN TYPES OF SEGMENTS (ITYPE): 1 = SFC WATER, 2 = LOWER WATER
C                            3 = UPPER BED, 4 = LOWER BED
C*******************************************************************
C
     IF (ICFL .GE. 2) THEN
       REWIND ICRD
     END IF
C
     IF (ICRD .EQ. IN) THEN
       READ (IN, 5010, ERR = 1000) SCALV, CONVV
C
C**** MONTE-CARLO STUFF --- CHANGE VOLUME SCALE FACTOR -MD- JULY 16/92
C        IRISK = 1
       IF (ISCALV.GT.0 .AND. IRISK.EQ.1) THEN
         JJCOUNT = EFIELD+1
         SCALV = SCALV * RISKV(JJCOUNT)
       END IF
C
c.... Changed format to F??.0 so it will always read properly -MD- Feb 15/94
c 5010    FORMAT(2E10.3)
 5010    FORMAT(2E10.0)
```

```
      ELSE
        SCALV = 1.0
        CONVV = 1.0
        do 10 k = 1, noseg + 1
          READ (IN, 5011, ERR = 1000) DUMMY
 5011     FORMAT(A80)
  10   continue
      END IF
      IF (CONVV .EQ. 0.) CONVV = 1.0
      WRITE (OUT, 6020) SCALV, CONVV
 6020 FORMAT(10X,'Scale Factor =',E12.4,1X,
    1         'Conversion Factor =',E12.4,//)
      SCALV = SCALV*CONVV
C
C*****************************************************************
C       OPTION 1 - CONSTANT VOLUMES
C*****************************************************************
C
C
C 5020 FORMAT(3I10,E10.3,4F10.5)
C 5020 FORMAT(3I10,5F10.0,I10,2F10.0)
c 5020 FORMAT(3I10,6F10.0,I10,2F10.0)
 5020 FORMAT(3I10,10F10.0)
c
      DO I = 1, NOSEG
c -MD- Changing Leopold-Maddox to allow for open water and ice covered
c      coefficients to be specified - January 5, 1996
        READ (ICRD, 5020, ERR = 1000) ISEG, NSEG,
    1     ITY, V, A1, B1, C1, D1, RLEN, A2, B2, C2, D2
c        READ (ICRD, 5020, ERR = 1000) ISEG, NSEG,
c   1      ITY, V, A1, B1, C1, D1, RLEN
        IBOTSG (ISEG) = NSEG
        ITYPE (ISEG) = ITY
        BVOL (ISEG) = V
        LENGTH (ISEG) = RLEN
        VMULT (ISEG) = A1
        VEXP (ISEG) = B1
        DMULT (ISEG) = C1
        DXP (ISEG) = D1
        TOPSEG (ISEG) = 0
c -MD- Added
        VMULT2 (ISEG) = A2
        VEXP2 (ISEG) = B2
        DMULT2 (ISEG) = C2
        DXP2 (ISEG) = D2
      ENDDO
c
c
      DO 1020 ISEG = 1, NOSEG
        NSEG = IBOTSG (ISEG)
        IF (NSEG .GT. 0) TOPSEG (NSEG) = ISEG
 1020 CONTINUE
      WRITE (OUT, 6030)
 6030 FORMAT(2X,'Seg #',3X,'BOTSG',3X,'Type',7X,'Volume',6X,'V mult',
    1     4X,'V exp',3X,'D mult',4X,'D exp')
      WRITE (OUT, 6040)
 6040 FORMAT(1X,73('~'),/)
      DO 1030 ISEG = 1, NOSEG
        WRITE (OUT, 6050) ISEG, IBOTSG (ISEG),
    1     ITYPE (ISEG), BVOL (ISEG),
    2     VMULT (ISEG), VEXP (ISEG), DMULT (ISEG), DXP (ISEG),
    3     LENGTH (ISEG)
 6050 FORMAT(1X,I5,3X,I5,2X,I5,1X,F15.3,4(3X,F6.3),3x,F15.3)
 1030 CONTINUE
      CALL SCALP (BVOL, SCALV, NOSEG)
      DO 1040 I = 1, NOSEG
        MVOL (I) = BVOL (I)
```

```
      B0VOL (I) = BVOL (I)
 1040 CONTINUE
      WRITE (OUT, 6060)
 6060 FORMAT('1')
c
      IF (IVOPT .EQ. 1) RETURN
C
C*************************************************************************
C        OPTIONS 2,3 :  VOLUMES ADJUSTED BY FLOW CONTINUITY
C*************************************************************************
C
      RETURN
C
 1000 CONTINUE
      CALL WEXIT('Error Reading Card Group C',1)
      END
c
```

```
C
C  Q2UPDATE()
C
C  This subroutine updates the river statistics based on a change
C  in flowrate.
C  Using the LEOPOLD-MADDOX equations, the river depth,
C  volumne, velocity are recalculated.
C  Q2UPDATE() then resets the WASP4 model parameters.
C
C
C
C WRITTEN
C  BRIAN ZELT Sep. 29, 1993
C
C REVISIONS
C  BWZ Feb 13, 1995
C   ..Update the lower cells volumes if it is initializing
C     or if it is a TYPE 1 or TYPE 2 cell. Otherwise leave
C     as initialized and only adjust the transfer areas
C
C
C
C
C
      SUBROUTINE Q2UPDATE()

      INCLUDE 'WASP.CMN'
c -MD- Changed to allow open water and ice cover coefficients Jan 5/95
c      environ.cmn added to allow TEMPN(1) to be used as ice cover flag
      include 'environ.cmn'

      INTEGER NF, I, J

C..quit if there ain't nothing t'do
      IF(NFIELD.EQ.0) RETURN

C..calculate the new cell volumns, depths, widths, etc..
C  from the new flow for ALL flow fields of
C  Type 1 (water column field)

C..Reset the water  column flow statisitcs.
C  The configuration information provides a list of the TYPE 1
C  flow fields in river reach sub-groups as outlined here:
C     NCFGr
C     iXFLOW(1), cfgno(1, 1), .., cfgno(IXFLOW(1), 1)
C     iXFLOW(2), cfgno(1, 2), .., cfgno(IXFLOW(1), 2)
C     ...
C     iXFLOW(NCFGr), cfgno(1, NCFGr), .., cfgno(IXFLOW(1), NCFGr)
C
      DO INR=1,NCFGR
       QTOTAL = 0.0
       DO IXF = 1,iXFLOW(INR)
         QTOTAL = QTOTAL + QSEG(cfgno(IXF,INR))
       END DO

       DO IXF = 1,iXFLOW(INR)
         ICELL = cfgno(IXF, INR)

C.. Calculate total section geometery
c -MD- Changed to allow open water and ice cover coefficients Jan 5/96
      if (TEMPN(1) .le. 0.0) Then
         DEP   = DMULT(iCELL)* QTOTAL**DXP(iCELL)
         VEL   = VMULT(iCELL)* QTOTAL**VEXP(iCELL)
         WID   = 1./(VMULT(iCELL)*DMULT(iCELL))*
     &           QTOTAL**(1.0-DXP(iCELL)-VEXP(iCELL))
      else
         DEP   = DMULT2(iCELL)* QTOTAL**DXP2(iCELL)
```

```
        VEL   = VMULT2(iCELL)* QTOTAL**VEXP2(iCELL)
        WID   = 1./(VMULT2(iCELL)*DMULT2(iCELL))*
     &          QTOTAL**(1.0-DXP2(iCELL)-VEXP2(iCELL))
      end if
c         DEP   = DMULT(iCELL)* QTOTAL**DXP(iCELL)
c         VEL   = VMULT(iCELL)* QTOTAL**VEXP(iCELL)
c         WID   = 1./(VMULT(iCELL)*DMULT(iCELL))*
c    &            QTOTAL**(1.0-DXP(iCELL)-VEXP(iCELL))
C.. Calculate the Cell geometry by adjusting for the fraction of the
C  flow this cell uses.
        IF(ITYPE(ICELL).EQ.1) THEN
          ODEPTHG(ICELL) = DEPTHG(ICELL)
          DEPTHG(ICELL) = DEP
          VELOCG(ICELL) = VEL
          WIDTH(ICELL)  = WID*QSEG(ICELL)/QTOTAL
c... -MD- Dec 8/93 - MVOLOLD ADDED to track volume prior to adjustment
c...              Used in MUPDATE
          MVOLOLD(ICELL) = MVOL(ICELL)
          MVOL(ICELL)   = LENGTH(ICELL) *DEP* WIDTH(ICELL)
C*** FIRST TIME THROUGH SET BVOL = MVOL  DEC 3/93 -MD-
          IF (ILEOMADF .EQ. 1) THEN
            BVOL(ICELL) = MVOL(ICELL)
            MVOLOLD(ICELL) = MVOL(ICELL)
          END IF

C..Reset cell topographical areas for all layers below the
C  water column.  Types should be type.ne.1 (assumed)

          ICELLB = IBOTSG(ICELL)
          WHILE(ICELLB.NE.0) DO
            WIDTH(ICELLB)= WIDTH(ICELL)
C  BWZ Feb 13, 1995
C..Update the lower cells volumes if it is initializing
C  or if it is a TYPE 1 or TYPE 2 cell. Otherwise leave
C  as initialized and only adjust the transfer areas
            IF((ITYPE(ICELLB).EQ.1 .OR. ITYPE(ICELLB).EQ.2) ) THEN
             MVOL(ICELLB) = LENGTH(ICELL)*DEPTHG(ICELLB)*WIDTH(ICELLB)
            ELSE IF (ILEOMADF .EQ. 1)  THEN
             MVOL(ICELLB) = LENGTH(ICELL)*DEPTHG(ICELLB)*WIDTH(ICELLB)
            ENDIF
C*** FIRST TIME THROUGH SET BVOL = MVOL  DEC 3/93 -MD-
            IF (ILEOMADF .EQ. 1) THEN
              BVOL(ICELLB) = MVOL(ICELLB)
            ENDIF
            ICELLB = IBOTSG(ICELLB)
          ENDWHILE

        ELSE
C..ERROR!!!!
          PRINT *,'TYPE IS ',ITYPE(ICELL),' FOR CELL :',ICELL
          CALL WEXIT('This probably shouldn''t happen (Q2UPDATE)',1)
        ENDIF
      ENDDO
    ENDDO

C..Loop through exchange fields and reset areas and lengths
    DO NF = 1,NRFLD
      DO NT = 1,NTEX(NF)
        NOR = NORS(NF,NT)
        IF(NOR.NE.0) THEN
          DO NR = 1,NOR
            I = IR(NF,NT,NR)
            J = JR(NF,NT,NR)

C..swap so that lower cell # is i
              IF(I.GT.J) THEN
                K = I
```

```
            I = J
            J = K
           ENDIF

C..-J. Yang- May 12/94: set longitudinal dispersion to be exchange field 3 (NRFLD=3)
C   for which L-M equations adjust only exchange areas, but not lengths
          IF(NF.EQ.3) THEN
           AI = WIDTH(I)*DEPTHG(I)
           AJ = WIDTH(J)*DEPTHG(J)
           EL = (LENGTH(I)+LENGTH(J))/2
           BR(NF,NT,NR) = 86400.*(AI+AJ)/2/EL
          ELSE

C..Type 1-1 exchanges  Water Column
C  Assumed lateral exchange
C  Determine BR from average area and average length between cell centres
           IF(ITYPE(I).EQ.1 .AND. ITYPE(J).EQ.1) THEN
            if(J .NE. IBOTSG(I)) THEN
             AI = LENGTH(I)*DEPTHG(I)
             AJ = LENGTH(J)*DEPTHG(J)
             EL = WIDTH(I)+ WIDTH(J)
             BR(NF,NT,NR) = 86400.*(AI+AJ)/EL
            ENDIF
C..Type 1-2 exchanges (assumed water column to sediment)
           ELSE IF(ITYPE(I).EQ.1 .AND. ITYPE(J).EQ.2) THEN
            AI = LENGTH(I)*WIDTH(I)
            EL = 0.5*(DEPTHG(I) + DEPTHG(J))
            BR(NF,NT,NR) = 86400 *AI/EL

C..Type 2-3 exchanges (assumed water column to sediment)
           ELSE IF(ITYPE(I).EQ.2 .AND. ITYPE(J).EQ.3) THEN
            AI = LENGTH(I)*WIDTH(I)
            EL = DEPTHG(J)
            BR(NF,NT,NR) = 86400.*AI/EL

C..Type 1-3 exchanges (assumed water column to sediment)
           ELSE IF(ITYPE(I).EQ.1 .AND. ITYPE(J).EQ.3) THEN
            AI = LENGTH(I)*WIDTH(I)
            EL = DEPTHG(J)
            BR(NF,NT,NR) = 86400.*AI/EL

C..Type 3-4 exchanges (assumed water column to sediment)
           ELSE IF(ITYPE(I).EQ.3 .AND. ITYPE(J).EQ.4) THEN
            AI = LENGTH(I)*WIDTH(I)
            EL = 0.5*(DEPTHG(I) + DEPTHG(J))
            BR(NF,NT,NR) = 86400 *AI/EL

C..Type X exchanges (unknown adjustment)
           ELSE
            CALL WEXIT('Don''t know what to do (QUPDATE)',1)
           ENDIF
          ENDIF
         ENDDO
        ENDIF
       ENDDO
      ENDDO

C***************************************************************************
C  Update Flow field Three Field areas in BQ() array
C***************************************************************************
      IF (NFIELD.GE.3) THEN
       DO NI=1,NINQ(3)
        DO NQ=1,NOQS(3,NI)
         ICELL     = JQ (3, NI, NQ)
C.. Or could use cell
C      ICELL = JQ (NF, NI, NQ)
C   Which should be the same, since it is underlying it
```

```
c Add changes for fields 4 and 5 as well. -MD- November 11, 1995
          BQ(3,NI,NQ) = LENGTH(ICELL)*WIDTH(ICELL)*86400.
          BQ(4,NI,NQ) = LENGTH(ICELL)*WIDTH(ICELL)*86400.
          BQ(5,NI,NQ) = LENGTH(ICELL)*WIDTH(ICELL)*86400.
        END DO
      END DO
    END IF

C***********************************************************************
C  WASP4 initializations
C***********************************************************************

C*** -BZ- jUNE 4,1993 Update the dispersion coeffients
C..
C
C
    CALL K2UPDATE()

C***********************************************************************
c... Adjust mass for increasing or decreasing segment volume -MD- 12/07/93
C***********************************************************************

    CALL MUPDATE()


    RETURN
    END
C----------------------------------------------------------
C .adjust the dispersion coefficient for change in depth according
C  to ARC report Dec.92 (ref.Fischer,H.B. et.al.1979, Mixing in inland
C  and coastal waters.)
C
C
C----------------------------------------------------------
    subroutine K2UPDATE()
    include 'wasp.cmn'

C..If the reference depths have not been initialized, then determine them.
    IF( iQREF.EQ.0) THEN
      DO iNF=1,NRFLD
        DO iNT=1,NTEX(iNF)
          QREFTOT = QREF (iNF, iNT)
C.. Calculate total section geometery
          NOR = NORS(iNF,iNT)
          IF(NOR.NE.0) THEN
            DO iNR = 1,NOR
              I = IR(iNF,iNT,iNR)
              J = JR(iNF,iNT,iNR)
              refDEPTH(I) = DMULT(I)* QREFTOT**DXP(I)
              refDEPTH(J) = DMULT(J)* QREFTOT**DXP(J)
            END DO
          ENDIF
        END DO
      END DO
      iQREF = 1
    ENDIF

C..adjust the dispersion coefficient for change in depth according
C  to ARC report Dec.92 (ref.Fischer,H.B. et.al.1979, Mixing in inland
C  and coastal waters.)
    DO iNF=1,NRFLD
      DO iNT=1,NTEX(iNF)
        NOR = NORS(iNF,iNT)
        IF(NOR.NE.0) THEN
          DO iNR = 1,NOR
            I = IR(iNF,iNT,iNR)
            J = JR(iNF,iNT,iNR)
```

```
C..swap so that lower cell # is i
          IF(I.GT.J) THEN
           K = I
           I = J
           J = K
          ENDIF

C..Type 1-1 exchanges  Water Column
         IF(ITYPE(I).EQ.1 .AND. ITYPE(J).EQ.1) THEN

C..adjust the dispersion coefficient for change in depth according
C  to ARC report Dec.92 (ref.Fischer,H.B. et.al.1979, Mixing in inland
C  and coastal waters.)
          DAVEIJ    = DEPTHG(I)+DEPTHG(J)
          refDAVEIJ = refDEPTH(I)+refDEPTH(J)
          FACT      = (DAVEIJ/refDAVEIJ)** 1.5
          BR(iNF,iNT,iNR) = BR(iNF,iNT,iNR)* FACT

C..Type 1-2 exchanges (assumed water column to sediment)
         ELSE IF(ITYPE(I).EQ.1 .AND. ITYPE(J).EQ.2) THEN
C..Type 1-3 exchanges (assumed water column to sediment)
         ELSE IF(ITYPE(I).EQ.1 .AND. ITYPE(J).EQ.3) THEN
C..Type X exchanges (unknown adjustment)
         ELSE
          CALL WEXIT('Don"t know what to do (KUPDATE)',1)
         ENDIF
        ENDDO
       ENDIF
      ENDDO
     ENDDO

     RETURN
     END

C-----------------------------------------------------------
c    Subroutine to adjust chemical mass to account for volume changes
c    resulting increasing or decreasing flows with Leopold-Maddox
c    routines.
c    If flow and hence volume increases mass is increased proportionately
c    to flow weighted concentrations in upstream segments.
c    If flow and volume decreases, mass is decreased to keep concentration
c    unchanged and mass and concentrations in downstream segment(s) are adjusted
c    to reflected the transfer of water and associated mass downstream.
C..  FINAL RESULT IS A CALCULATED TOTAL FLOW WEIGHT CONCENTRATION OF TOTAL
C    INFLOW TO EACH CELL.
c    Code is adapted from QCALC where segment flows are calculated.
C-----------------------------------------------------------

     SUBROUTINE MUPDATE()

     INCLUDE 'WASP.CMN'
     INTEGER NF, I, J, II
     REAL CONCC,MDER,MASS

c.. Reset arrays .....

c... Not WORKING *** SCARY *** MD Jan 23, 1995
c      CALL SETRA (QinSEG, SG, 1, 0.0)
c      CALL SETRA (QoutSEG, SG, 1, 0.0)
c      CALL SETRA (FWc, SY, SG, 0.0)
c      CALL SETRA (MASSinSG, SY, SG, 0.0)
     DO 1000 JJ = 1, NOSEG + 1
       QinSEG(JJ) = 0.0
       QoutSEG(JJ) = 0.0
       J = JJ - 1
       QSUM (0, J) = 0.0
       DO 1010 II = 1, NOSEG + 1
```

```
        I = II - 1
        QSUM (I, J) = 0.0
 1010   CONTINUE
       DO isys=1,nosys
        FWC(isys,JJ) = 0.0
        MASSINSG(isys,JJ) = 0.0
       END DO
 1000 CONTINUE

C... INCLUDE ONLY FIELD (NF) 1 FLOWS
     NF = 1
     NINQX = NINQ (NF)
     IF (NINQX .GT. 0) THEN
C
C      LOOP THROUGH INFLOWS
C
       DO 1020 NI = 1, NINQX
         NOQ = NOQS (NF, NI)
C
C        SEGMENT LOOP
C
c.. determine upstream (J) and downstream (I) segments and store
         DO 1030 NQ = 1, NOQ
           Q = BQ (NF, NI, NQ)*QINT (NF, NI)
           IF (Q .GE. 0.) THEN
             I = IQ (NF, NI, NQ)
             J = JQ (NF, NI, NQ)

           ELSE
             J = IQ (NF, NI, NQ)
             I = JQ (NF, NI, NQ)
             Q = - Q
           END IF

c... CALCULATE FLOW WEIGHTED MASS LOADINGS to each cell (MASSinSG(I))
           IF (I .GT. 0) THEN
            DO ISYS=1,NOSYS
             IF (J .GT. 0) CONCC = C(ISYS,J)
c...          if upstream segment = 0 then use boundary condition
             IF (J .EQ. 0) THEN
              NBC = NOBC(ISYS)
              DO JJ = 1, NBC
               IF (I .EQ. IBC (ISYS, JJ))
   +              CONCC = BBC (ISYS, JJ) +
   +              MBC (ISYS, JJ)*(TIME - NBCT (ISYS, JJ))
              END DO
             END IF
             MASSinSG(ISYS,I) = MASSinSG(ISYS,I)
   +                     + Q*CONCC
            END DO
           END IF

C
C      Sum Segment Flows
C
           IF (J .GT. 0) QOUTSEG (J) = QOUTSEG (J) + Q
           IF (I .GT. 0) QINSEG (I) = QINSEG (I) + Q
           QSUM (I, J) = QSUM (I, J) + Q
 1030     CONTINUE
 1020   CONTINUE

     END IF

c... Calculate Flow weight Concentrations of total inflow to each cell

     DO II = 1,NOSYS
      DO I = 1, NOSEG
```

```
      IF (QINSEG(I) .GT. 0.) FWc(II,I) = MASSinSG(II,I)/QINSEG(I)
     END DO
    END DO


c... Adjust mass derivatives for increasing or decreasing volumes
    DO INR=1,NCFGR
     DO IXF = 1,iXFLOW(INR)
      ICELL = cfgno(IXF, INR)
      ICELLD = cfgno(IXF, INR+1)
c... make sure downstream segment is on the same stream -MD- 12/10/93
      IF (IBRNCHH(INR+1) .NE. IBRNCHH(INR)) ICELLD = 0
      IF (INR .EQ. NCFGR) ICELLD = 0
      IF (ITYPE(ICELL) .EQ. 1) THEN
       DO ISYS = 1,NOSYS

c... adjust mder to reflect flow weighted inflow conc. for increase in volume
        IF (MVOL(ICELL) .GT. MVOLOLD(ICELL)) THEN
         CD2(ISYS,ICELL) = CD2(ISYS,ICELL) + FWc(ISYS,ICELL) *
   +                 (MVOL(ICELL)-MVOLOLD(ICELL))/dt
c... adjust mder to keep conc. unchanged
c... then adjust mder in next cell downstream
        ELSE IF (MVOL(ICELL) .LT. MVOLOLD(ICELL)) THEN
         CD2(ISYS,ICELL) = CD2(ISYS,ICELL) - C(ISYS,ICELL)*
   +                 (MVOLOLD(ICELL)-MVOL(ICELL))/dt
c... Jan 23/95 MD removed. Not sure why this was put in in the first place
c...       I suspect to attempt to route flow downstream, however, we
c...       would have to adjust volume of downstream cell, which would
c...       not work with considering the flow wave (i.e. unsteady flows)
c          IF (ICELLD .GT. 0) CD2(ISYS,ICELLD) = CD2(ISYS,ICELLD) +
c   +          (FWc(ISYS,ICELLD) -
c   +          C(ISYS,ICELLD))* (MVOLOLD(ICELL)-MVOL(ICELL))/dt
        END IF
C...     SET BVOL(ICELL) = MVOL(ICELL) SO THAT CONC. EFFECT OF LEOPOLD-
C        MADDOX VOLUME CHANGE IS NOT ACCOUNTED FOR AGAIN IN EULER
        BVOL(ICELL) = MVOL(ICELL)
       END DO
      END IF
     END DO
    END DO
    DO ISYS = 1,NOSYS
     DO ISEG = 1,NOSEG
      IF (ITYPE(ISEG) .EQ. 1) THEN
       MASS = C (ISYS, ISEG) * MVOLOLD(ISEG)
       MDER = CD2(ISYS,ISEG)
       C (ISYS, ISEG) = (MASS + DT*MDER)/MVOL(ISEG)
       CD2(ISYS,ISEG) = 0
       IF (NEGSLN .EQ. 1) GOTO 1051

C       Protect Against Underflows or Negative Solutions
C=================================================================================
       IF (C (ISYS, ISEG) .LT. 1.0E-25) C (ISYS,ISEG) = 0.0

 1051    CONTINUE
      END IF
     END DO
    END DO

    RETURN
    END
```

```
C=====================================================================
C        *-*-*-*- TOXI4 INCLUDE COMMON BLOCK -*-*-*-*
C=====================================================================
C   Last Revised: Date: Monday, 25 February 1991.  Time: 09:15:35.
C*** -BZ- June 4,1993 added REFDEPTH(SG) for calculating the dispersion coefficient
C           in the TRSMIX subroutines
C---------------------------------------------
C
C                  WASP Dimensionable Variables
C                  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~
C    ASSIGN    SY = Number of State Variables (Typically 6)
C              SG = Number of Segments
C              CX = Number of Kinetical Constants
C              PR = Number of Segment Parameters
c              BC = Number of Boundary Segments
c              WK = Number of Loads
c              TF = Number of Env. Time Functions
c              MB = Maximum number of Time Breaks EACH for all Functions
c             MNF = Number of Flow Fields (Typically 6)
c             MNI = Number of Time Functions per Inflow field
C
c
c                   Input/Output Units
c                   ~~~~~~~~~~~~~~~~~~
c              IN = The User Provided Input Dataset
c             OUT = WASP generated Echoing of User Input File
c           HYDRO = Hydrodynamic Interface file
c             AUX = Non Point Source File for Loads
c            MESS = Runtime Message File
c          RESTRT = Model Restart File
c           ITRNS = Water Transport Analysis Table
c           IMASS = Mass Balance Analysis Table
c            IDMP = Simulation Result Dump File
c            HDBG = Hydrodynamic Debug Table (Set IQOPT = 10)
c             CTL = Runtime Control File
c
C *** -MD- FEB 11/92 added xarea(iseg) as segment area (a constant for each seg)
C *** -MD- FEB 16/92 added VDSLOPE(iseg) AND VDCONST (ISEG) and IDOPT (ISEG)
C**** -MD- MAR 24/92 ADDED T2W FILE UNIT NO. FOR CEQUALW2 TEMP FILE
C***  -MD- MAR 24/92 ADDED NQSEG, NDEPTHG, ODEPTHG AND NVELOCG, W2TEMP AS PART OF CEQUALW2
LINKAGE
C***  -MD- MAR 24/92 ADDED ITER AND ITMAVG CEQUALW2 LINKAGE
C *** -BZ- SEP 24/93 removed VDSLOPE(iseg) AND VDCONST (ISEG) and IDOPT (ISEG)
c           Added LENGTH(SG) and WIDTH(SG) for segment lengths for use with
c           Leopold-Maddox
c           recalculation of Areas, volumes, etc... based on flow
c           Removed the XAREA arrays
c           Added QREF(MNF,MNI) array for reference flow for dispersion
c           coefficients
C---------------------------------------------
C
      INTEGER SY, SG, S2, CX, PR, BC, WK, TF, MP, MB, MB1,
     &        MNF, MNI, M30, M50, M70, M73, M75, SY1, OUT, IN,
     &        HYDRO, AUX, FRQ, MESS, RESTRT, HDBG, CTL
C
C**** -MD- MAR 24/92 ADDED T2W FILE UNIT NO. FOR CEQUALW2 TEMP FILE
      INTEGER ITRNS, IMASS, IDMP, SYSBY, RBY, QBY, TOPSEG, OUT1, T2W
c
C*** -MD- MAR 24/92 MODIFIED TO INCREASE S2 TO > 300
C     PARAMETER (SY=6, SG=86, S2=3*SG/4, CX=1800, PR=18, BC=7, WK=7,
c     PARAMETER (SY=6, SG=86, S2=SG*4, CX=1800, PR=18, BC=7, WK=7,


c
c
c     PARAMETER (SY=6, SG=220, S2=SG*4, CX=1800, PR=18, BC=40, WK=40,
c    +  TF=17, MP=365, MB=400, MD=1, SY1=SY+1, MB1=MB+1, MNF=6,MNI=65,
c    +  M30=2*BC*SY, M50=2*WK*SY, M70=S2+1, M73=2*TF, M75=2*MB,
```

```
C*** -BZ- March 18/93 increase SG to 300 to accomodate larger model
C*** -BZ- APR 15/93 REDUCED:  SG to 250 FM 350
C*** -BZ- APR 15/93 REDUCED:  MB to 100 FM 400
C*** -BZ- APR 19/93 INCREASES:  BC to 100 FM 40
C*** -BZ- OCt 08/93 INCREASES:  MB to 250 FM 100
C*** -BZ- Oct 10/93 INCREASES:  MB to 1250 FM 250
C*** -BZ- Oct 27/93 CHANGES:  MB to 100 fm 1250
C                     SG to 1000 fm 100
C                     MNI to 10 fm 65

      PARAMETER (SY=6,SG=920, S2=SG*4, CX=1800, PR=21, BC=50, WK=15,
     &  TF=21, MP=365, MB=7000, MD=1, SY1=SY+1, MB1=MB+1, MNF=6,MNI=20,
     &  M30=2*BC*SY, M50=2*WK*SY, M70=S2+1, M73=2*TF, M75=2*MB,


C
C*** -BZ- Feb 1/93 decreased SG to 100 to accomodate inadequate computer
C   power.
C
c     PARAMETER (SY=6, SG=100, S2=SG*4, CX=1800, PR=18, BC=40, WK=40,
c    +  TF=17, MP=365, MB=400, MD=1, SY1=SY+1, MB1=MB+1, MNF=6,MNI=65,
c    +  M30=2*BC*SY, M50=2*WK*SY, M70=S2+1, M73=2*TF, M75=2*MB,

c     PARAMETER (SY=6, SG=100, S2=3*SG/4, CX=1800, PR=18, BC=15, WK=15,
c    +  TF=17, MP=40, MB=400, MD=1, SY1=SY+1, MB1=MB+1,MNF=6,MNI=10,
c    +  M30=2*BC*SY, M50=2*WK*SY, M70=S2+1, M73=2*TF, M75=2*MB,
C
C   +  Define all I/O units:
C
C *** -MD- T2W UNIT NUMBER MAR 24/92
     &  IN=10, OUT=11, HYDRO=7, AUX=4, MESS=6, RESTRT=9,
C *** -BZ- changed CTL from 1 to 12
     &  ITRNS=16, IMASS=20, IDMP=15, HDBG=8, CTL=18, T2W=36,
C *** -BZ- Sep 29/93 added cfg for reading VOPT=5 configuration
C    files
     &  iCFG=17)
C
C-----------------------------------------------------------
C
C... -MD- DEC 8/93 ADDED MASSinSG, QINSEG, QOUTSEG, FWc, MVOLOLD, CD2
C*** -MD- MAR 24/92 CEQUALW2 LINKAGE (ADDED - NMVOL,NDEPTHG,NQSEG,NVELOCG,OMNOL,ODEPTHG)
c... -MD- Mar 4/94 added timeold (display with reg display off- see WAS13)
c... -MD- Nov 6/95 Added D65, Tcd, SEDICEFC for Krish's Sed Trans Algorithm
      REAL   NVOLT, NBCT, NWKT, NFUNT, NTF, NTB, NTW, MVOL, MBC, MWK,
     &       MFUNC, NPSWK,NMVOL,NDEPTHG,NQSEG,NVELOCG,OMNOL,ODEPTHG,
     &       LENGTH, MASSinSG, QINSEG, QOUTSEG, FWc, MVOLOLD, TIMEOLD,
     &       D65,Tcd, SEDICEFC
c    &       LENGTH
C
      REAL*8 AIMASS, AOMASS, RIMASS, ROMASS, XLMASS, XKMASS, XBMASS,
     &       XMASS0, CD, XBFLUX, XKFLUX, DTMAX,CD2
C
C-----------------------------------------------------------
C
      CHARACTER*40 CHEML(SY)
C... Added SEDOPT for Krish's Sed Transport Algorithm -MD- Nov 6/95
      INTEGER   DMPCT, IPTR, TRNUM, SEDOPT
      LOGICAL WQ,WISP

C-----------------------------------------------------------
C       INTEGERS
C-----------------------------------------------------------
C
C*** ADDED ITER AND ITMAVG -MD- MAR 24/92   CEQUALW2 LINKAGE
C... Added SEDOPT for invoking Krish's Sed Transport Algorithm -MD- Nov 6/95
      COMMON /INTGRS/ NOSYS,TRNUM,NCHEM,NOSEG,ISYS,ISEG,ISIM,INITB,
     &             IPRNT,IDISK,IREC,MXDMP,NBCPSY,NWKPSY,NEGSLN,ICRD,
```

```
     &             IVOPT,NOV,IQOPT,INTYP,NOPAM,NFUNC,ITIMV,ITCHCK,
     &             MXITER,INPERR,NFIELD,MFLAG,NRFLD,IBEDV,KSIM,JMASS,
     &             ICFL,IDSY,IDSG1,IDSG2,MXSYS,MXSEG,LDAY,NDAY,
     &             NEWDAY,NWKS,NOWKS,LOPT,ITRNIT,IFIRST,IPROP,
     &             ITMAVG, ITER, limseg, SEDOPT
C
      COMMON /INTGR1/ SYSBY(SY),RBY(SY),QBY(SY),IBCOP(SY),
     &             NOBC(SY),IWKOP(SY),NOWK(SY),ITIMF(TF),NCONS(SY1),
     &             NINQ(MNF),IBOTSG(SG),NTEX(MNF),TOPSEG(SG),
     &             IFIELD(SY),ITYPE(0:SG),INPS(WK)
C
      COMMON /ISCRT1/ NBRK30(SY,BC),NBRK50(SY,WK),NBRK72(TF),NBRK73(TF),
     &             NBRK75(TF),ISEGOUT(6)

C
      COMMON /INTGR2/ IWK(SY,WK),IBC(SY,BC),NOQS(MNF,MNI),
     &             ITIMB(SY,BC),ITIMW(SY,WK),ITIMQ(MNF,MNI),
     &             NBRKQ(MNF,MNI), NORS(MNF,MNI),NBRKR(MNF,MNI),
     &             ITIMR(MNF,MNI)
C
      COMMON /INTGR3/ IQ(MNF,MNI,S2),JQ(MNF,MNI,S2),IR(MNF,MNI,S2),
     &             JR(MNF,MNI,S2), DMPCT, IPTR, iend, istart

C**** -BZ- MAR/93 ADDITION GROUP A PARAMETERS
      COMMON /INTGR9/ ISSOPT,ILINOFF
C
C------------------------------------------------
C       REALS
C------------------------------------------------
C
c... -MD- Mar 4/94 added timeold (display with reg display off- see WAS13)
C... Added SEDICEFC for Krish's Sed Transport Algorithm -MD- Jan 96
      COMMON /REALS/ TIME,DT,TZERO,SCALT,TEND,PRNT,OMEGA,NVOLT,NTF,
     &            TDINTS,TMARKS,TADJ,DAY,DQTIME,DRTIME,DWKTIM,ADFAC,
     &            TPRINT,CHEML, DTMAX,FTIME, timeold, SEDICEFC
c
C*** -MD- MAR 24/92 ADDED NQSEG, NDEPTHG, ODEPTHG AND NVELOCG, W2TEMP AS PART OF CEQUALW2
LINKAGE
C*** -MD- MAR 24/92 ADDED NMVOL,  OMVOL AS PART OF CEQUALW2 LINKAGE
C*** -MD- DEC 17/92 ADDED TOTDISMD AS PART OF MONTE CARLO OUTPUT MODIFICATIONS
C*** -BZ- June 4,1993 added REFDEPTH(SG) for calculating the dispersion coefficient
C          in the TRSMIX subroutines
C*** -IY- JUNE 1, 1994 ADDED ENUMD(SG) FOR OUTPUT NUMERICAL DISP. DEDUCTED
c -MD- January 5, 1996 Added 2nd set of leopold maddox coefficients
      COMMON /REAL1/ CMAX(SY),CMIN(SY),BVOL(SG),BFUNC(TF),MVOL(SG),
     &            MFUNC(TF),NFUNT(TF),NTB(SY),NTW(SY),DSED(SY),
     &            FRW(SG),B0VOL(SG),DEPTHG(SG),VELOCG(SG),VMULT(SG),
     &            VEXP(SG),DMULT(SG),DXP(SG),QSEG(SG),PRINT(MP),
     &            TPRNT(MP),SUMM (SY,SG),
     &            NVELOCG(SG),NQSEG(SG), ODEPTHG(SG),
     &            W2TEMP(SG), NDEPTHG(SG),
     &            NMVOL(SG),OMVOL(SG),TOTDISMD(3,SG),
     &            REFDEPTH(SG),
     &            LENGTH(SG), WIDTH(SG),ENUMD(SG),
     &            VMULT2(SG), VEXP2(SG), DMULT2(SG), DXP2(SG)
C
C... -MD- DEC 8/93 ADDED MASSinSG, QINSEG, QOUTSEG, FWc
C*** -BZ- MAR 1993 ADDED COLD() FOR OLD TOTAL CHEMICAL VALUES
c... -MD- Nov 6/95 Added D65 and Tcd for Krish's Sed Trans Algorithm
C... -MD- JAN 30/96 ADDED TSOLFRAC(MNF,SY,SG) FOR USE IN QSED2 AND FRCION ROUTINES
      COMMON /REAL2/ C(SY,SG),BBC(SY,BC),BWK(SY,WK),MBC(SY,BC),
     &            MWK(SY,WK),NBCT(SY,BC),NWKT(SY,WK),QINT(MNF,MNI),
     &            TNQ(MNF,MNI),BRINT(MNF,MNI),TNR(MNF,MNI),
     &            NPSWK(SY,WK), COLD(3,SG),
     &            QREF(MNF,MNI), MASSinSG(SY,SG), QINSEG(SG),
     &            QOUTSEG(SG), FWc(SY,SG), MVOLOLD(SG),
     &            D65(mnf,mni),Tcd(mnf,mni), TSOLFRAC(SY,SG)
```

```
C
      COMMON /RSCRT1/FILE30(MB,M30),FILE50(MB,M50),FILE73(MB,M73),
     &           FILE75(M75,1),FILE80(SY,20),QSUM(0:SG+1,0:SG+1)
C
C... -MD- MAR 10/94 ADDED TRTA AND TRTB TO TRACK TIME STEP IN EACH CELL
C... -JY- JUNE 1/94 ADDED ENUMER (NUMERICAL DISP. DEDUCTED FROM LONG
C..   DISP. COEFF)
      COMMON /REAL3/ BQ(MNF,MNI,S2),F(MNF,SY,SG),QT(MNF,MNI,MB),
     &           TQ(MNF,MNI,MB),BR(MNF,MNI,S2),RT(MNF,MNI,MB),
     &           TR(MNF,MNI,MB),TRTA(SG),TRTB(SG),ENUMER(MNF,MNI,S2)
C
      COMMON /EQUV1/ CONST(CX)
C
      COMMON /EQUV2/ PARAM(SG,PR)
C
      COMMON /MASS1/ AIMASS,AOMASS,RIMASS,ROMASS,XLMASS,XKMASS,
     &           XBMASS,XMASS0,AIFLUX,AOFLUX,RIFLUX,ROFLUX,XBFLUX,
     &           XKFLUX
C
C... -MD- DEC 9/93 ADDED CD2 (LEOPOLD-MADDOX STUFF)
      COMMON /MASS2/ CD(SY,SG), CD2(SY,SG)
      common /logdata/ wq
C
C=====================================================================
c.. -BZ- Sep 29/93 addition for use of Leopold Maddox equations
c.. -MD- DEC  9/93 addition ILEOMADF for use of Leopold Maddox equations
c... make sure downstream segment is on the same stream -MD- 12/10/93
      INTEGER NCFGR, iXFLOW, CFGNO, IBRNCHH
      COMMON /LMADX1/ NCFGR, iXFLOW(SG), CFGNO(20,SG), iQREF,ILEOMAD,
     & ILEOMADF, IBRNCHH(SG)
```

APPENDIX B: INITIAL SIMULATION RESULTS

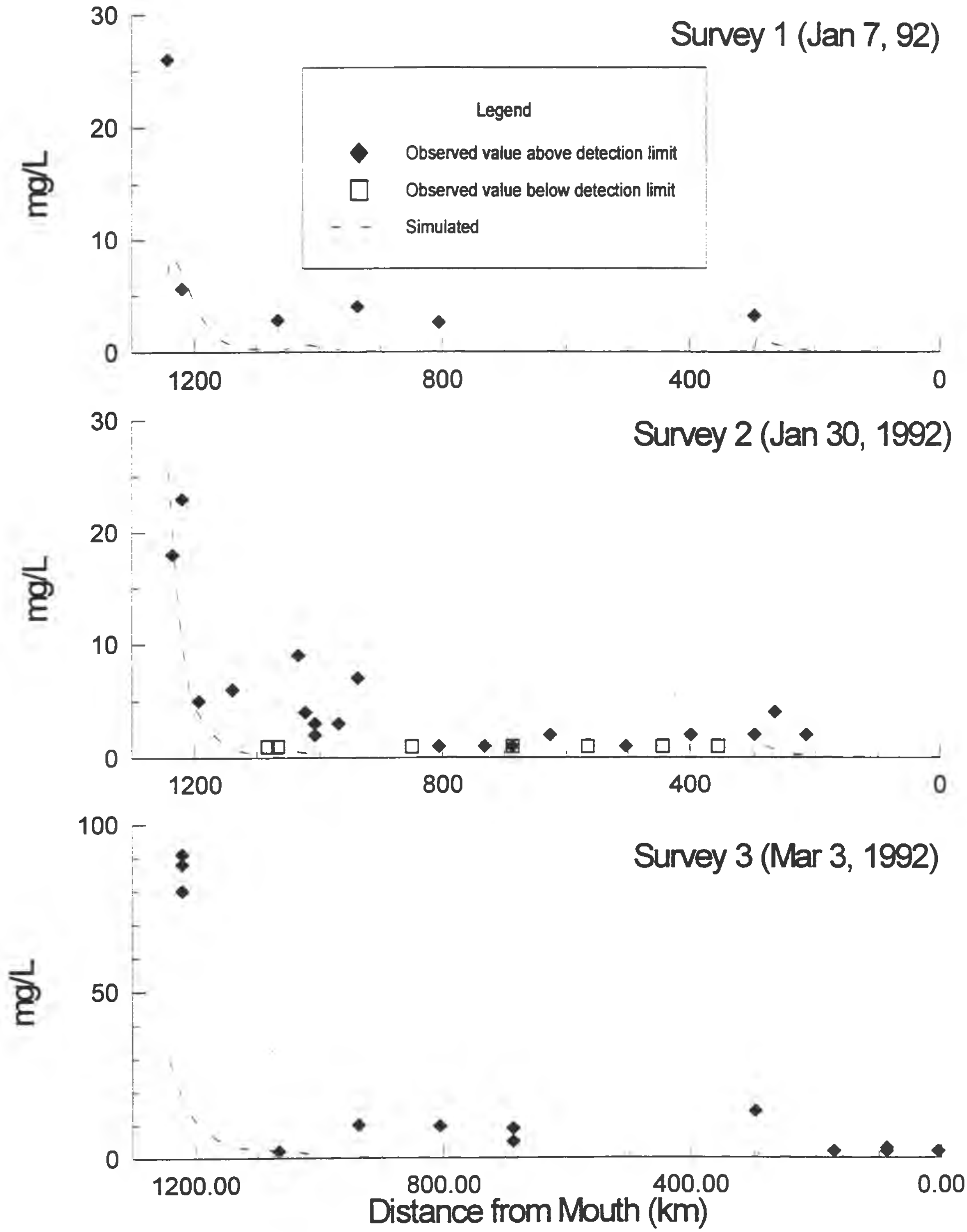


Figure 4.5.
Athabasca River, Total Suspended Solids, Synoptic Surveys

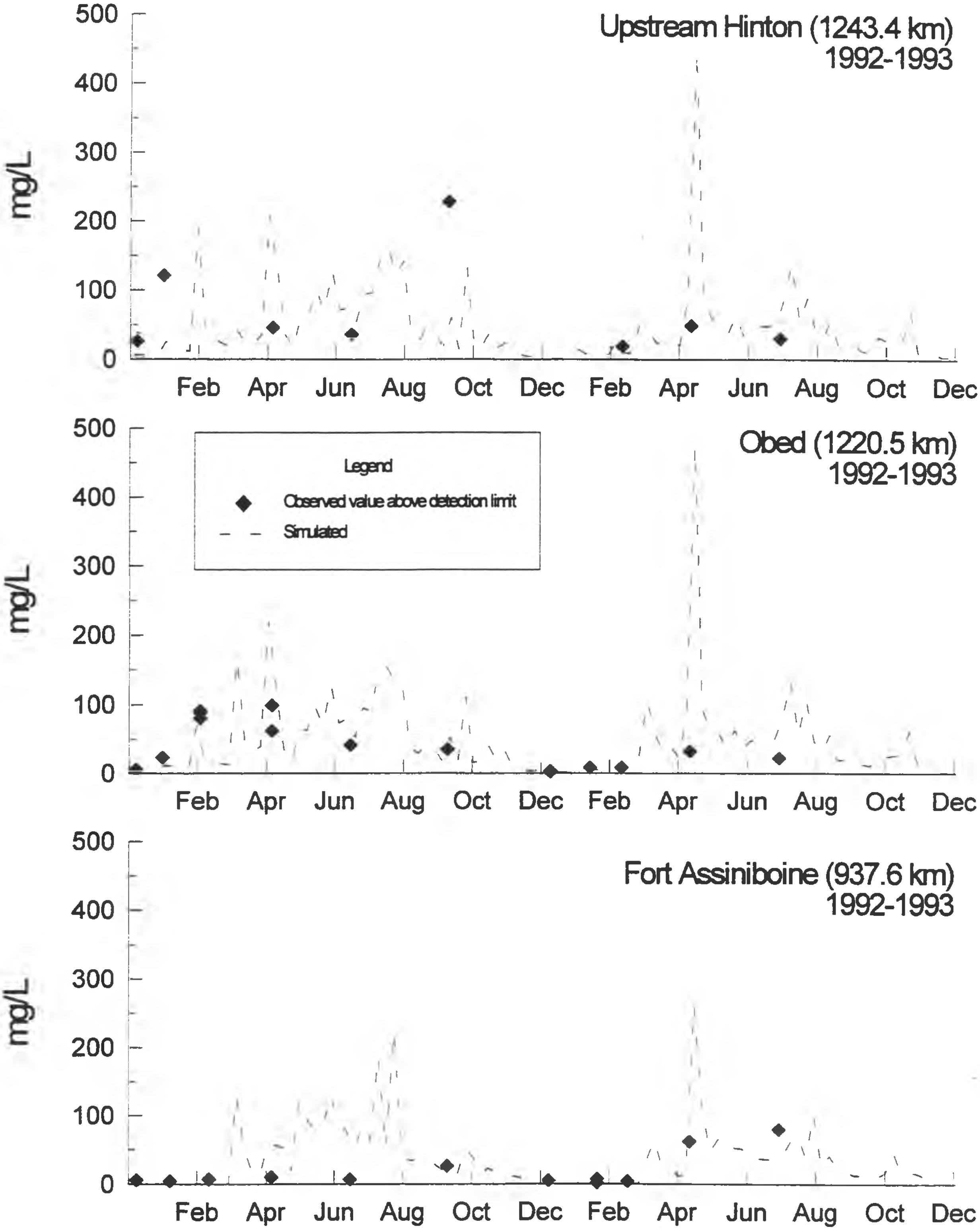


Figure 4.6a.
Athabasca River, Total Suspended Solids, Time Series

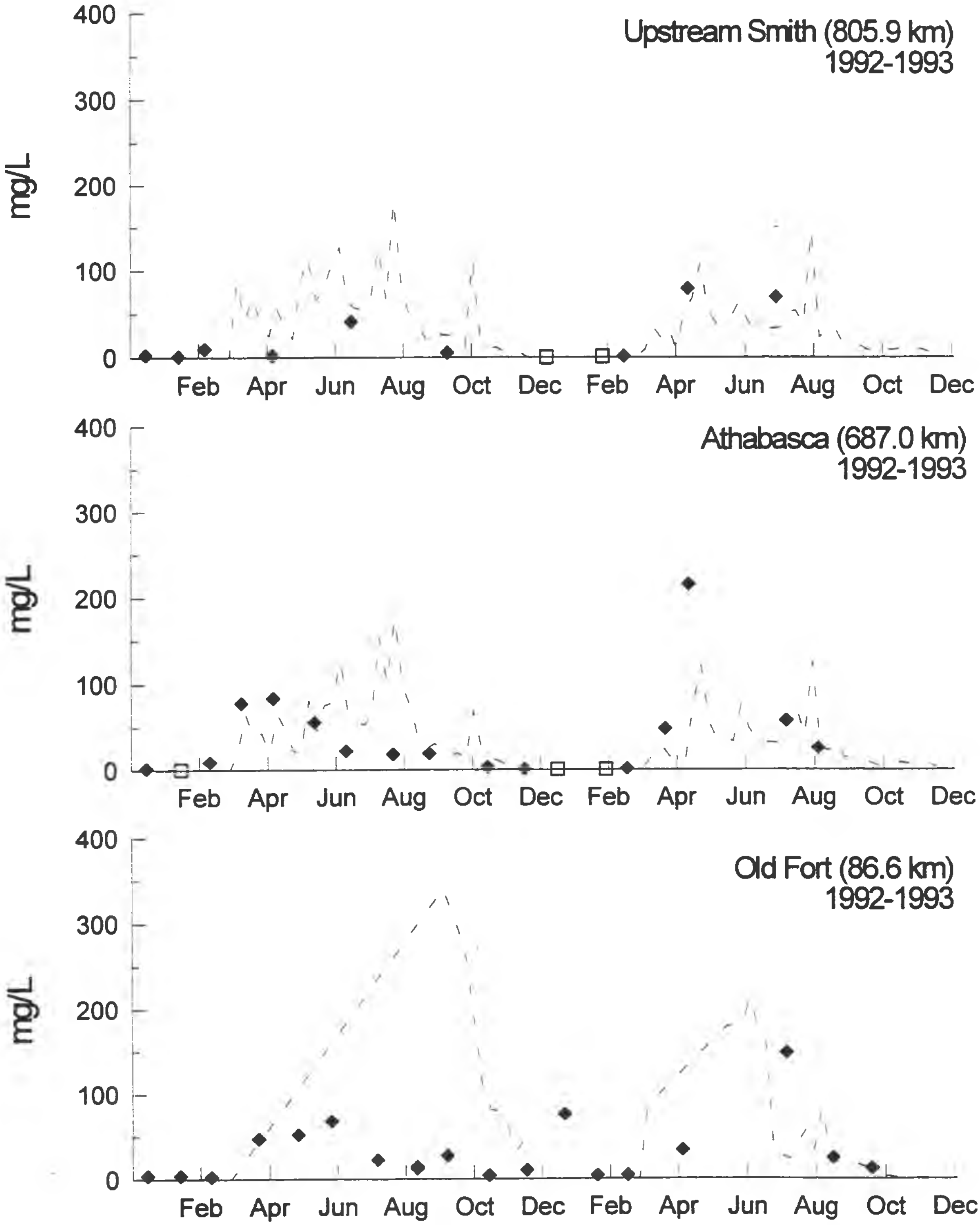


Figure 4.6b.
Athabasca River, Total Suspended Solids, Time Series

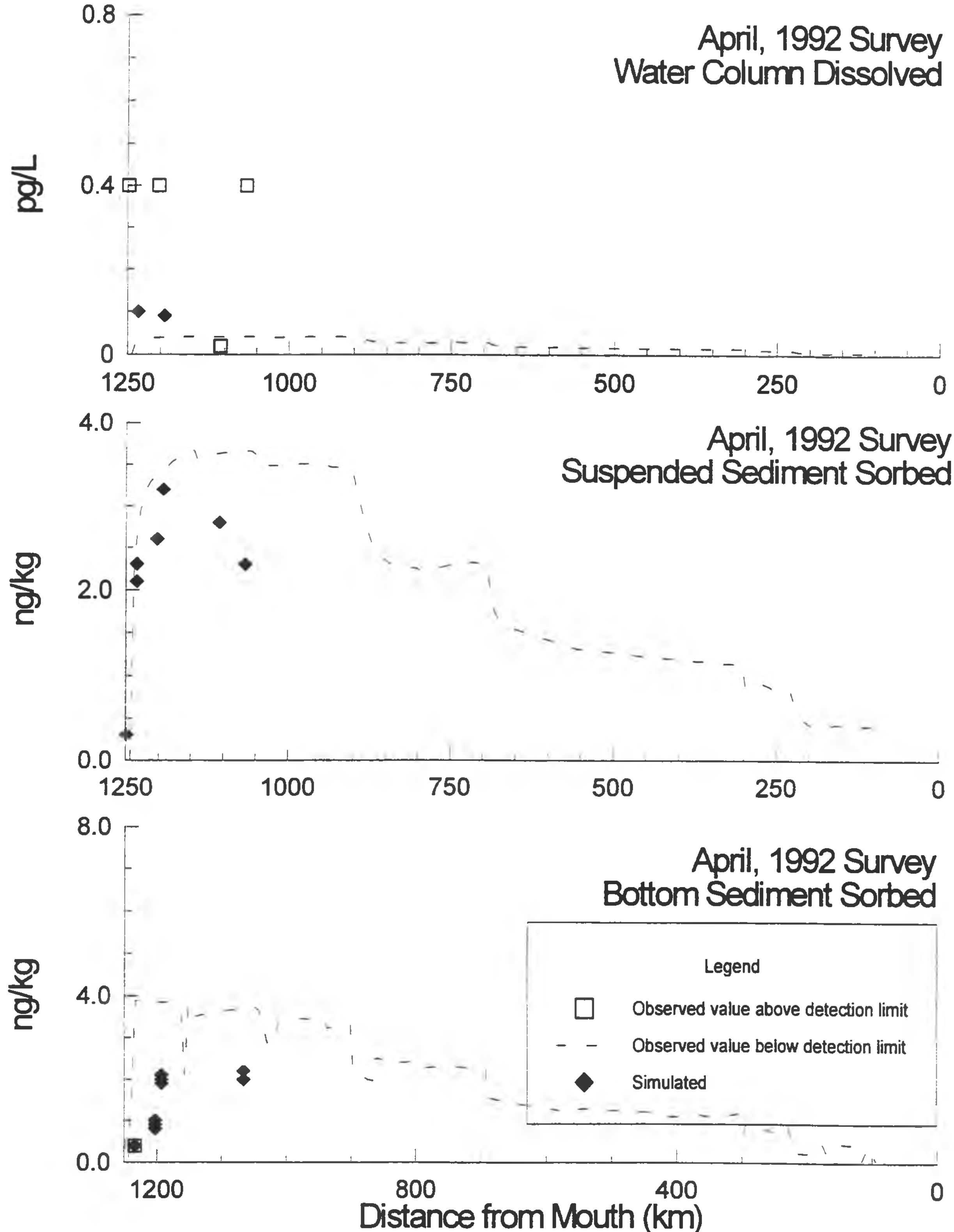


Figure 4.9a.
Athabasca River, 2,3,7,8-TCDF Calibration, Synoptic Surveys

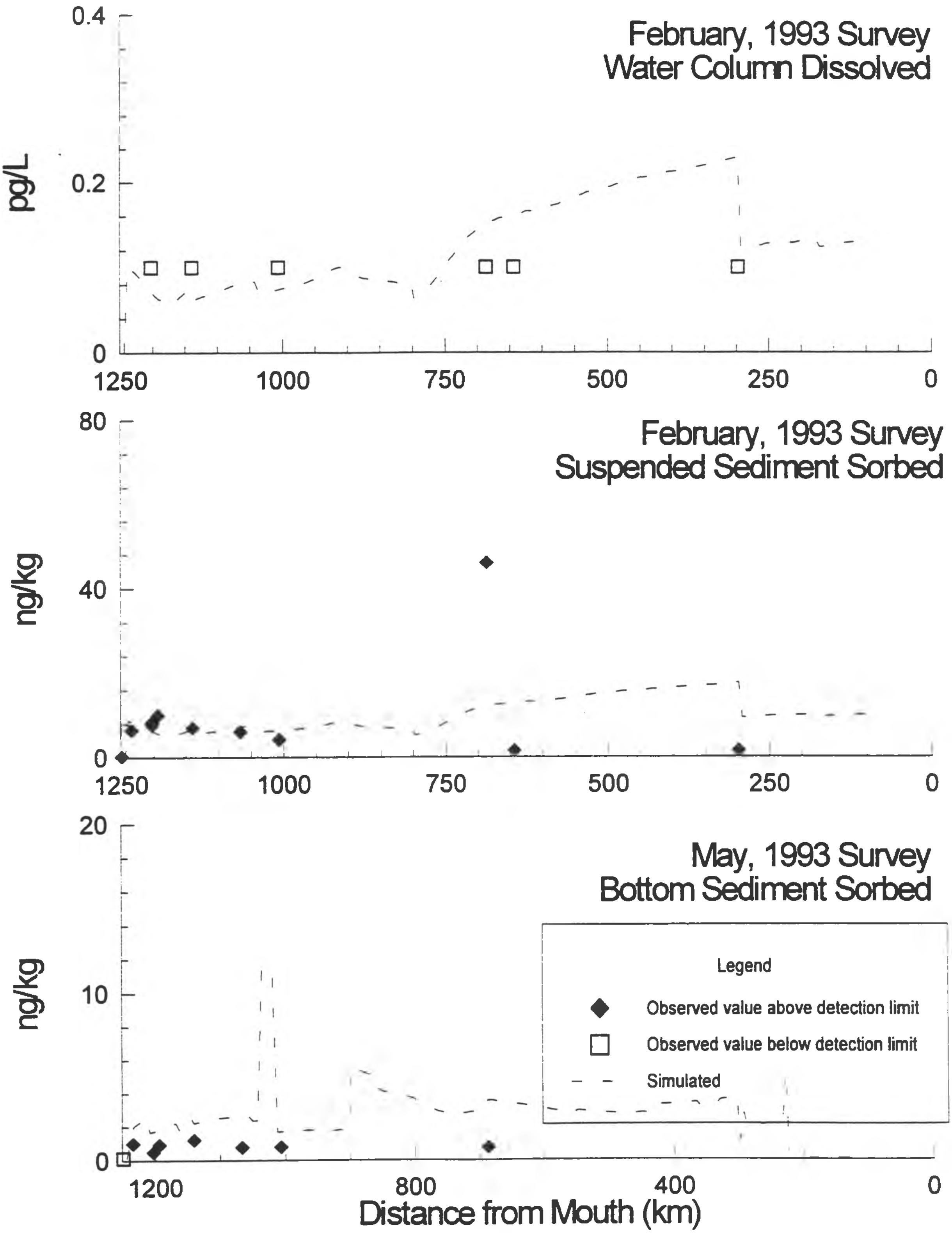


Figure 4.9b.
Athabasca River, 2,3,7,8 TCDF Calibration, Synoptic Surveys

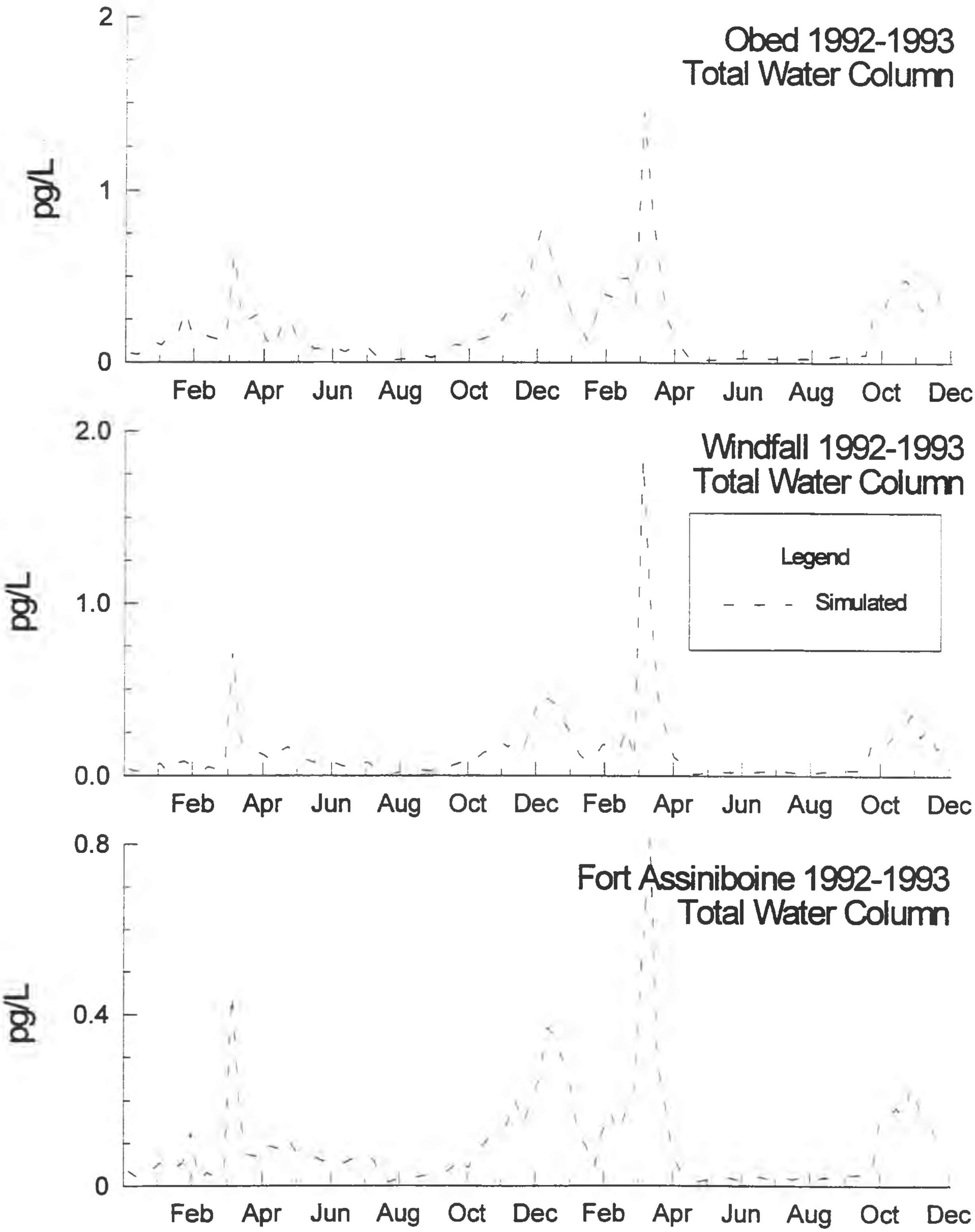


Figure 4.10a.
Athabasca River 2,3,7,8-TCDF Calibration, Time Series

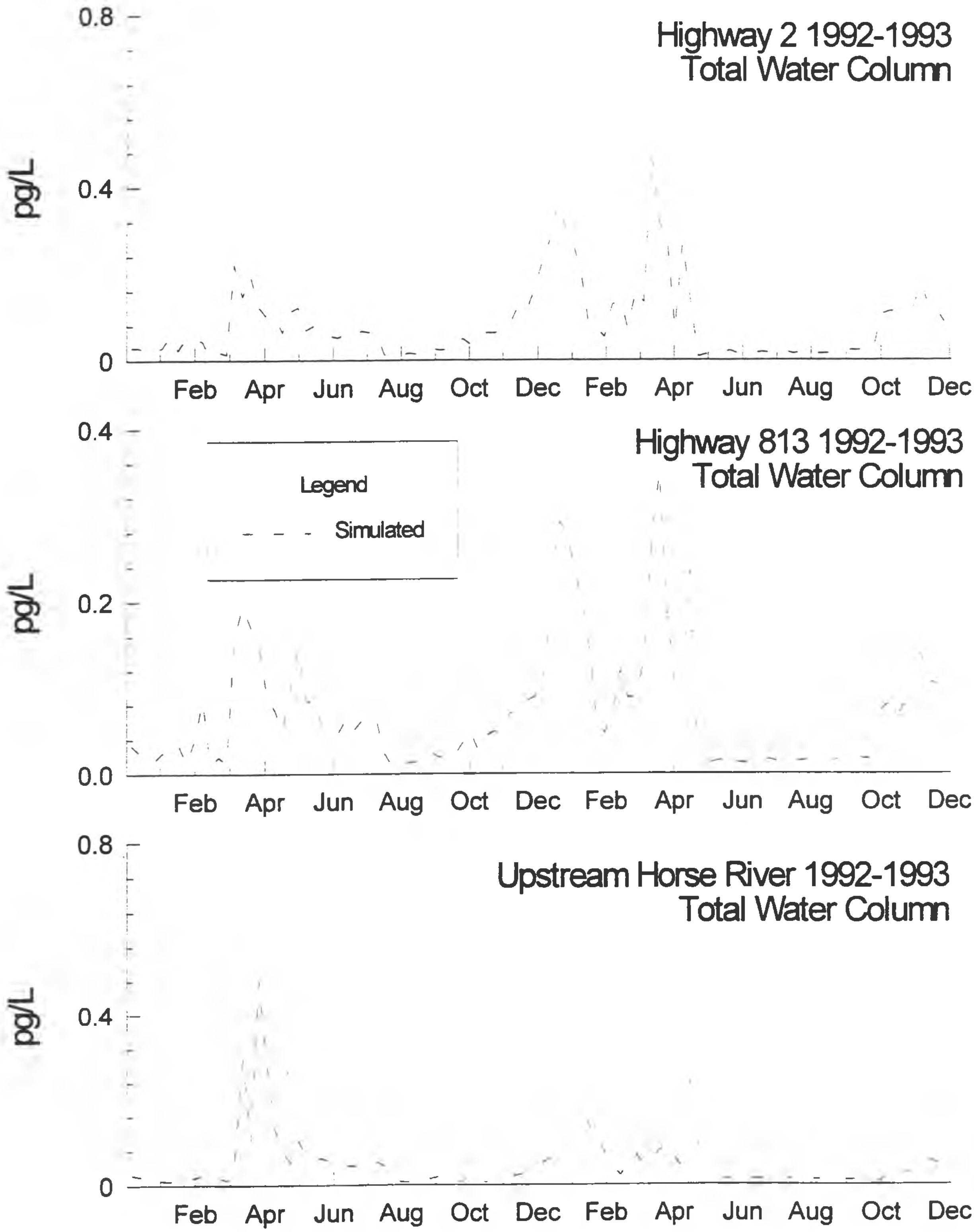


Figure 4.10b.
Athabasca River 2,3,7,8-TCDF Calibration, Time Series

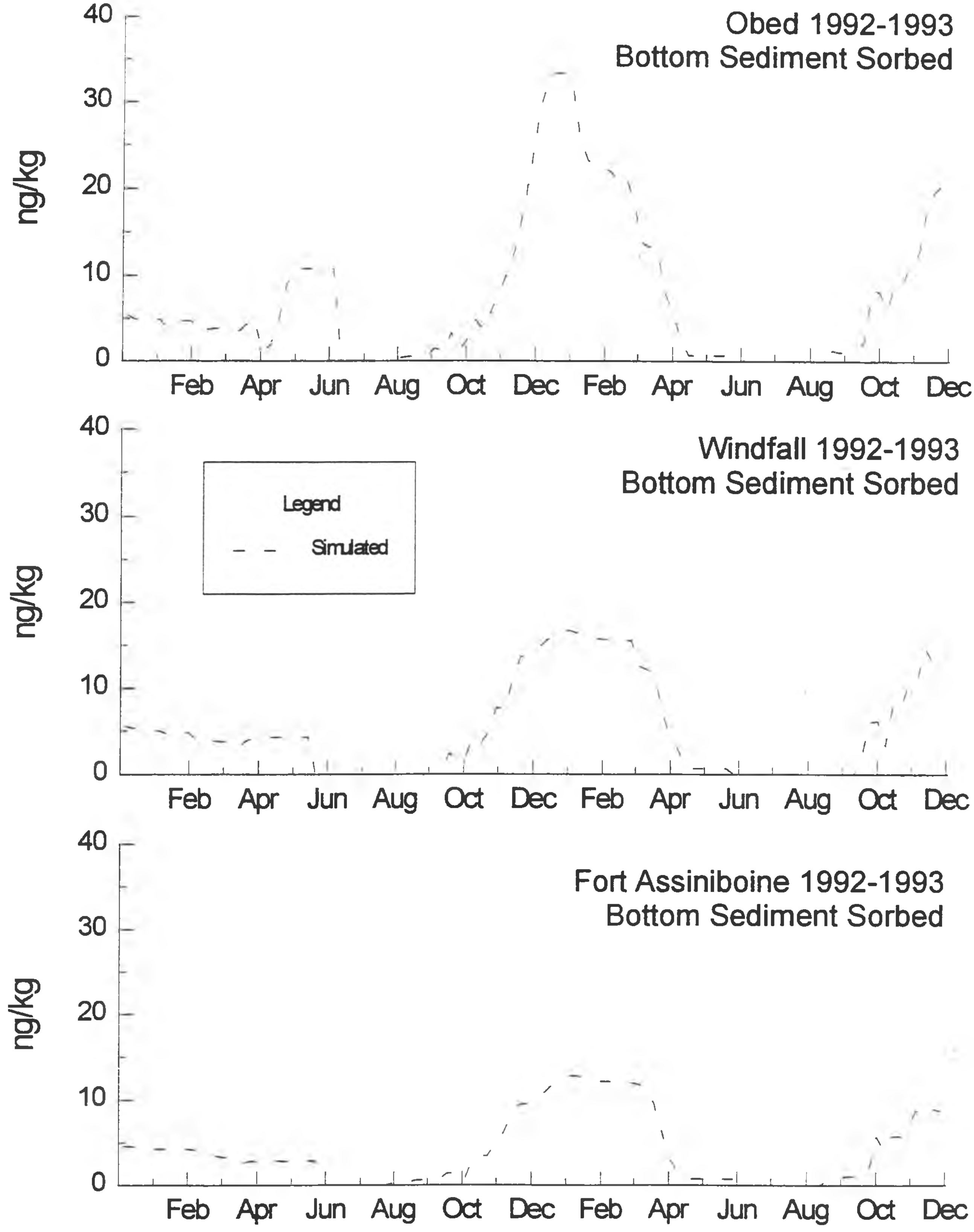


Figure 4.10c.
Athabasca River, 2,3,7,8-TCDF Calibration, Time Series

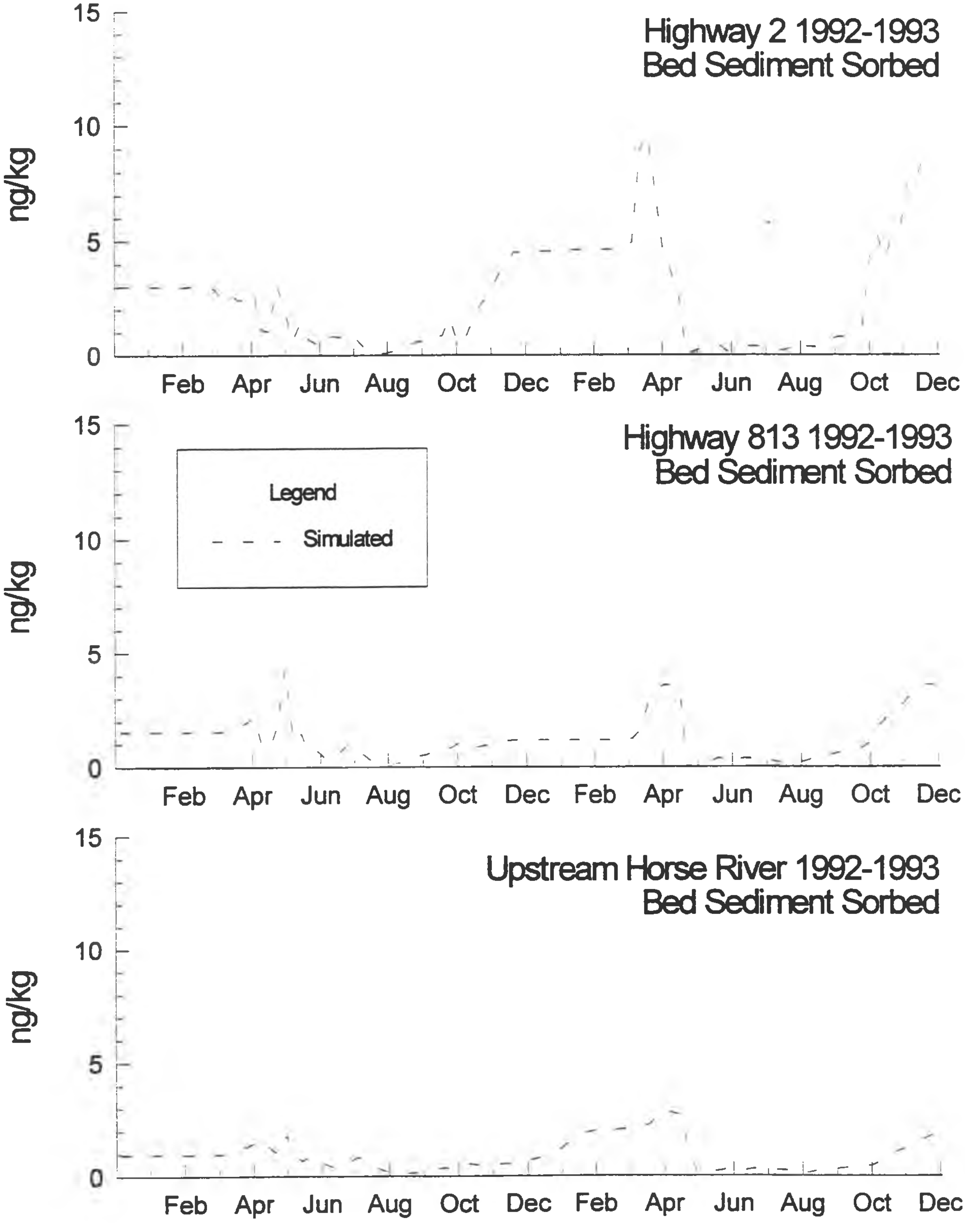


Figure 4.10d.
Athabasca River 2,3,7,8-TCDF Calibration, Time Series

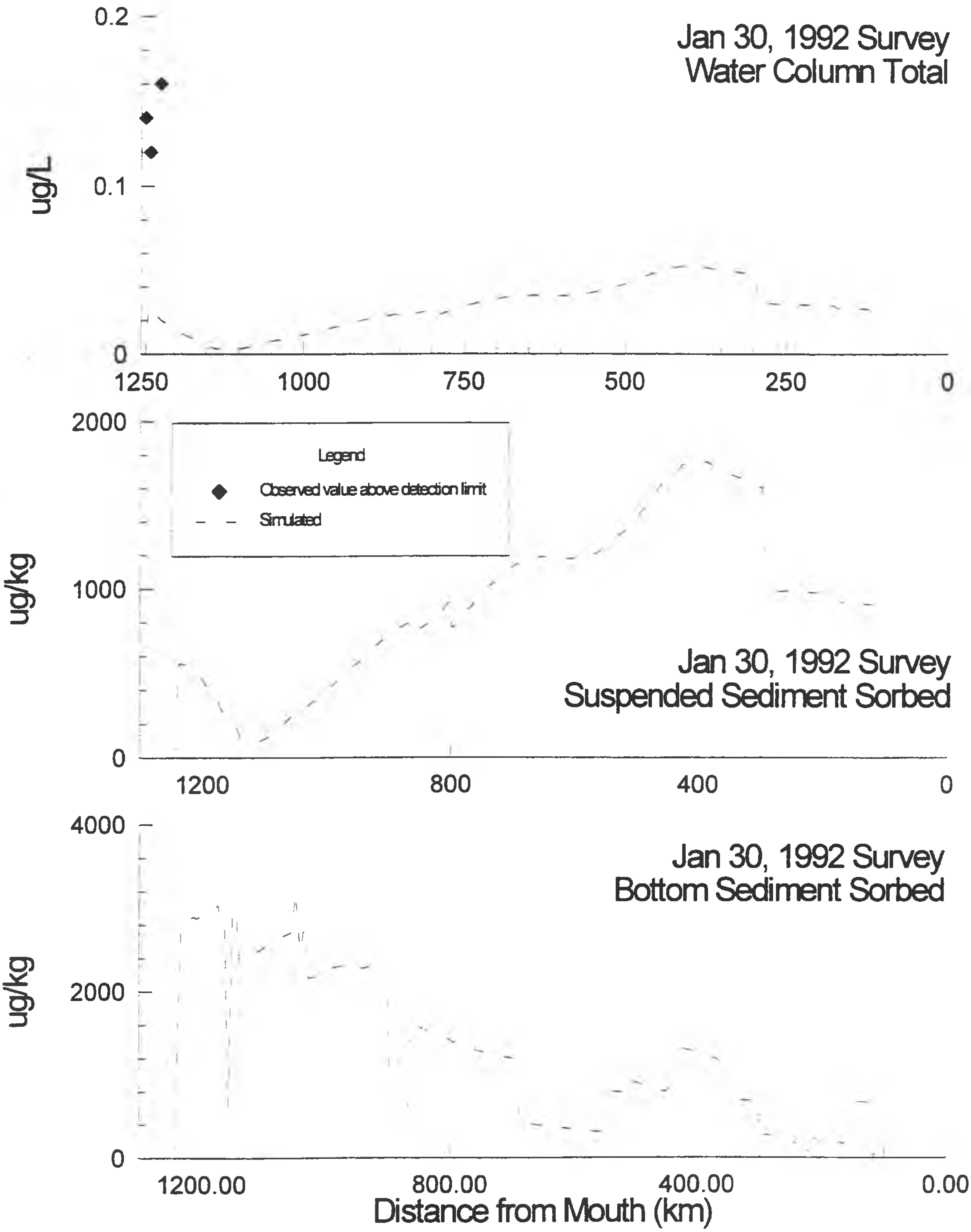


Figure 4.13a.
Athabasca River, DHA Calibration, Synoptic Surveys

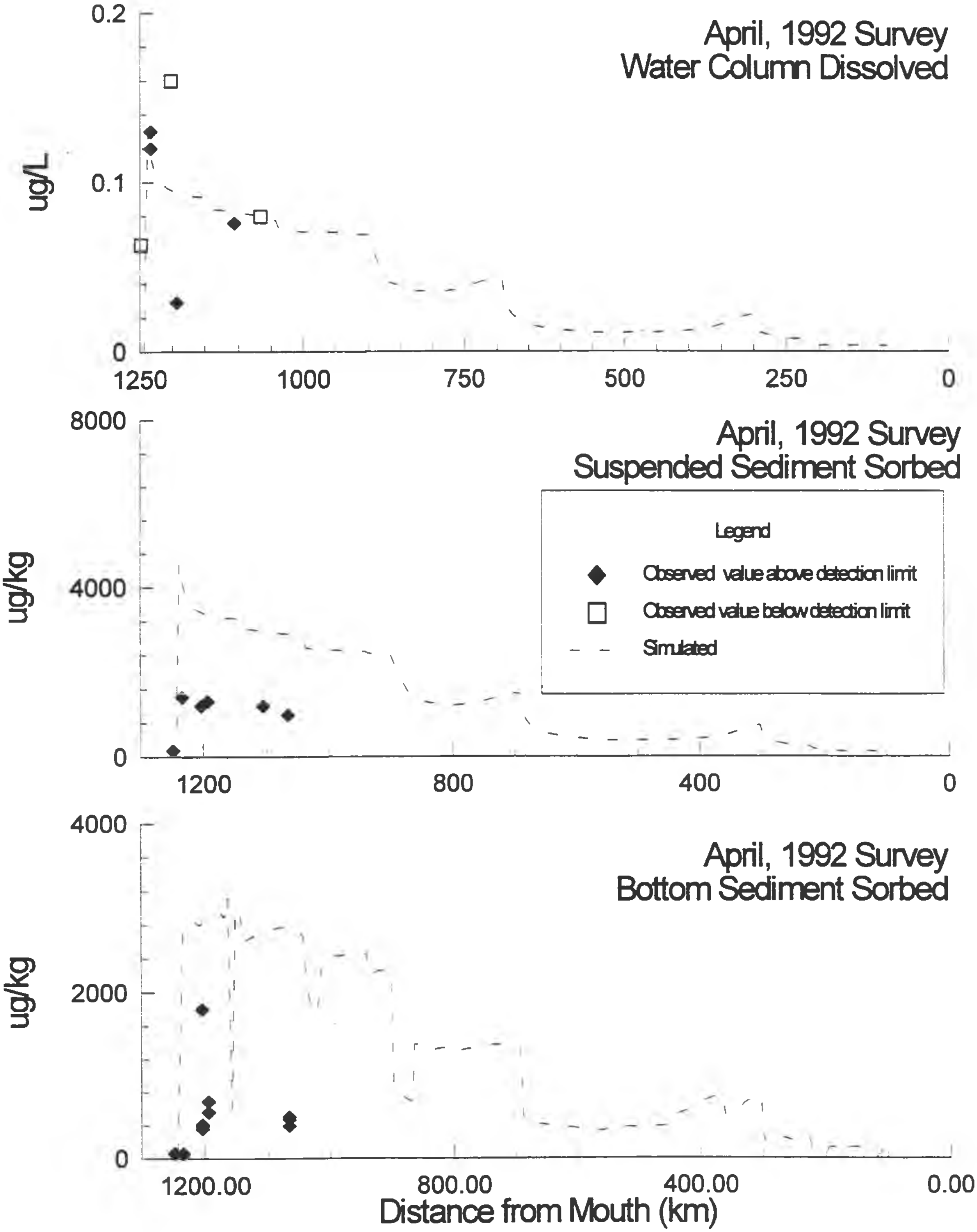


Figure 4.13b.
Athabasca River, DHA Calibration, Synoptic Surveys

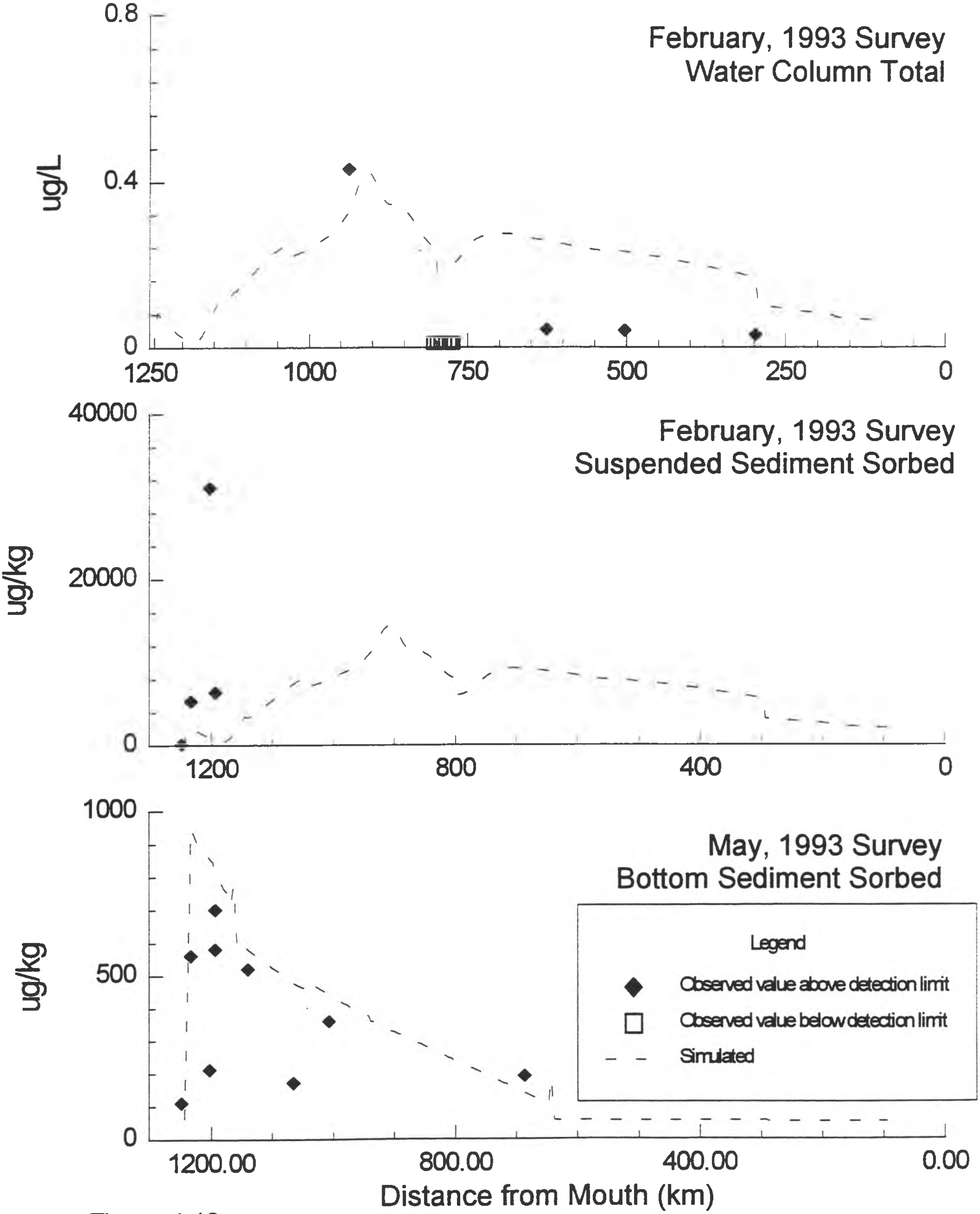


Figure 4.13c.
Athabasca River, DHA Calibration, Synoptic Surveys

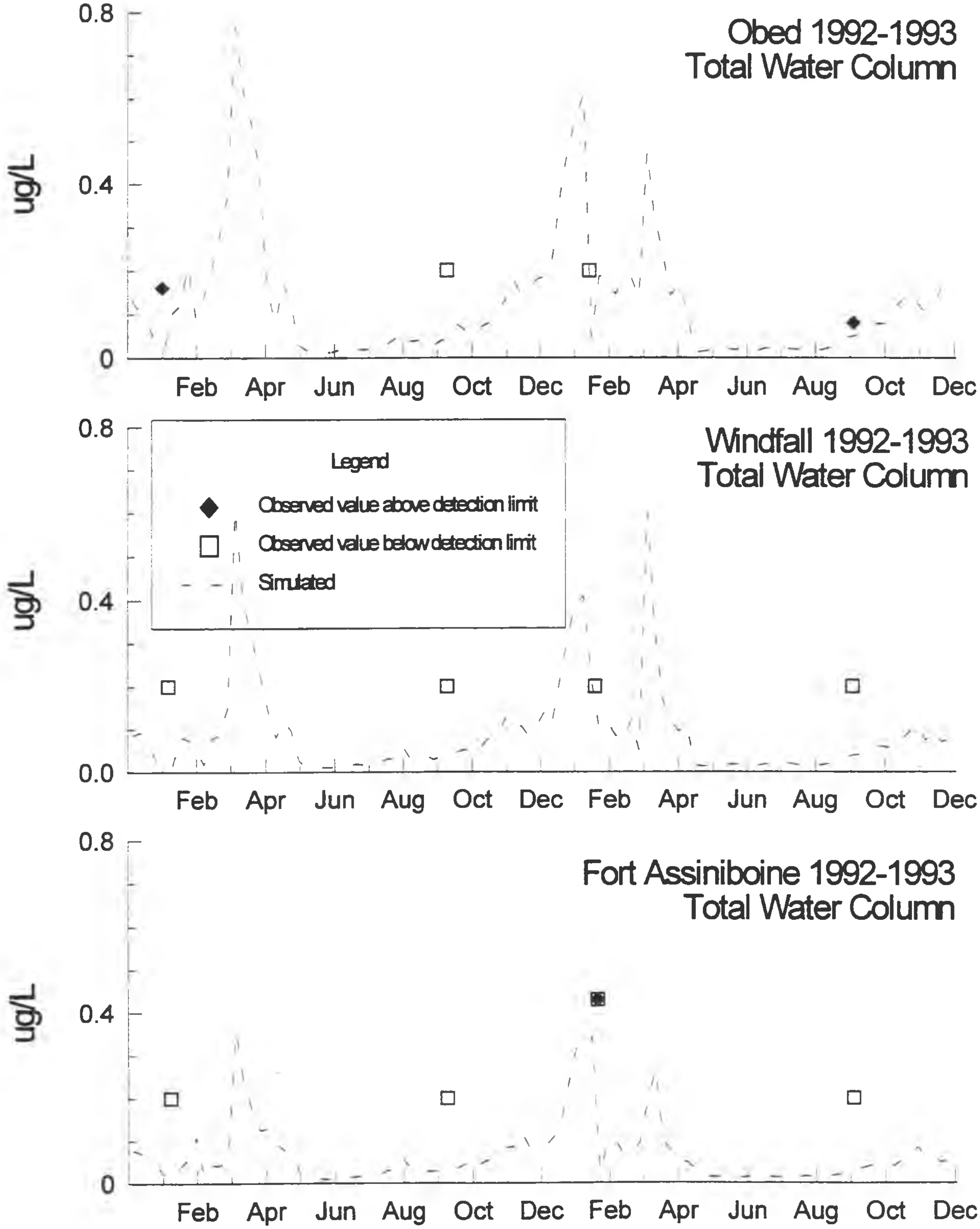


Figure 4.14a.
Athabasca River, DHA Calibration, Time Series

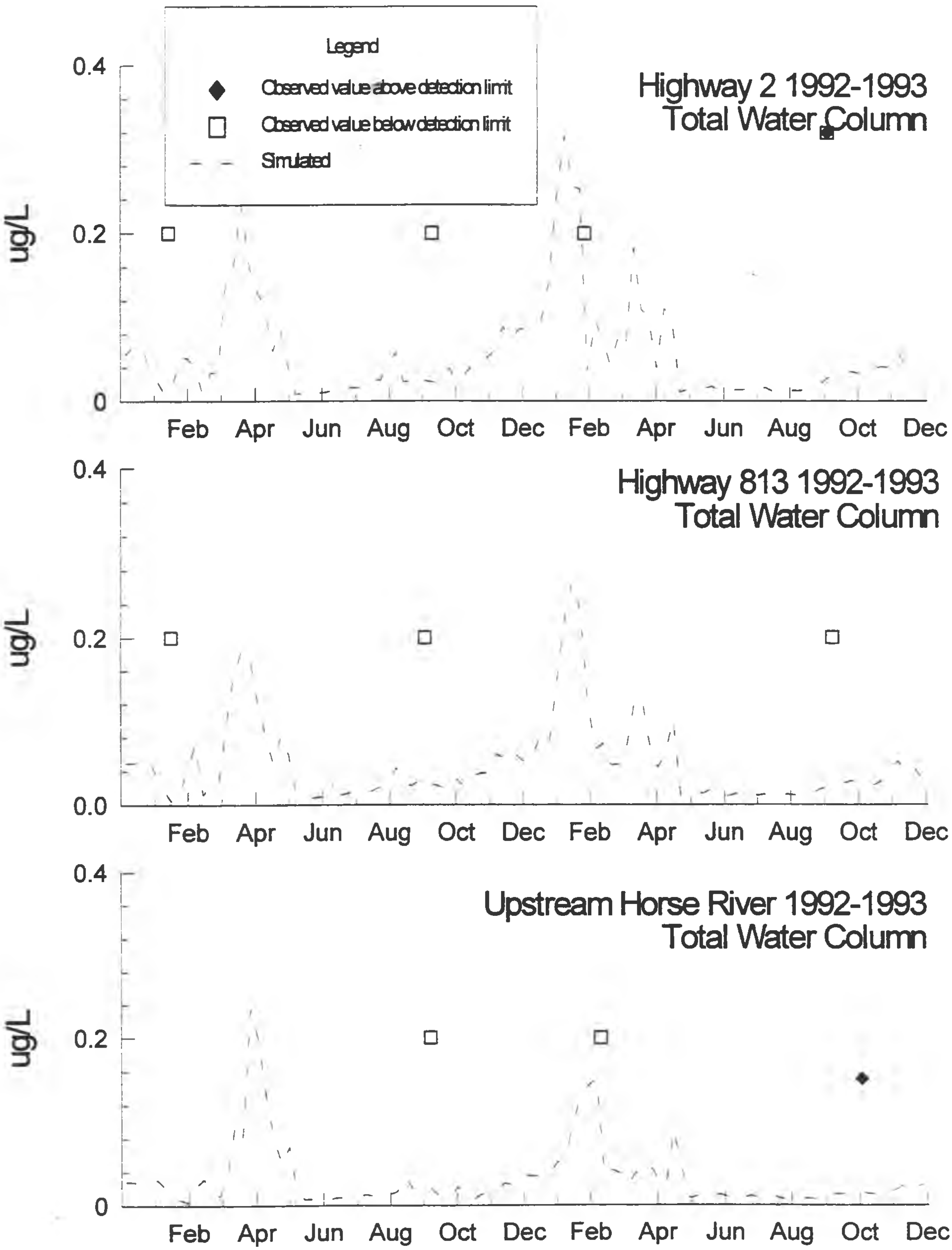


Figure 4.14b.
Athabasca River, DHA Calibration, Time Series

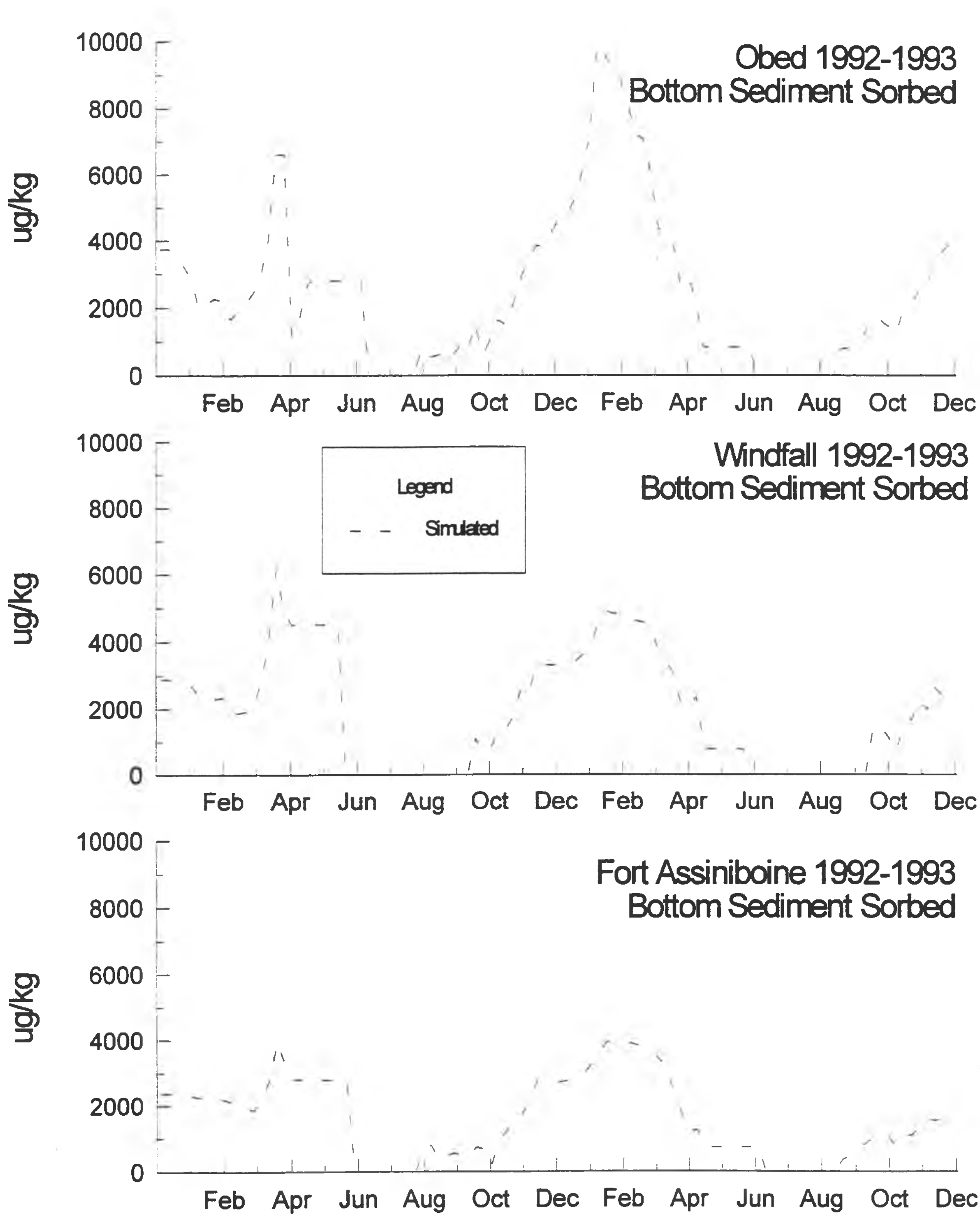


Figure 4.14c.
Athabasca River, DHA Calibration, Time Series

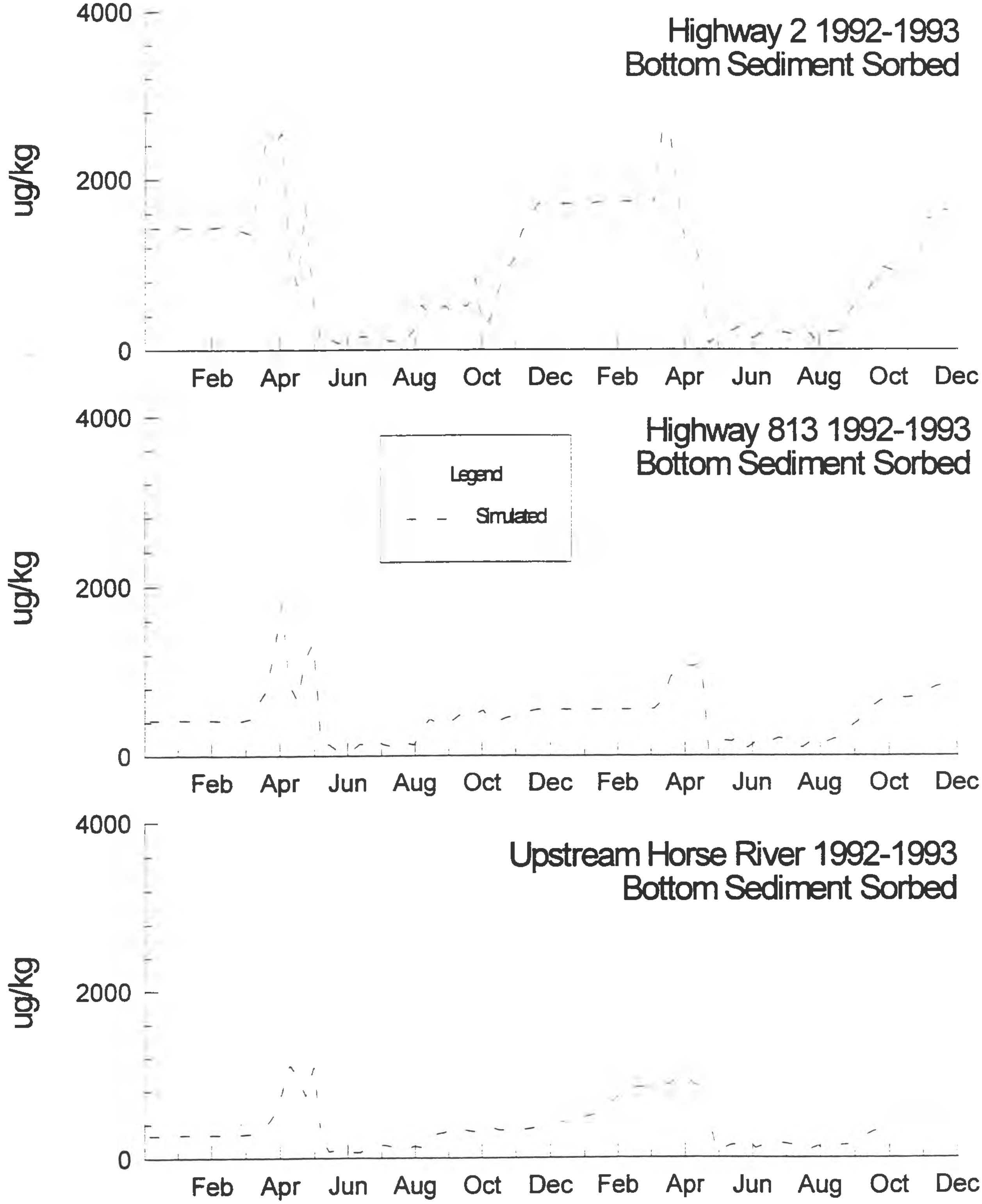


Figure 4.14d.
Athabasca River, DHA Calibration, Time Series

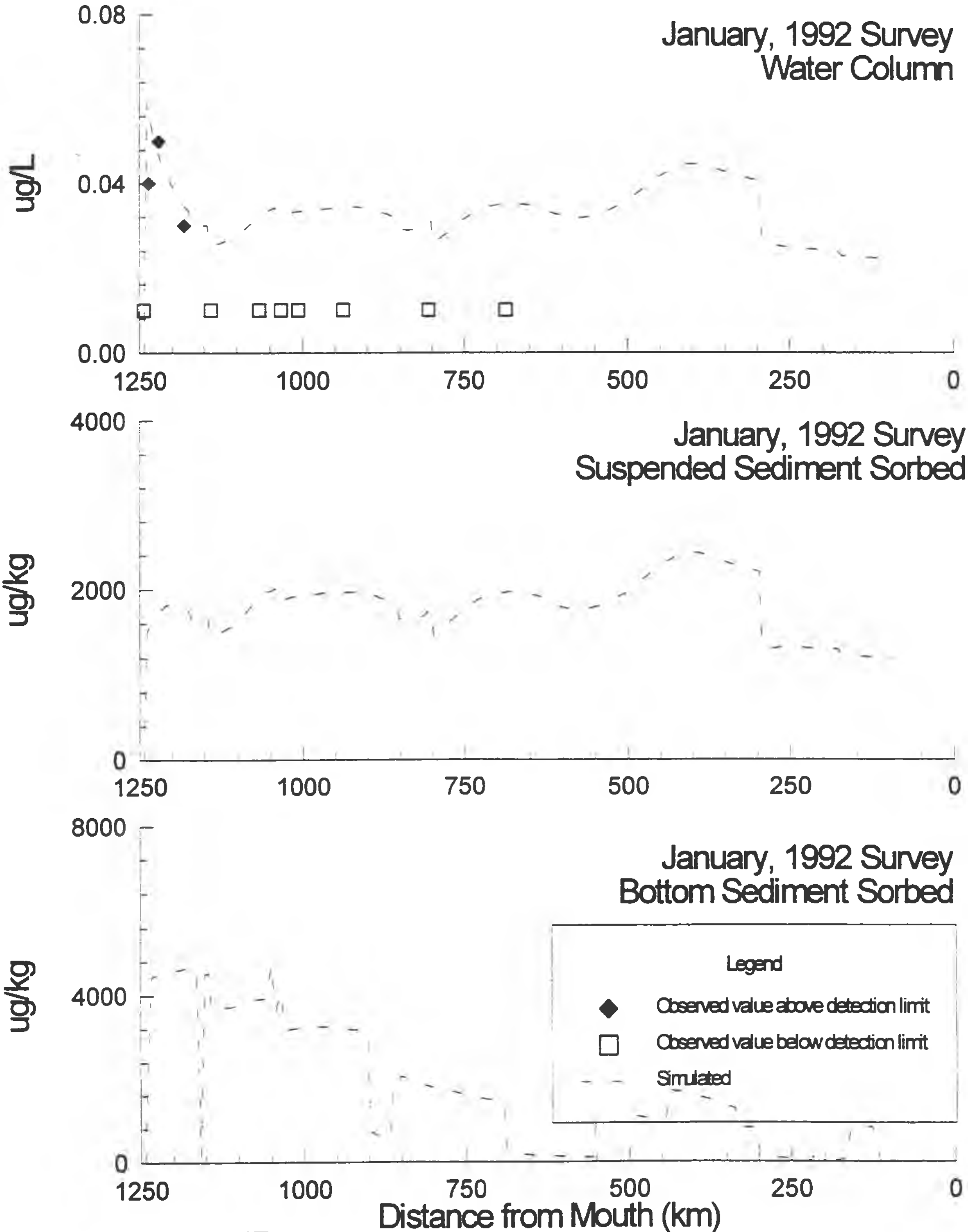


Figure 4.17a.
Athabasca River, 12,14-dichloro-DHA Calibration,
Synoptic Surveys

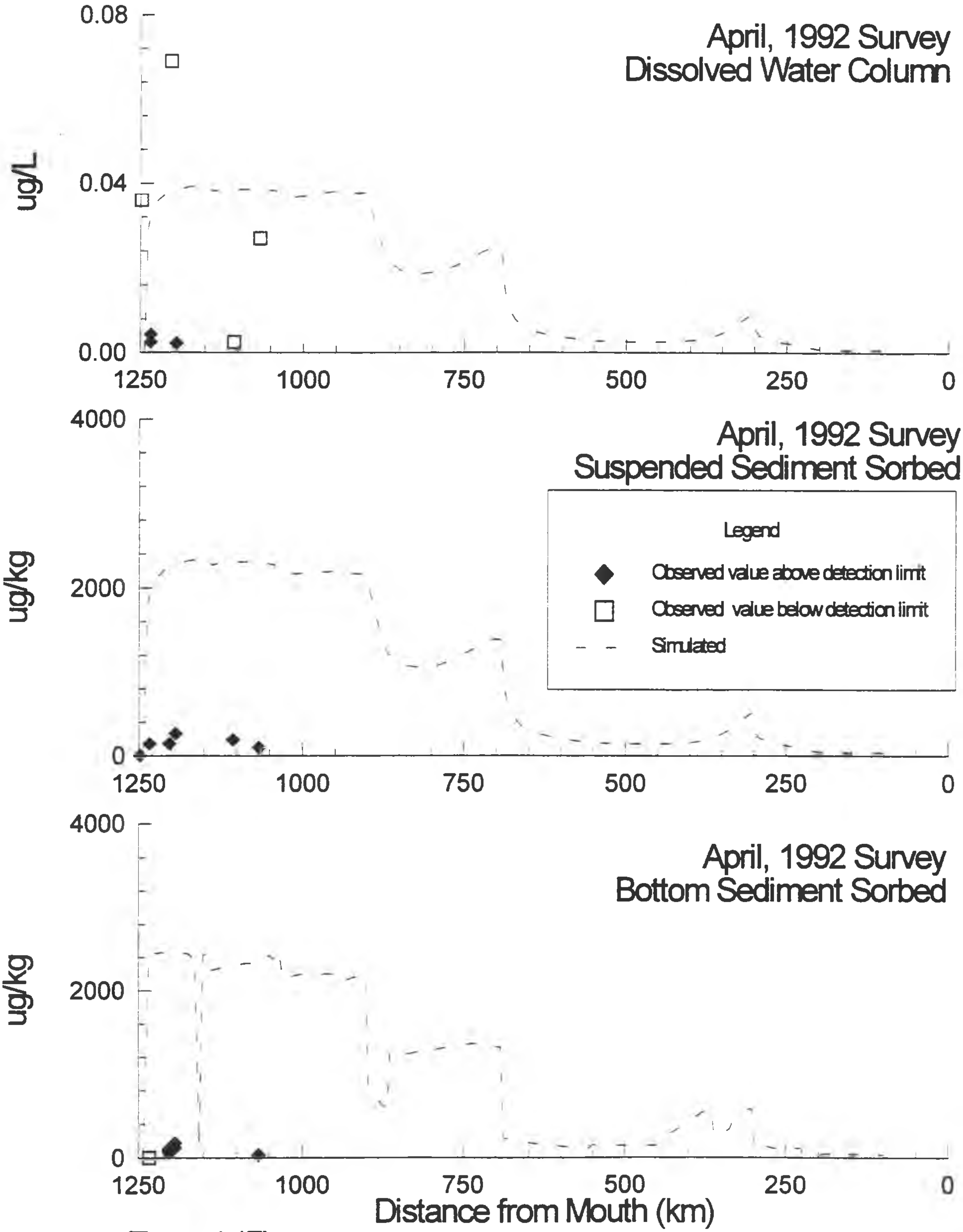


Figure 4.17b.
Athabasca River, 12,14-dichloro-DHA Calibration,
Synoptic Surveys

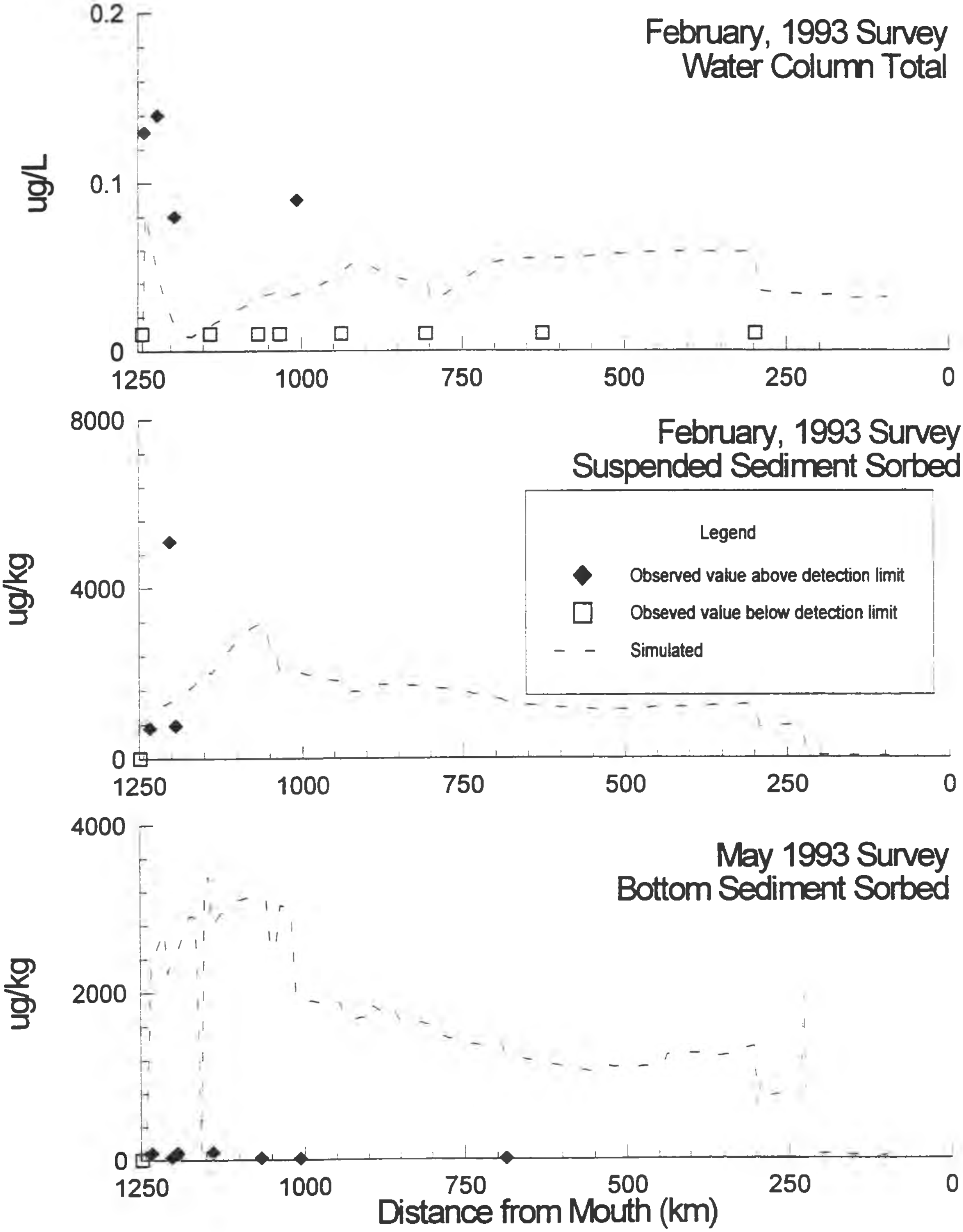


Figure 4.17c.
Athabasca River, 12,14-dichloro-DHA Calibration,
Synoptic Surveys

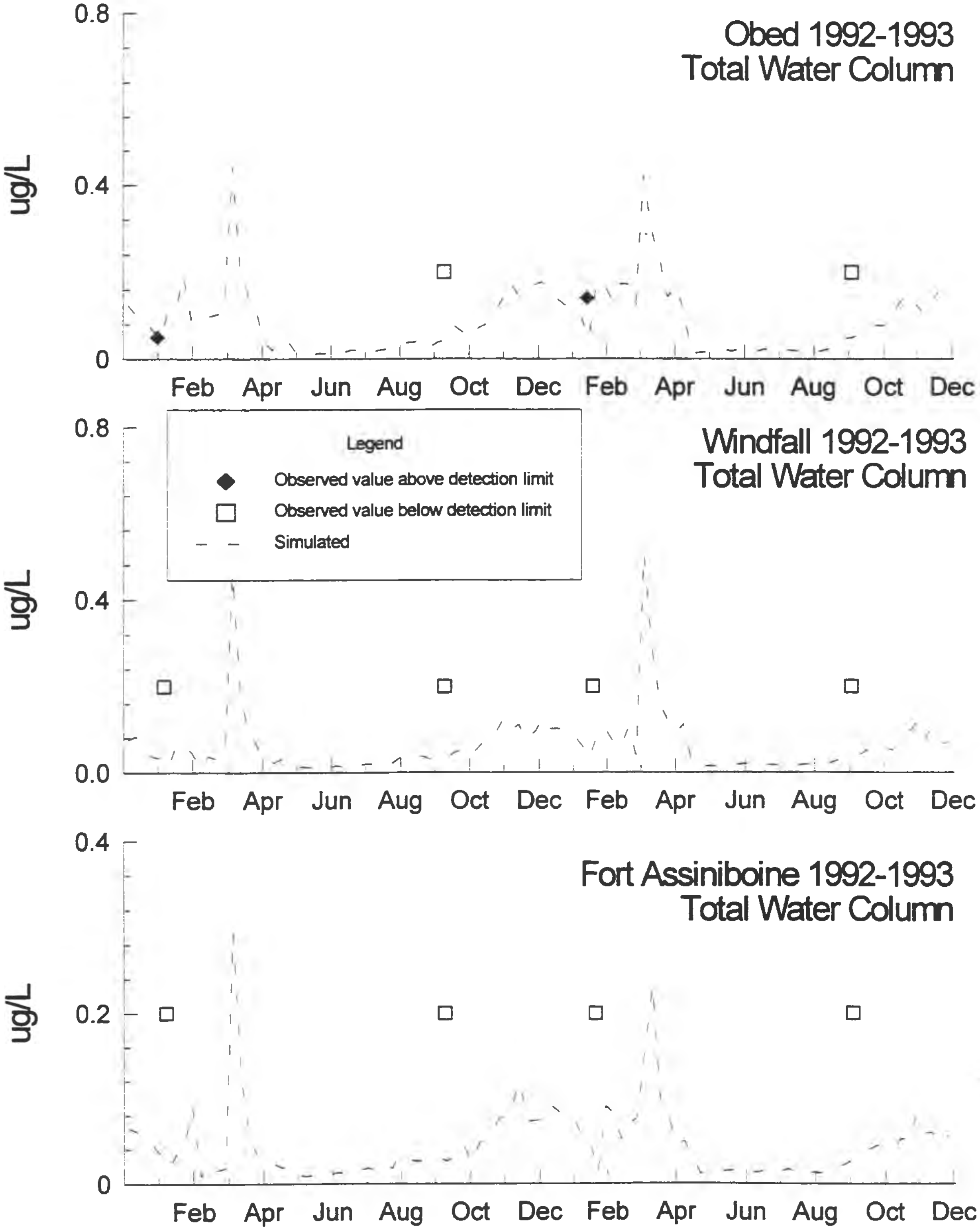


Figure 4.18a.
Athabasca River, 12,14-dichloro-DHA Calibration,
Time Series

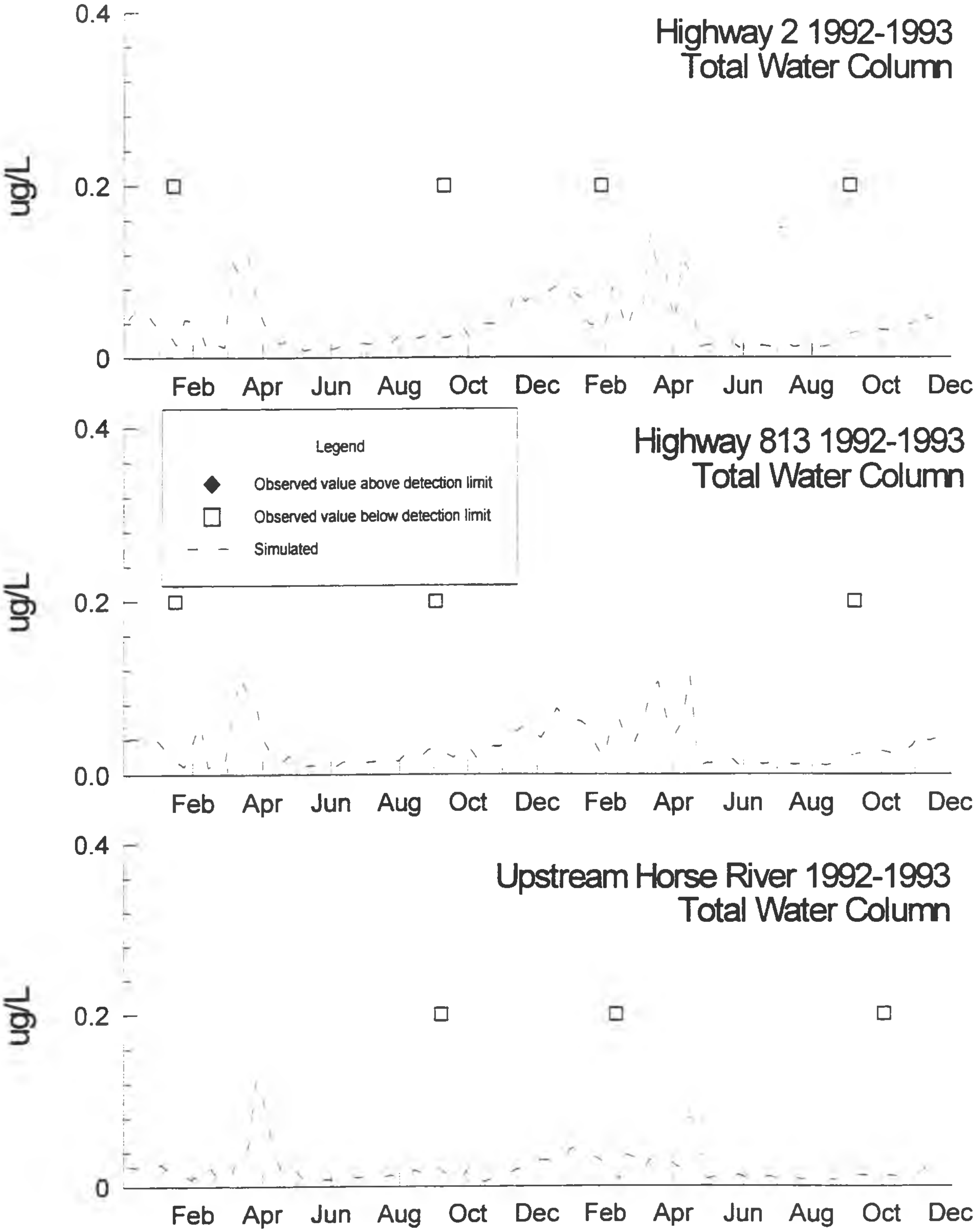


Figure 4.18b.
Athabasca River, 12,14-dichloro-DHA Calibration,
Time Series

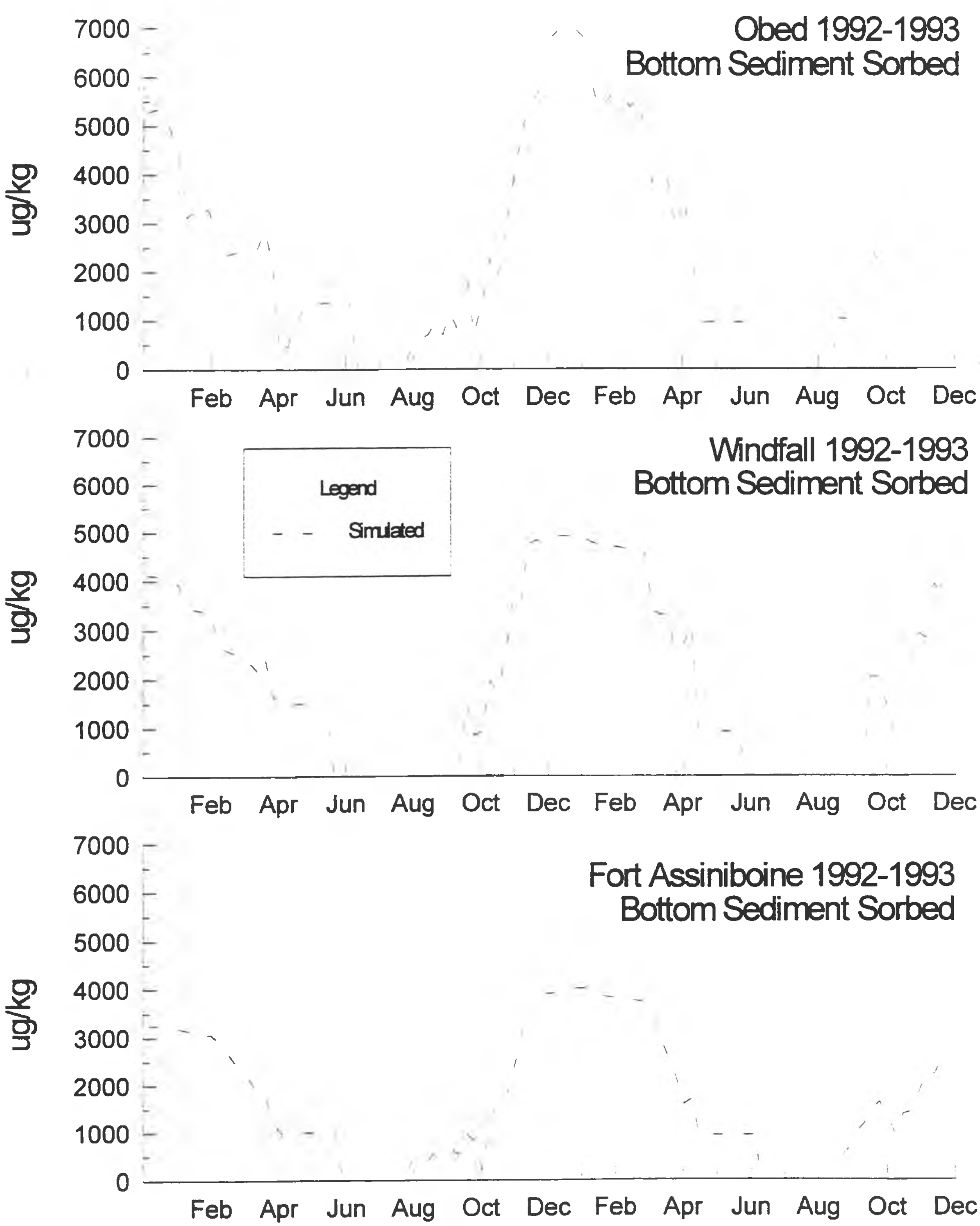


Figure 4.18c.
Athabasca River, 12,14-dichloro-DHA Calibration, Time Series

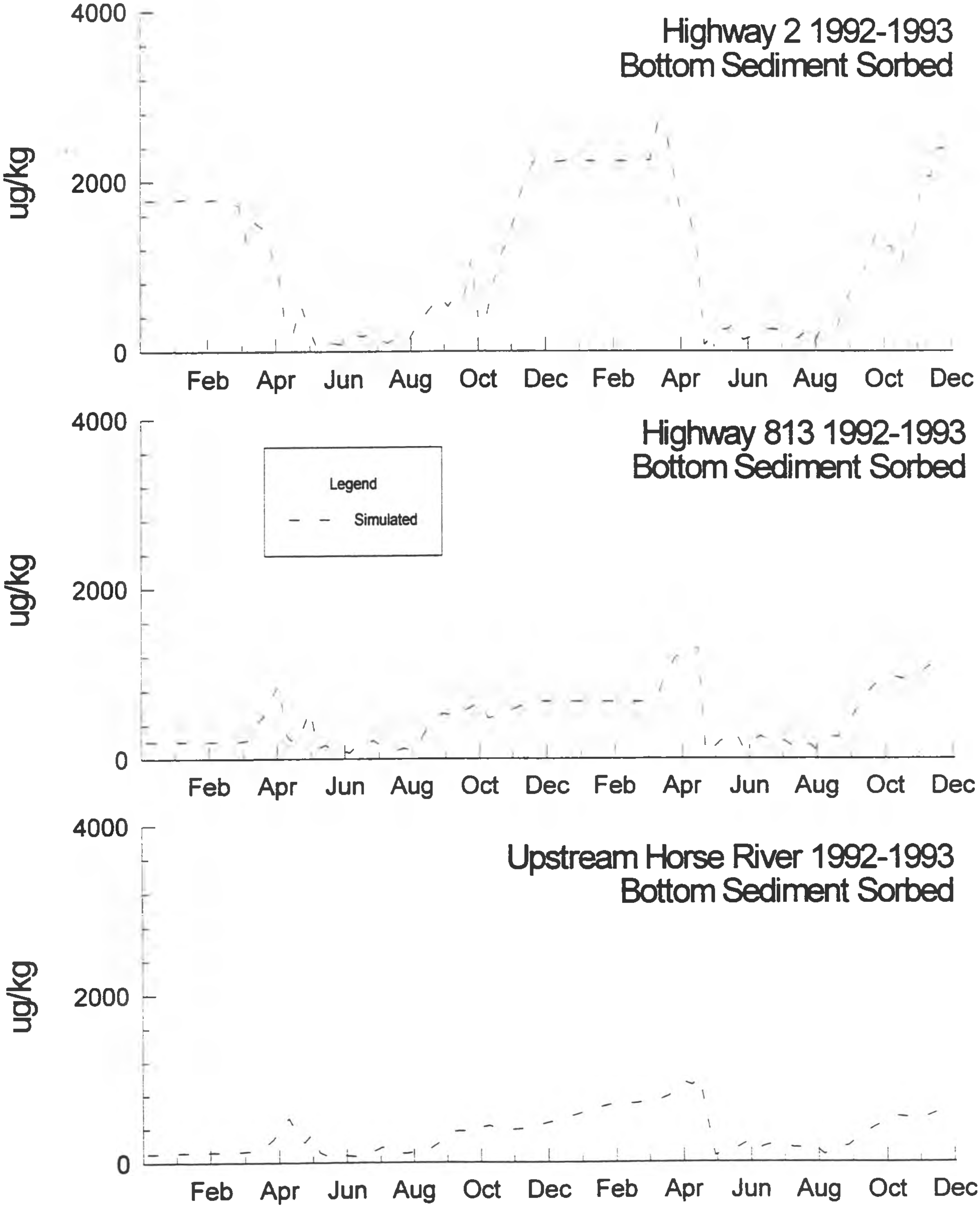


Figure 4.18d.
Athabasca River, 12,14-dichloro-DHA Calibration,
Time Series

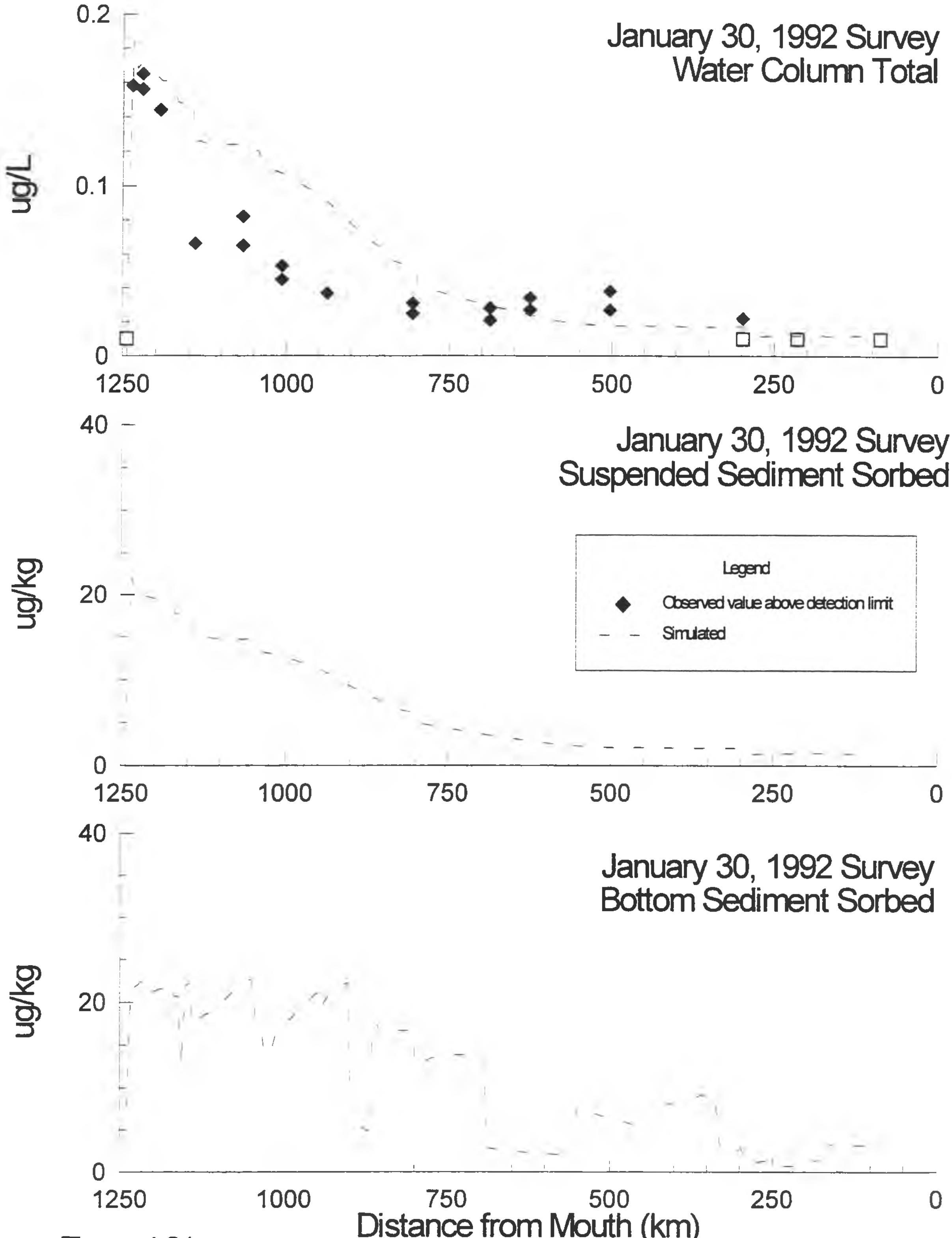


Figure 4.21a.
Athabasca River, 3,4,5-TCC Calibration, Synoptic Surveys

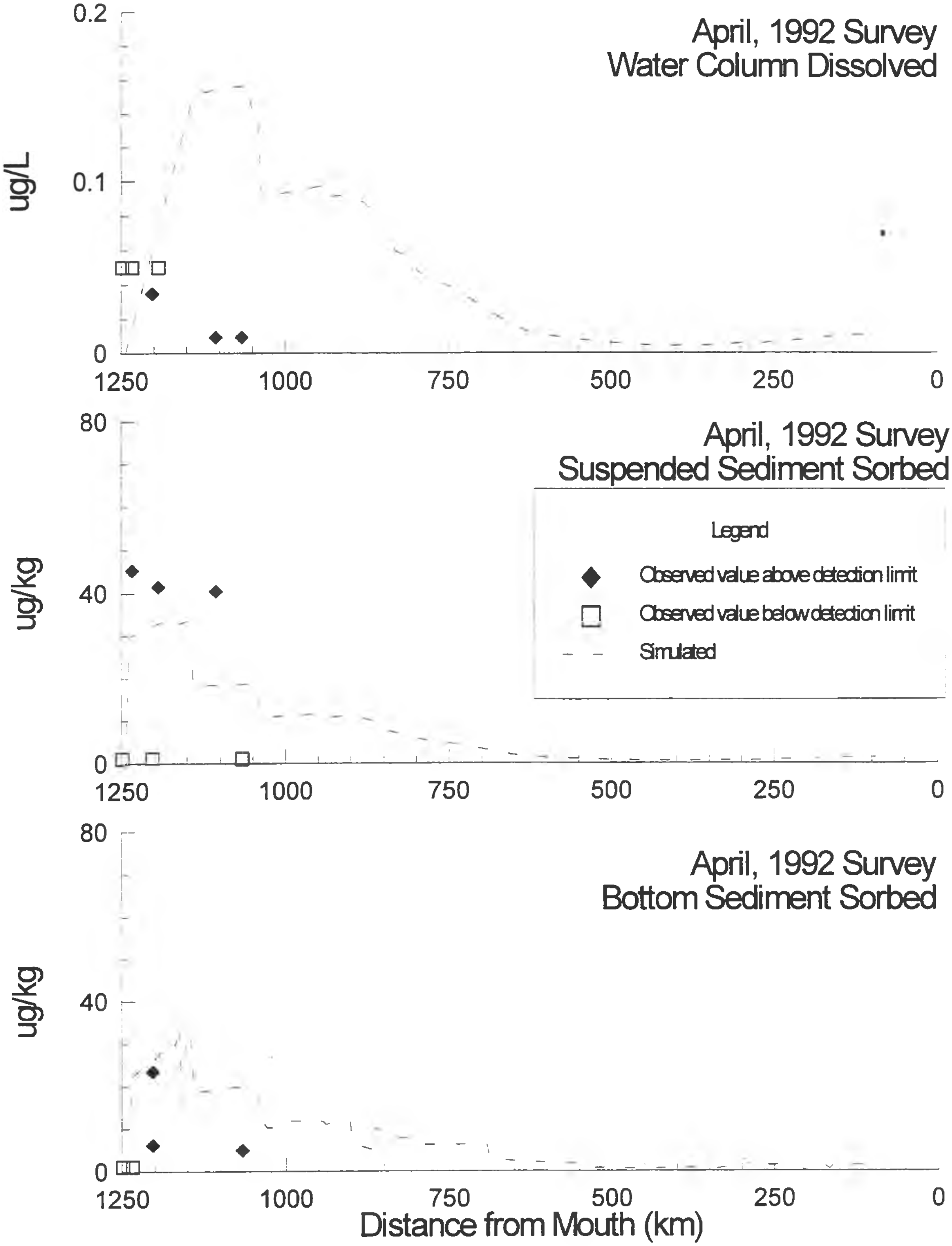


Figure 4.21b.
Athabasca River, 3,4,5-TCC Calibration, Synoptic Surveys

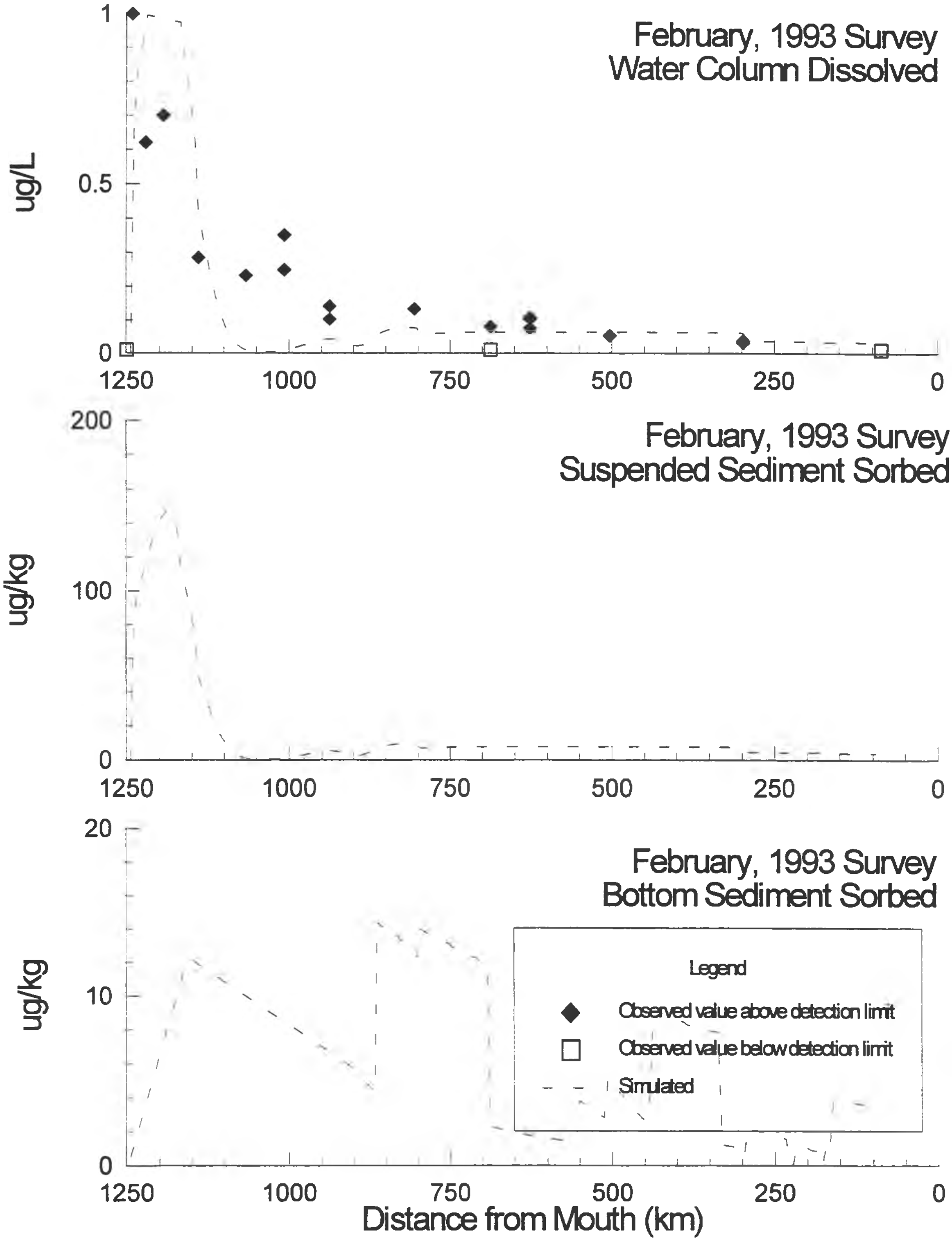


Figure 4.21c.
Athabasca River, 3,4,5-TCC (ug/L and ug/kg) Calibration, Synoptic Surveys

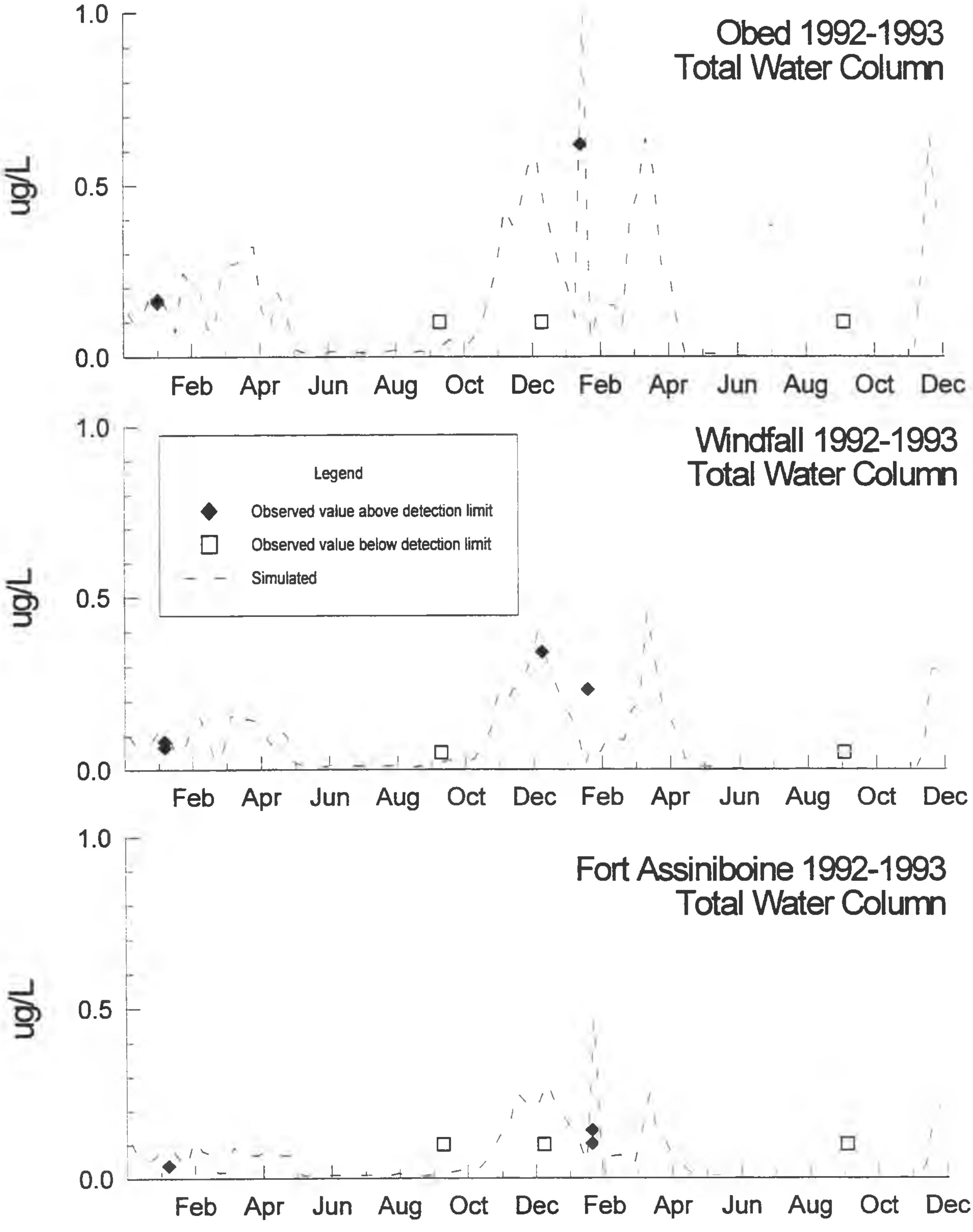


Figure 4.22a.
Athabasca River, 3,4,5-TCC Calibration, Time Series

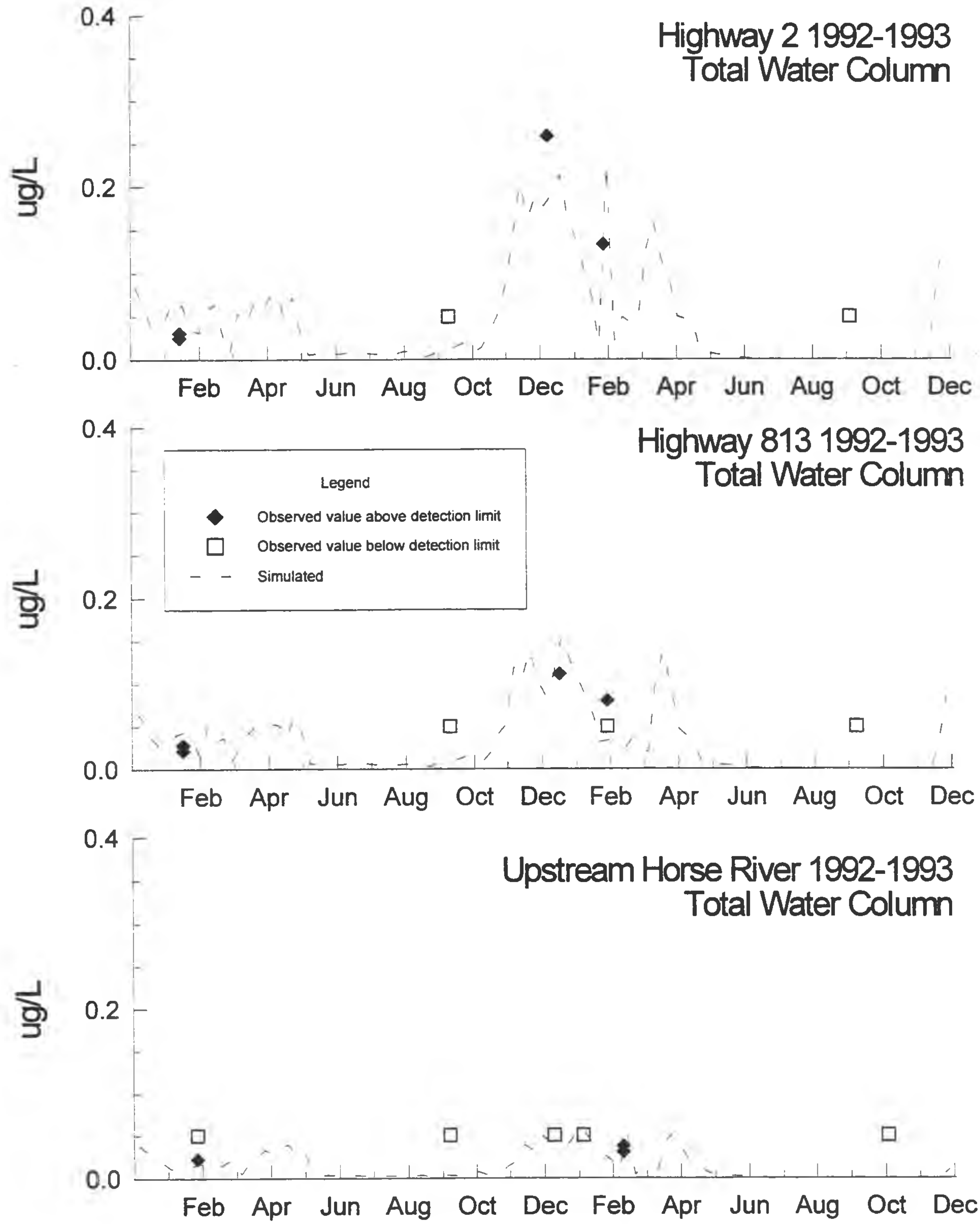


Figure 4.22b.
Athabasca River, 3,4,5-TCC Calibration, Time Series

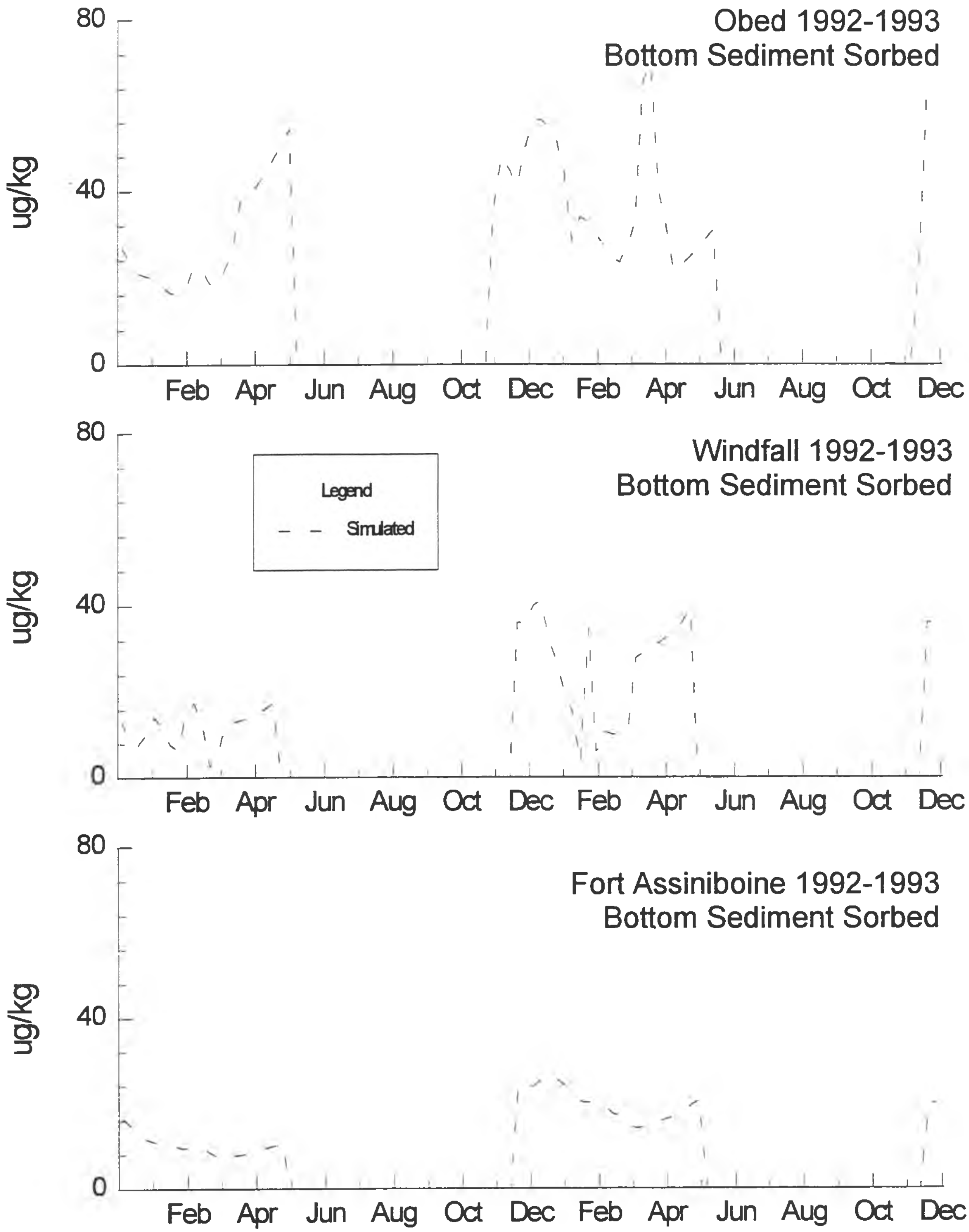


Figure 4.22c.
Athabasca River, 3,4,5-TCC Calibration, Time Series

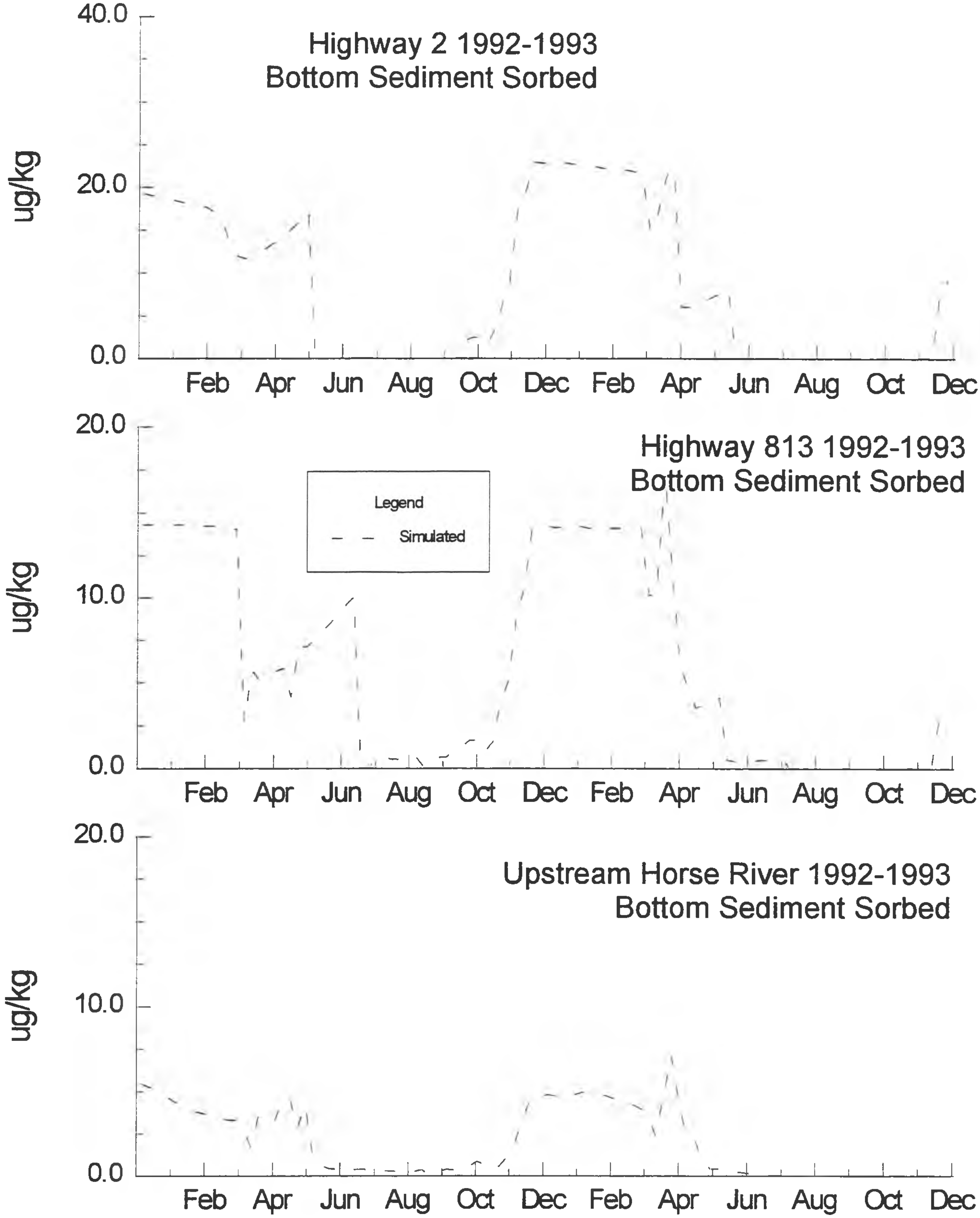


Figure 4.22d.
Athabasca River, 3,4,5-TCC Calibration, Time Series

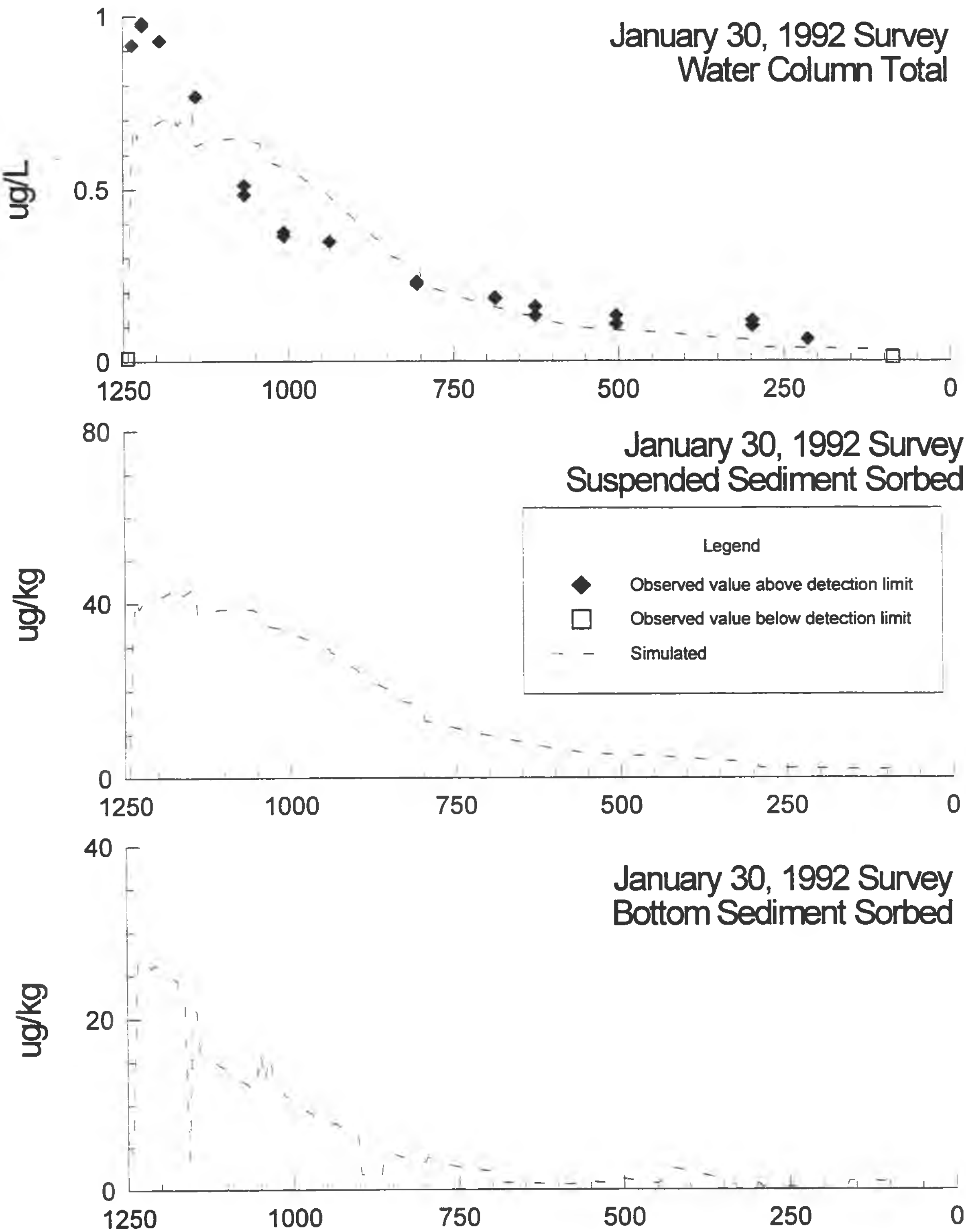


Figure 4.25a
Athabasca River, 3,4,5-TCG Calibration, Synoptic Surveys

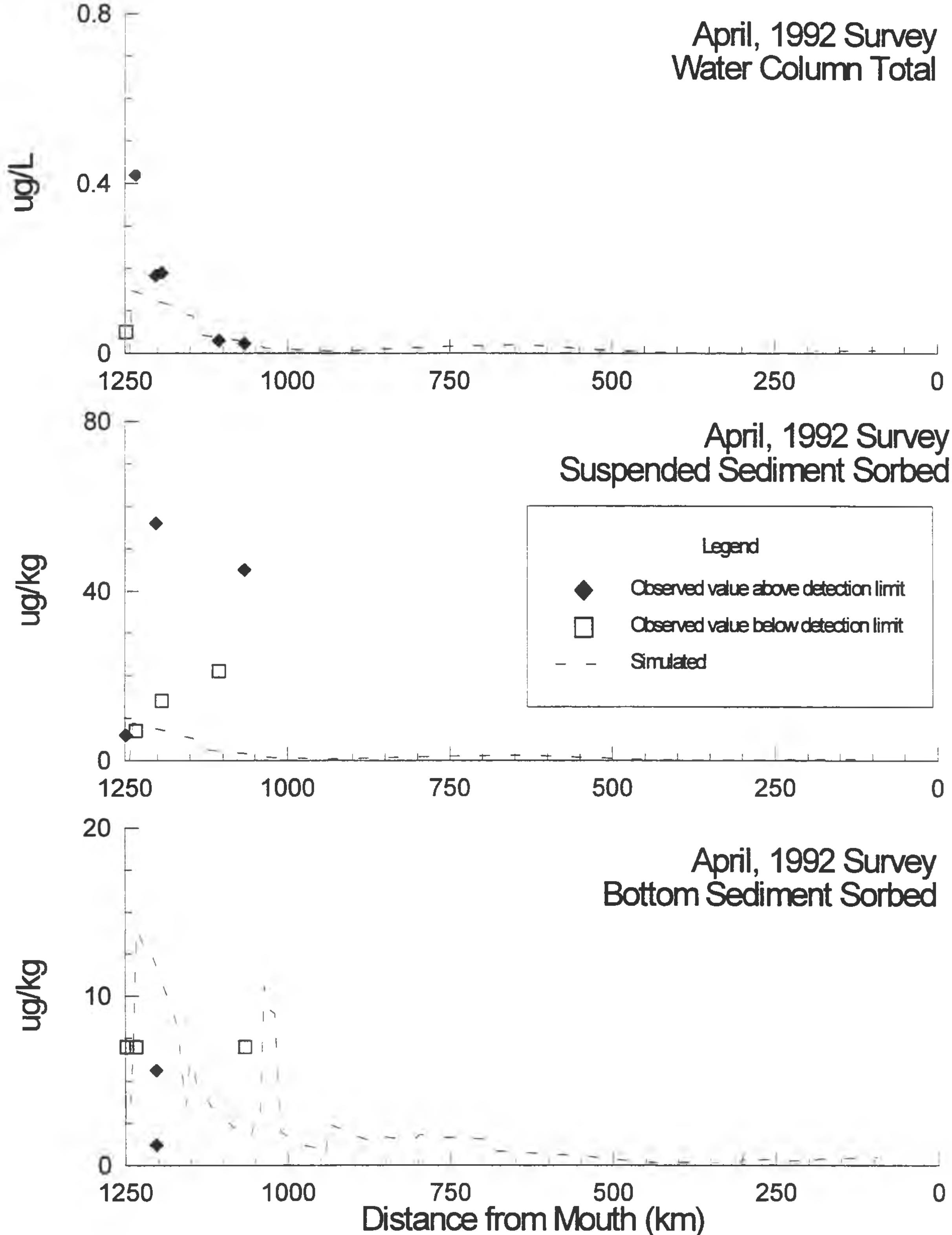


Figure 4.25b.
Athabasca River, 3,4,5-TCG Calibration, Synoptic Surveys

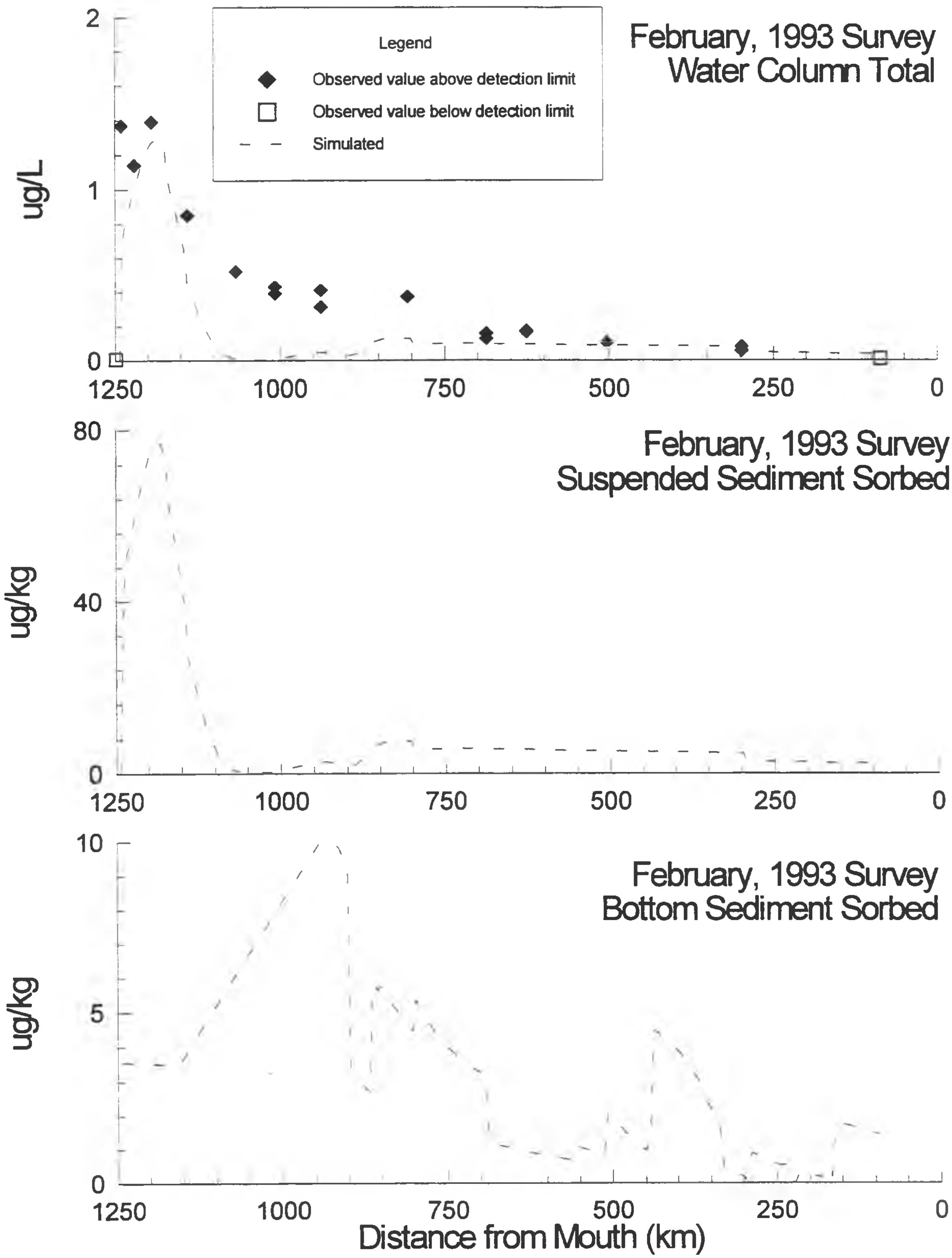


Figure 4.25c.
Athabasca River, 3,4,5-TCG Calibration, Synoptic Surveys

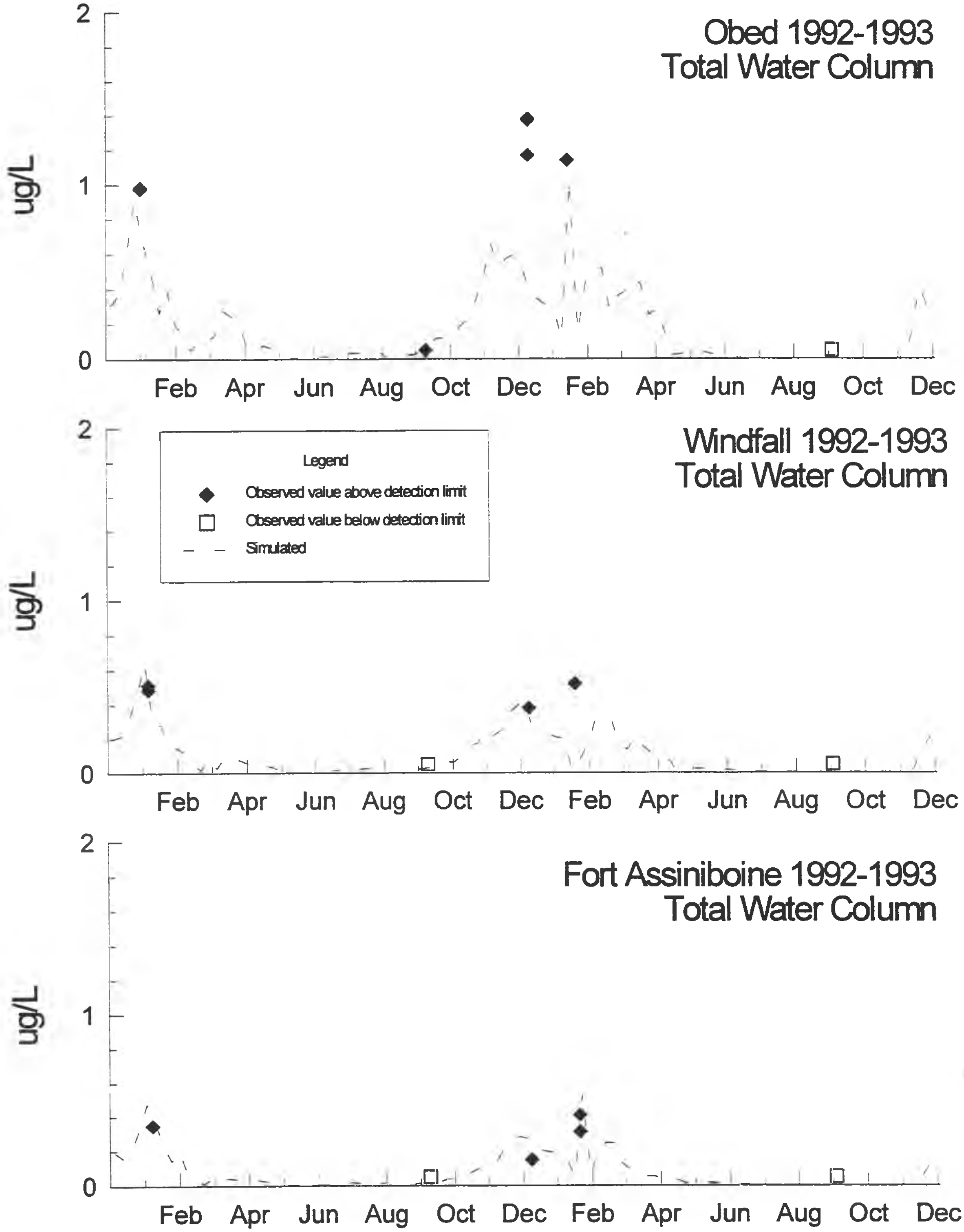


Figure 4.26a.
Athabasca River, 3,4,5-TCG Calibration, Time Series

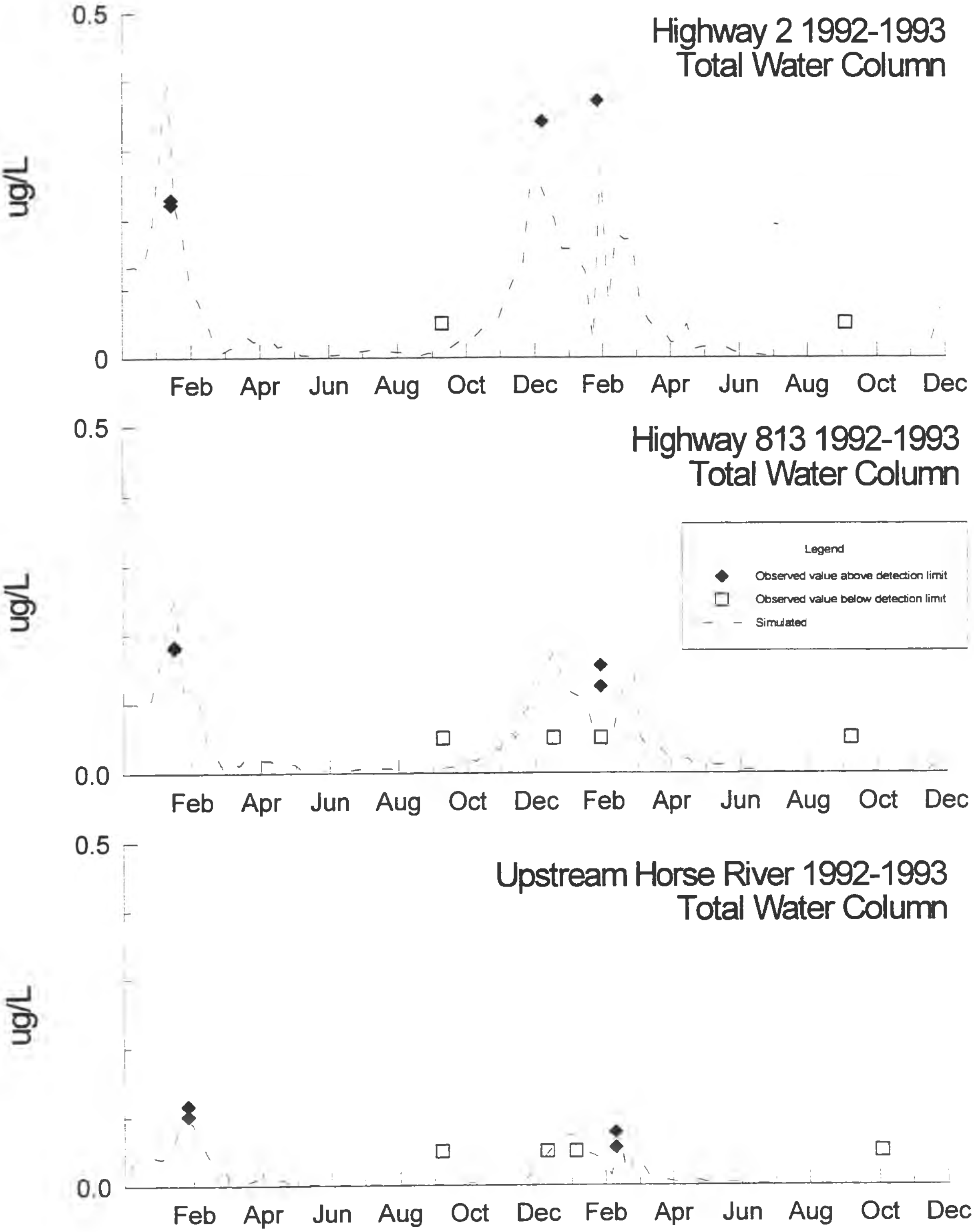


Figure 4.26b.
Athabasca River, 3,4,5-TCG Calibration, Time Series

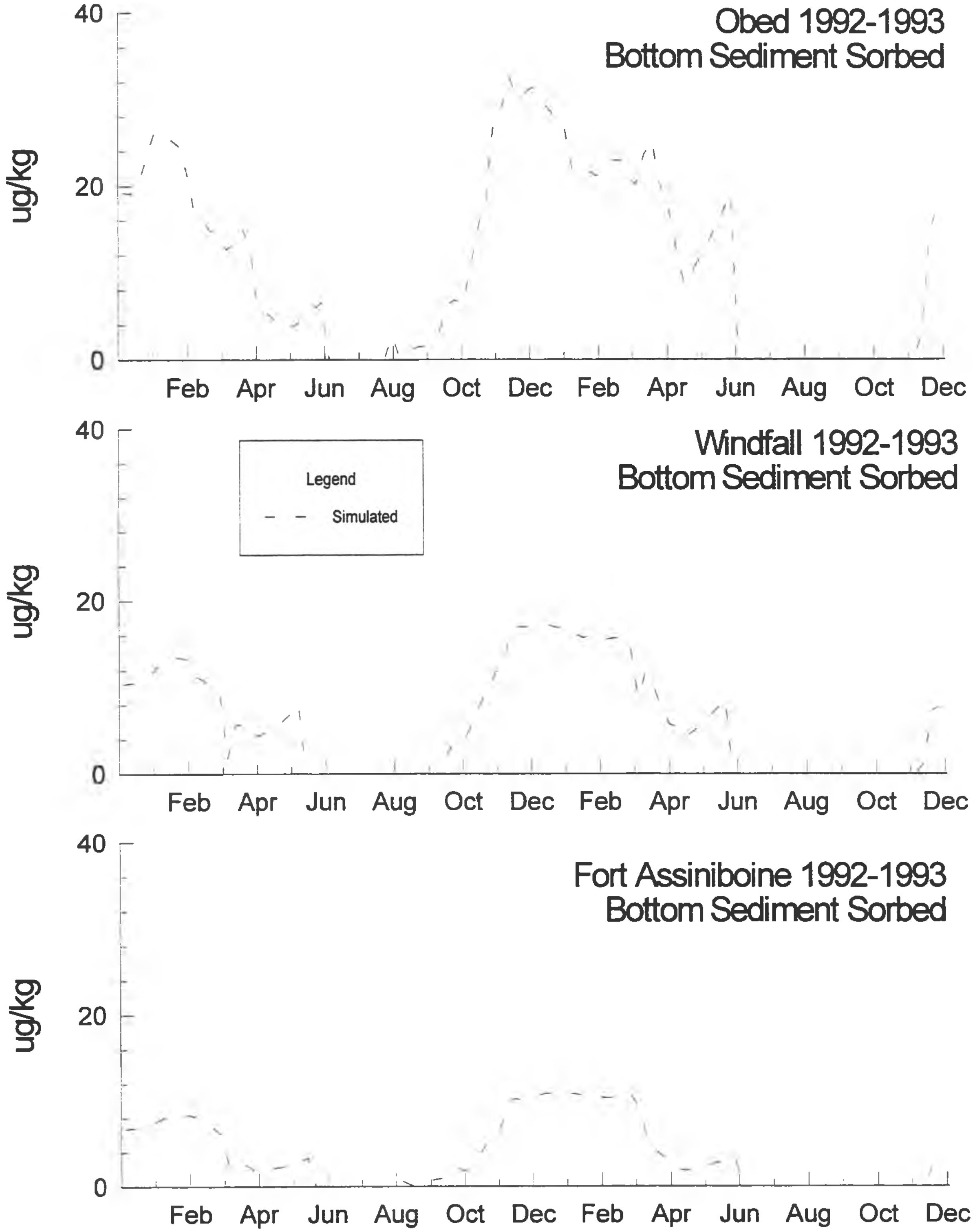
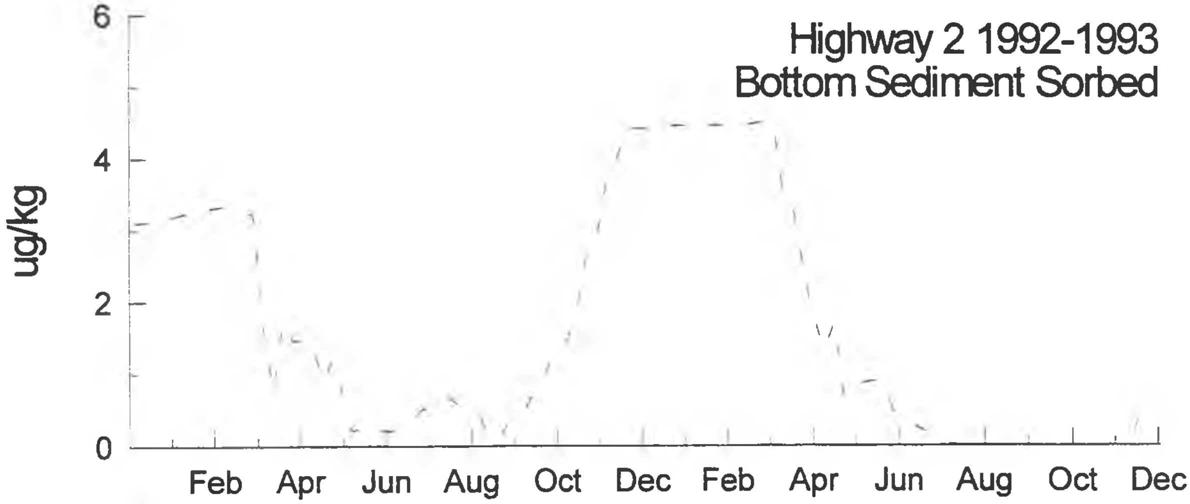
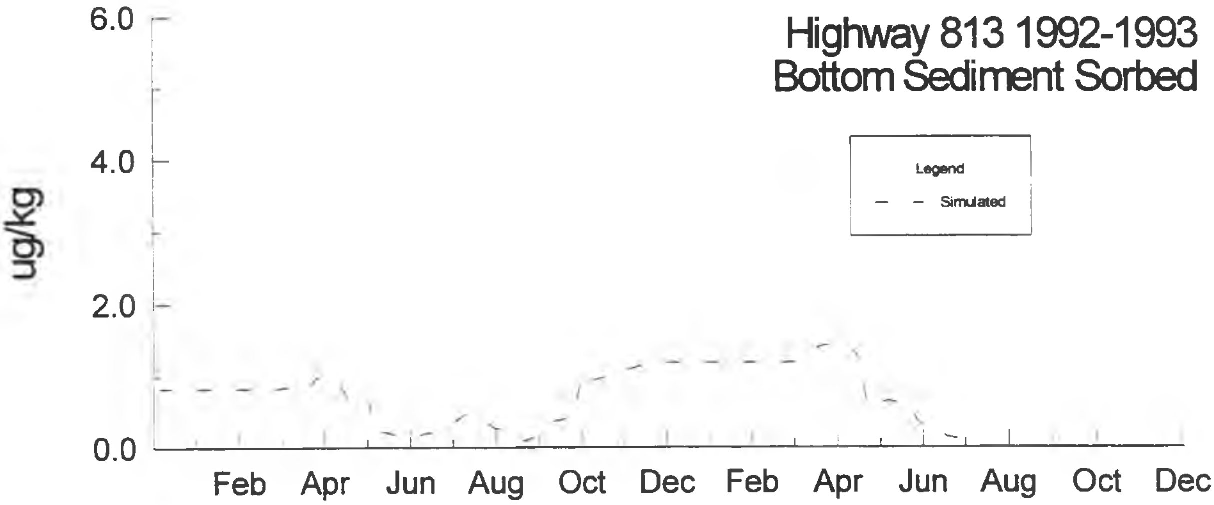


Figure 4.26c.
Athabasca River, 3,4,5-TCG Calibration, Time Series





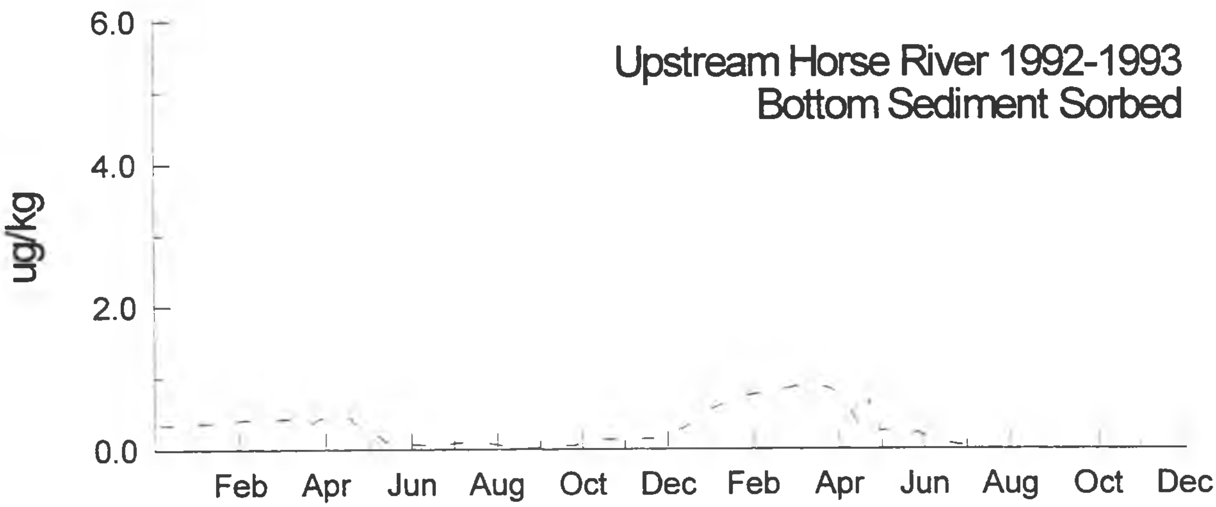


Figure 4.26d.
Athabasca River, 3,4,5-TCG Calibration, Time Series

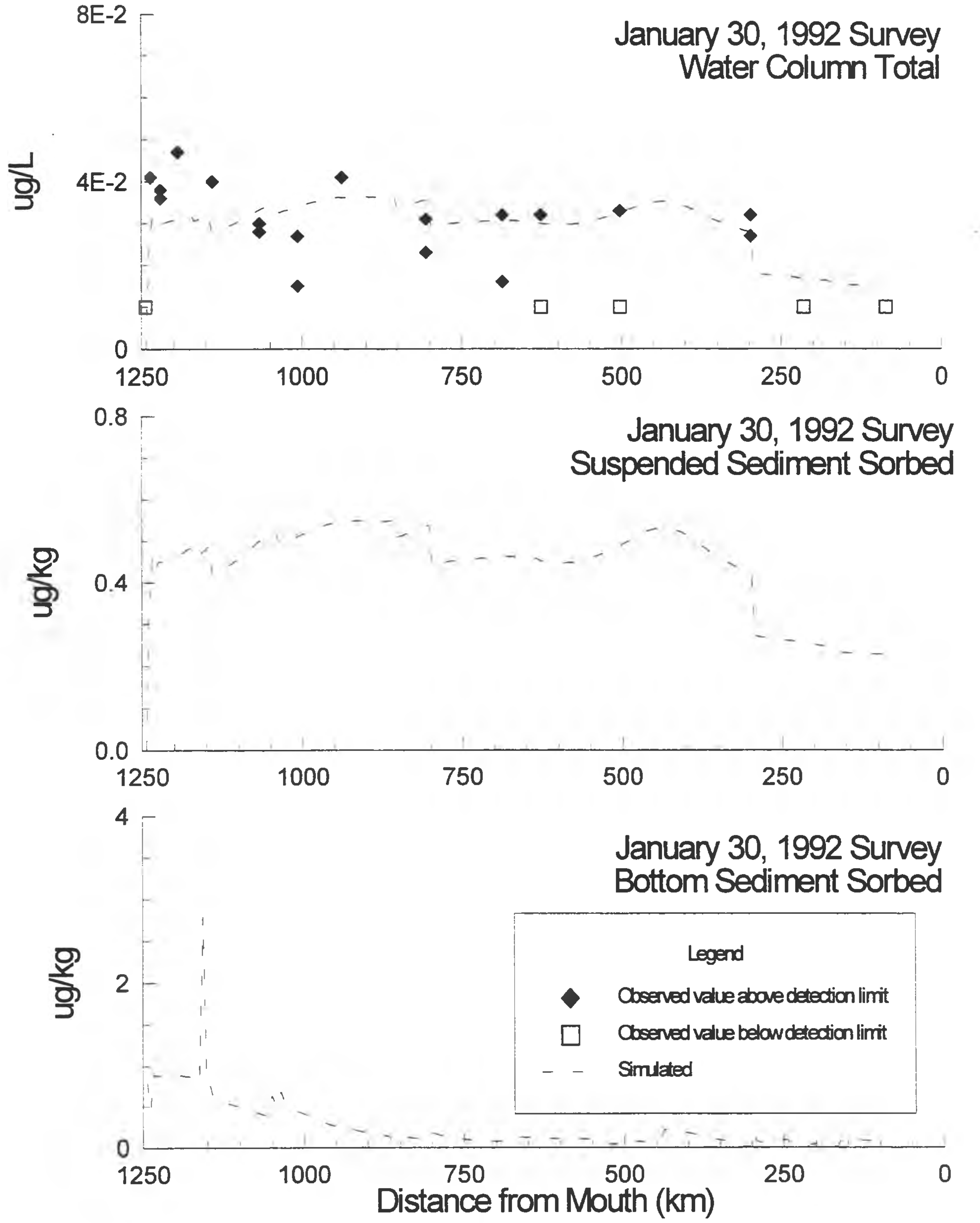


Figure 4.29a.
Athabasca River, 3,4,5-TCV Calibration, Synoptic Surveys

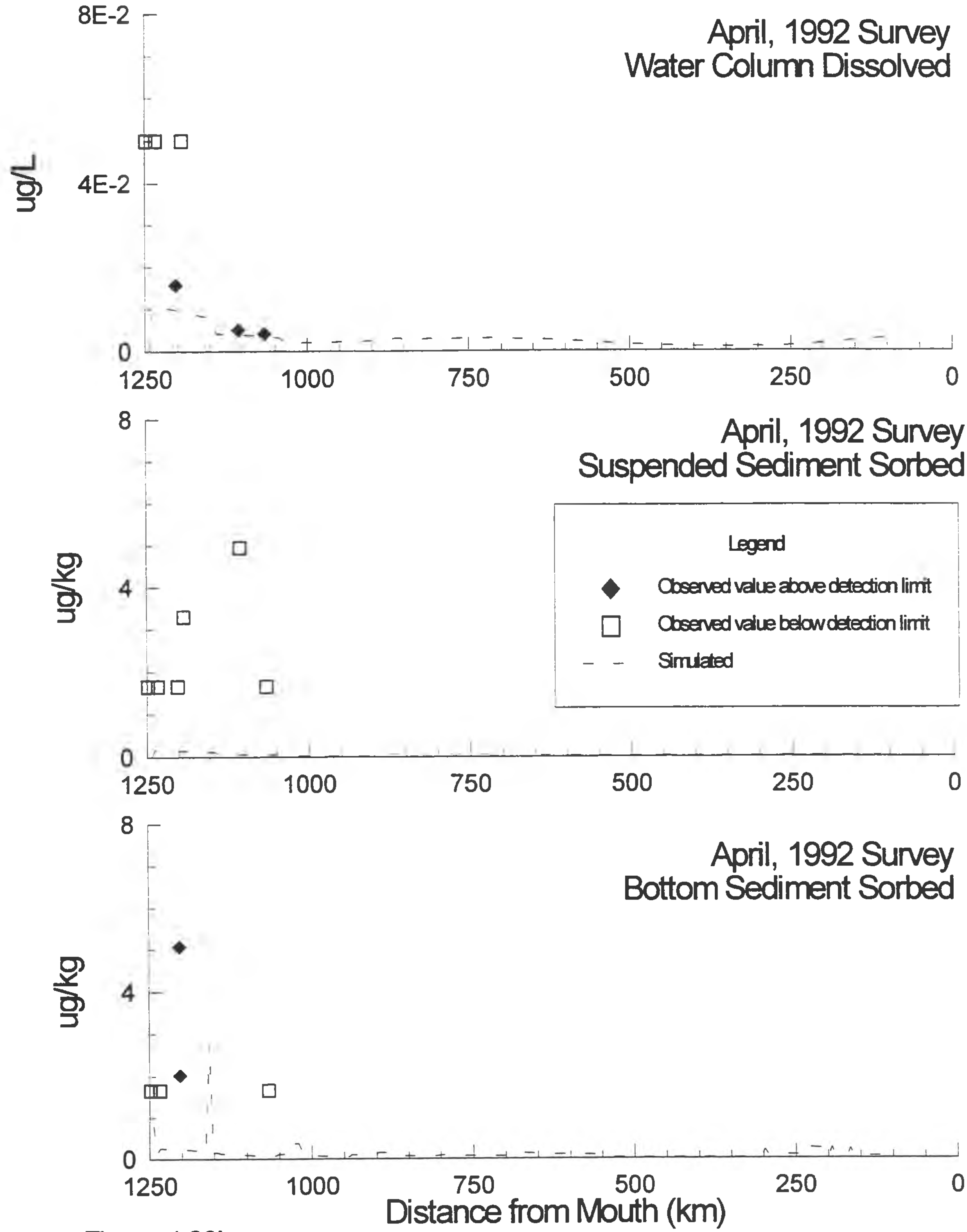


Figure 4.29b.
Athabasca River, 3,4,5-TCV Calibration, Synoptic Surveys

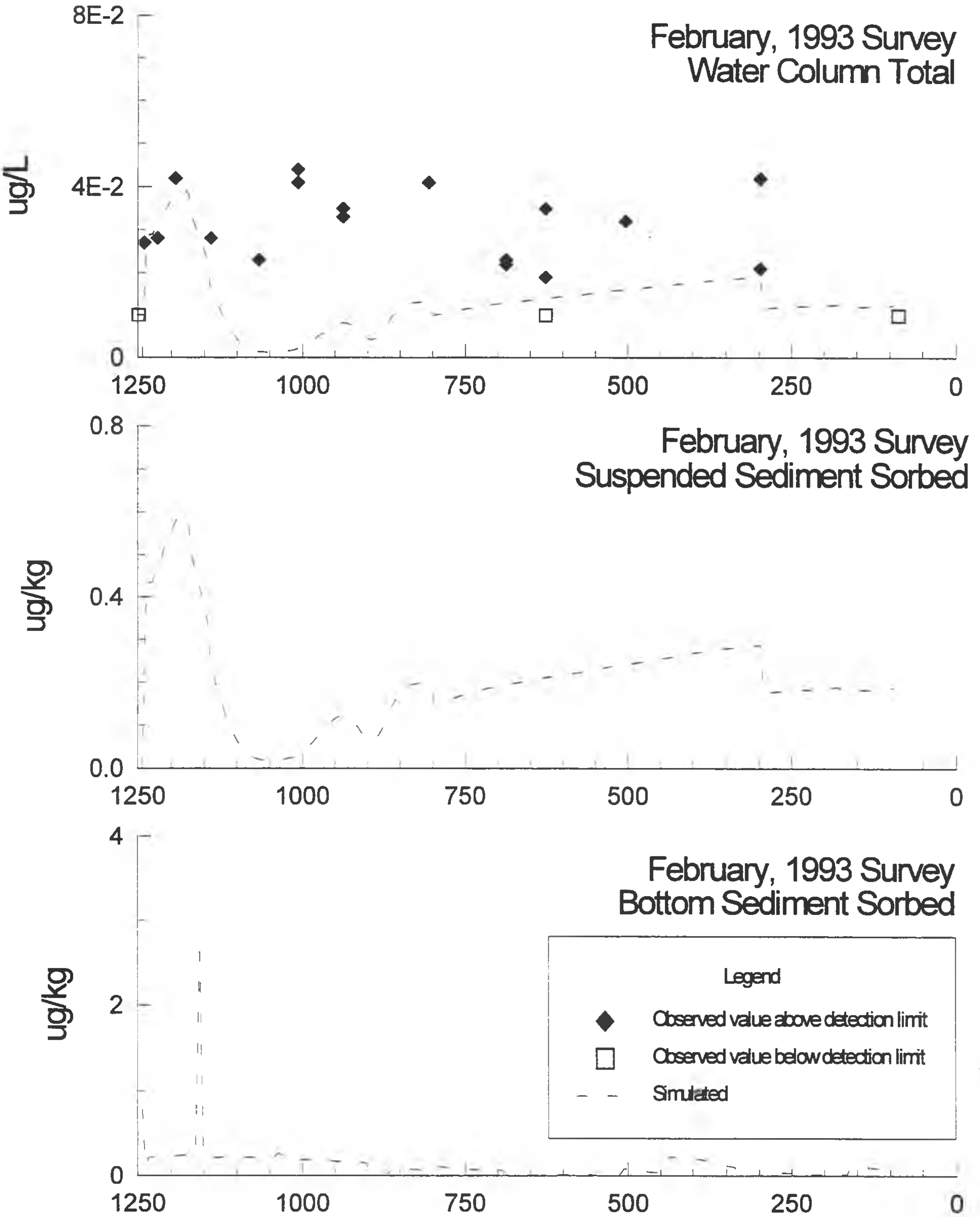


Figure 4.29c.
Athabasca River, 3,4,5-TCV Calibration, Synoptic Surveys

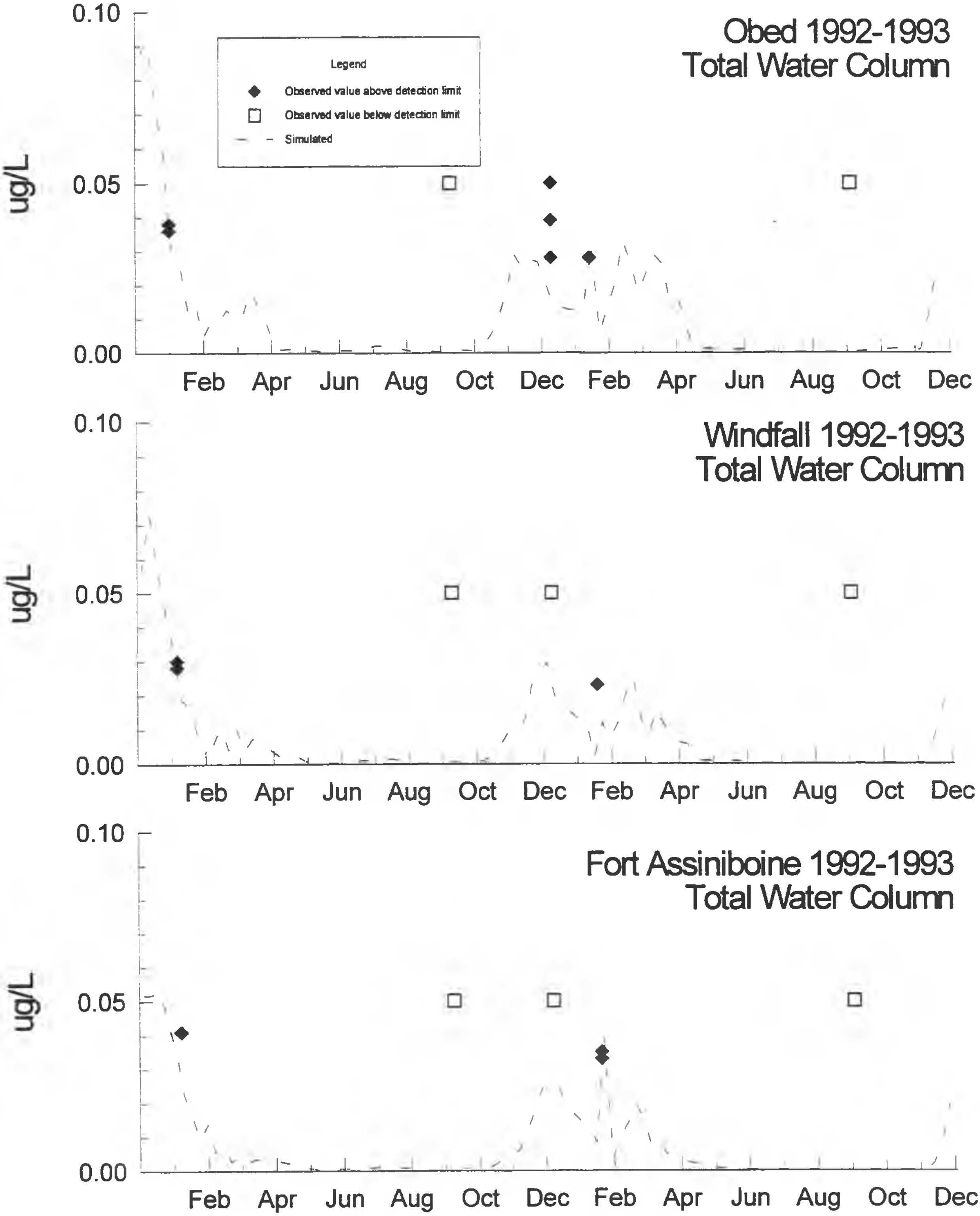


Figure 4.30a.
Athabasca River, 3,4,5-TCV Calibration, Time Series

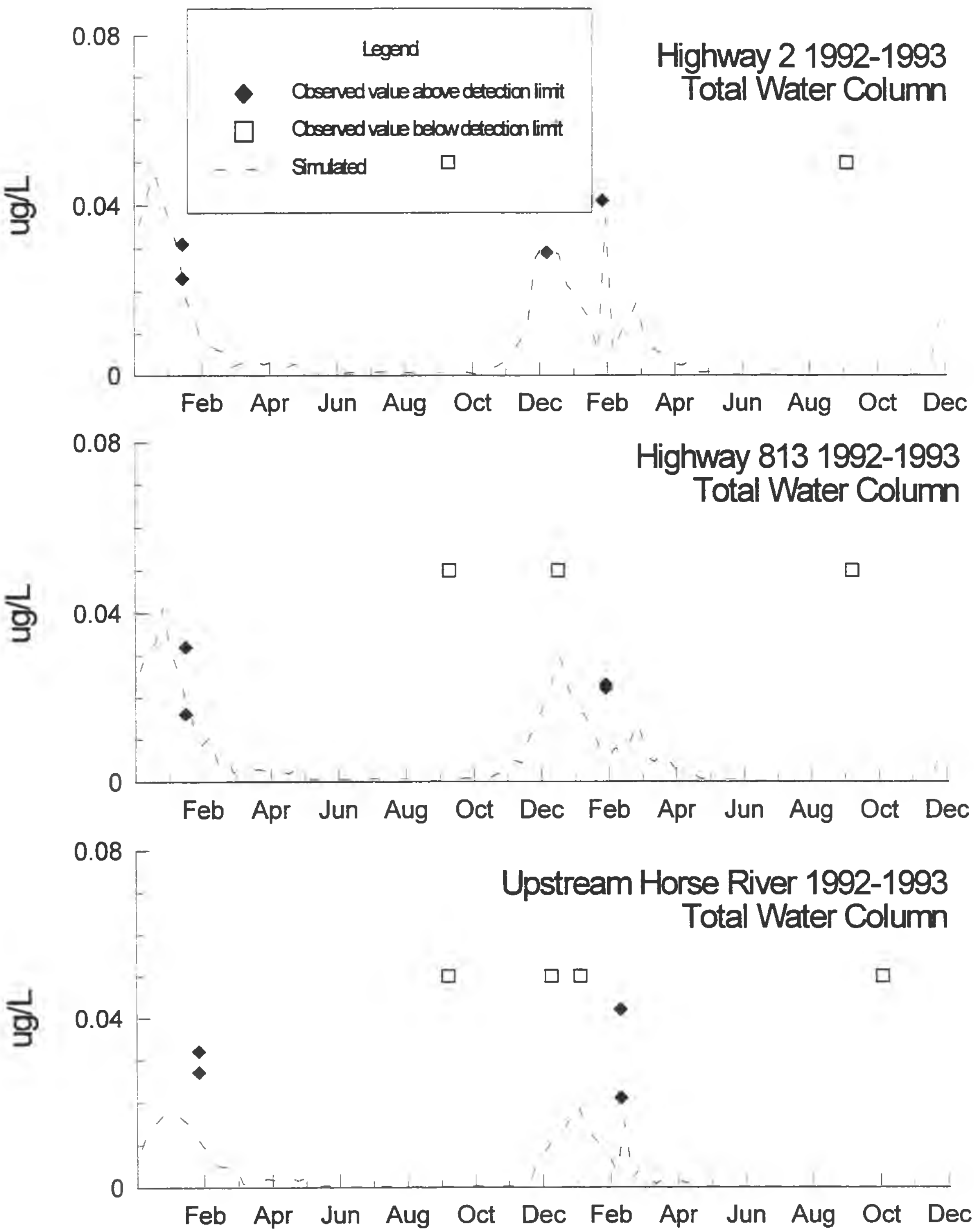


Figure 4.30b.
Athabasca River, 3,4,5-TCV Calibration, Time Series

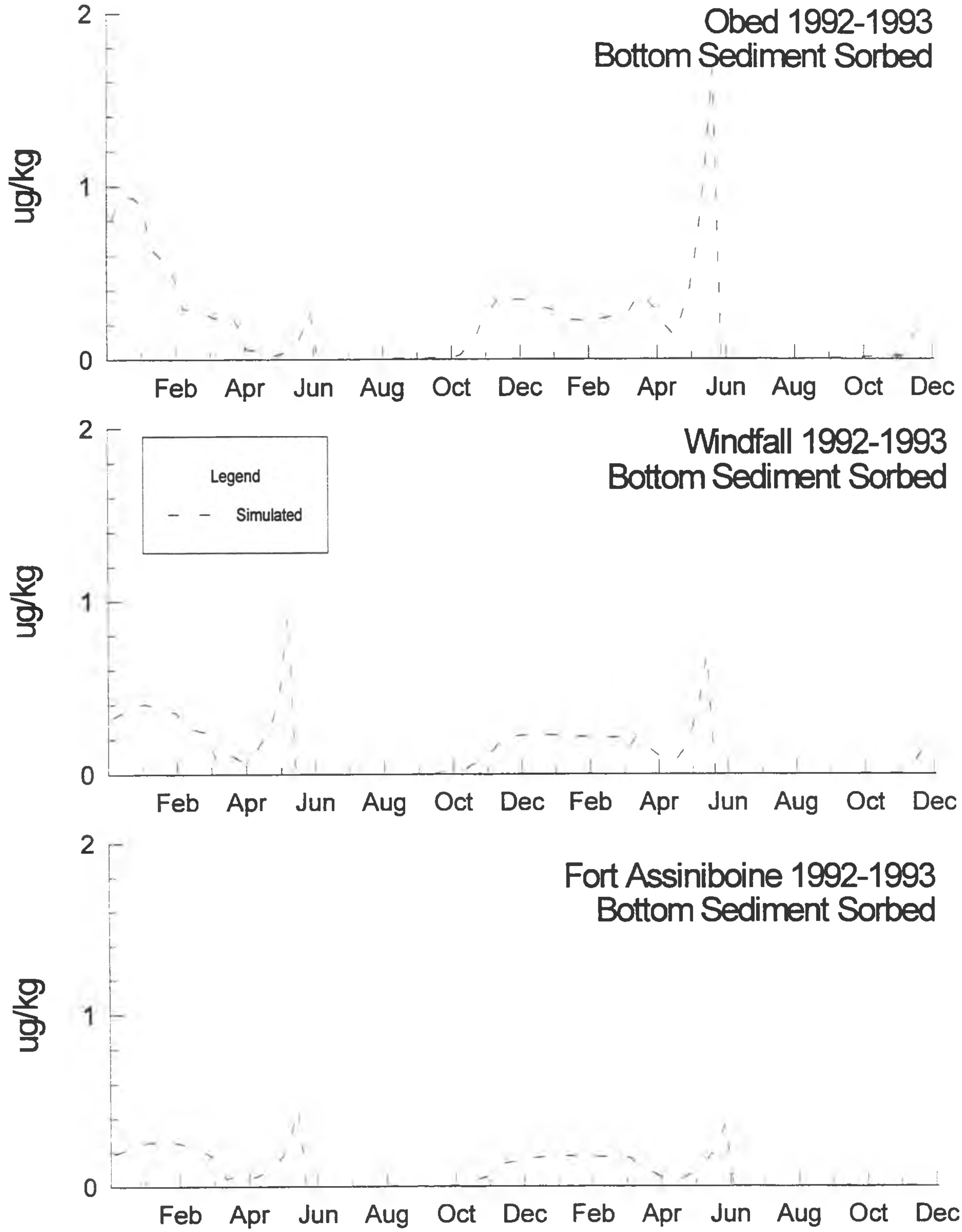


Figure 4.30c.
Athabasca River, 3,4,5-TCV Calibration, Time Series

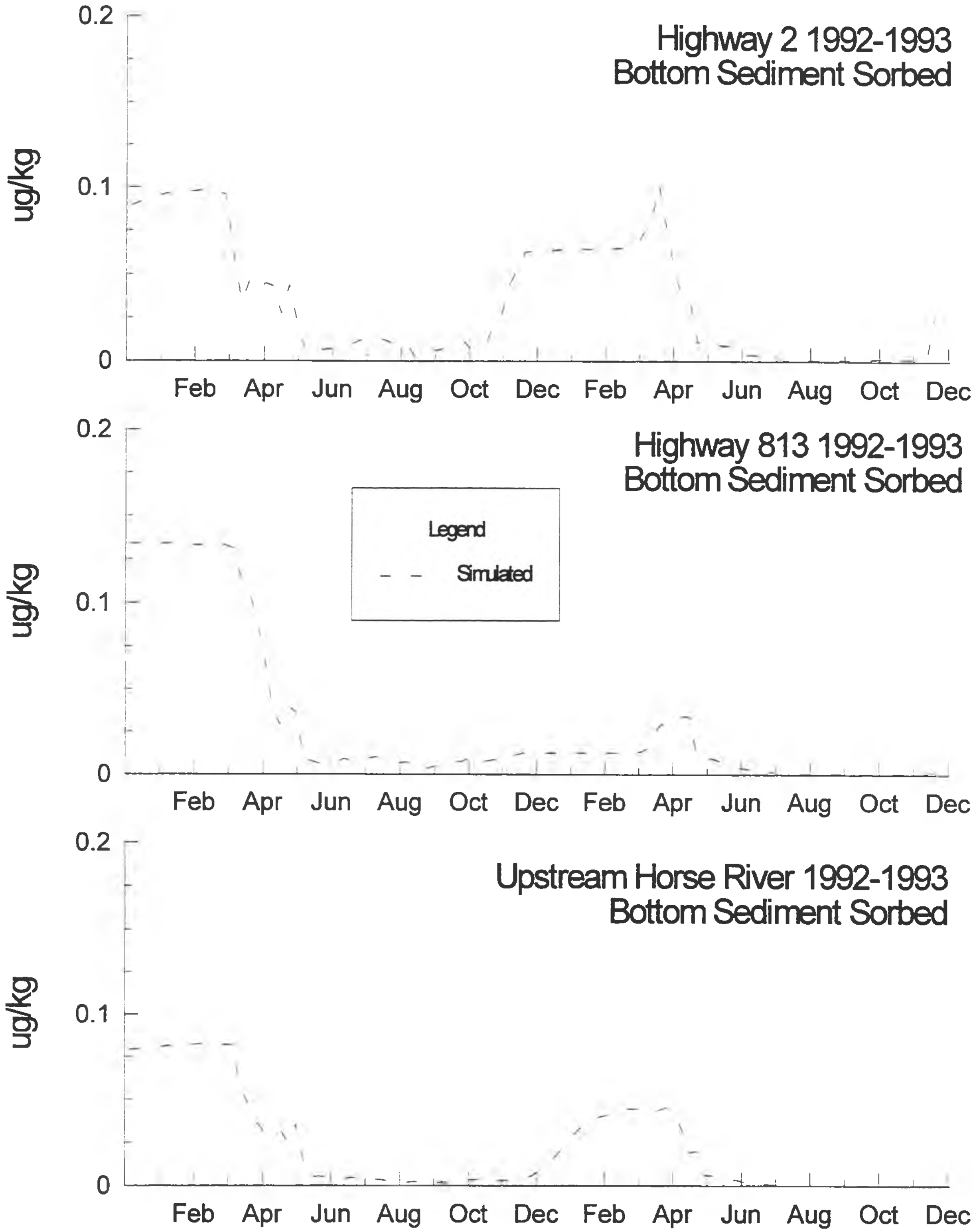


Figure 4.30d.
Athabasca River, 3,4,5-TCV Calibration, Time Series

APPENDIX C: SECOND SIMULATION RESULTS

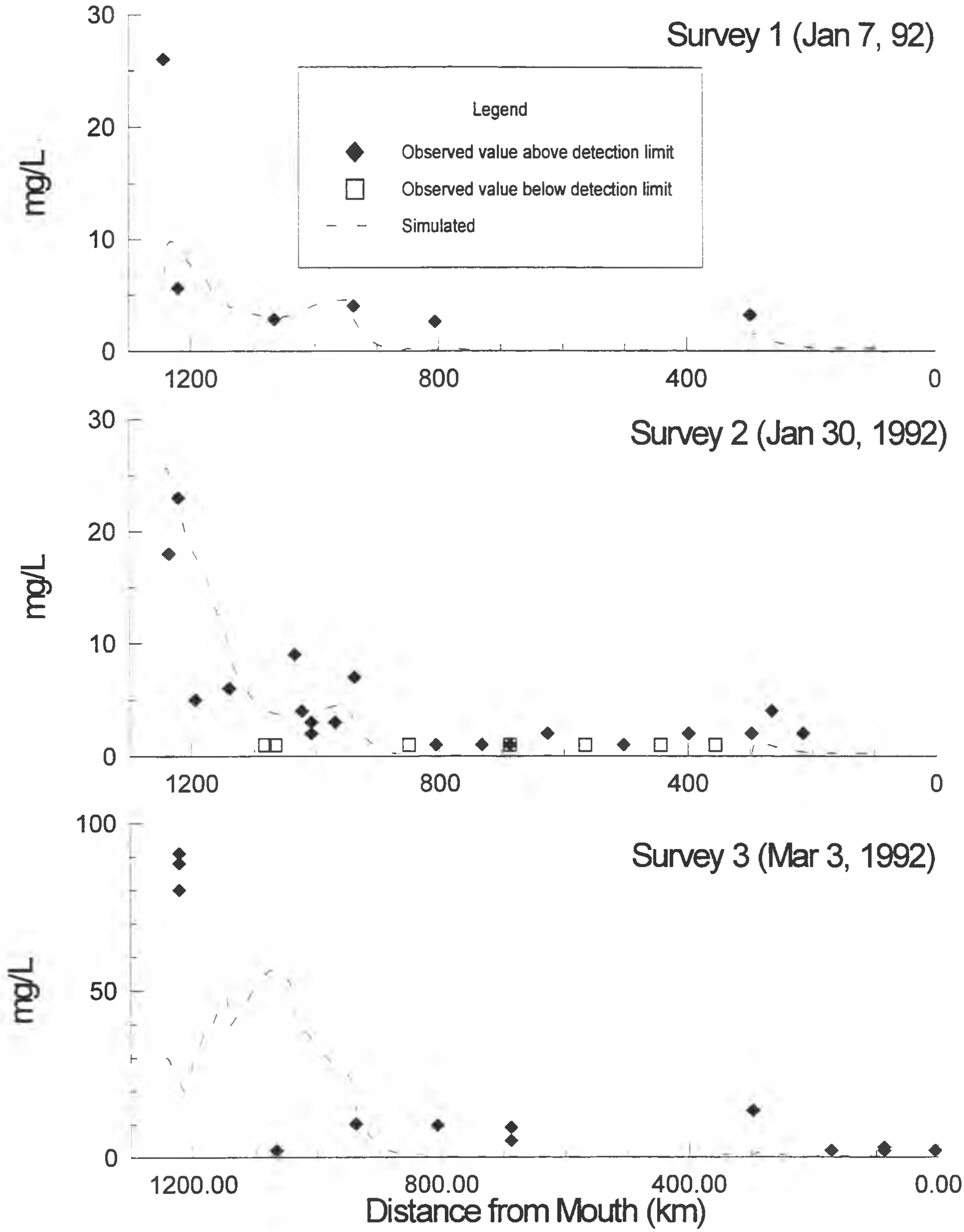


Figure 4.5.
Athabasca River, Total Suspended Solids, Synoptic Surveys

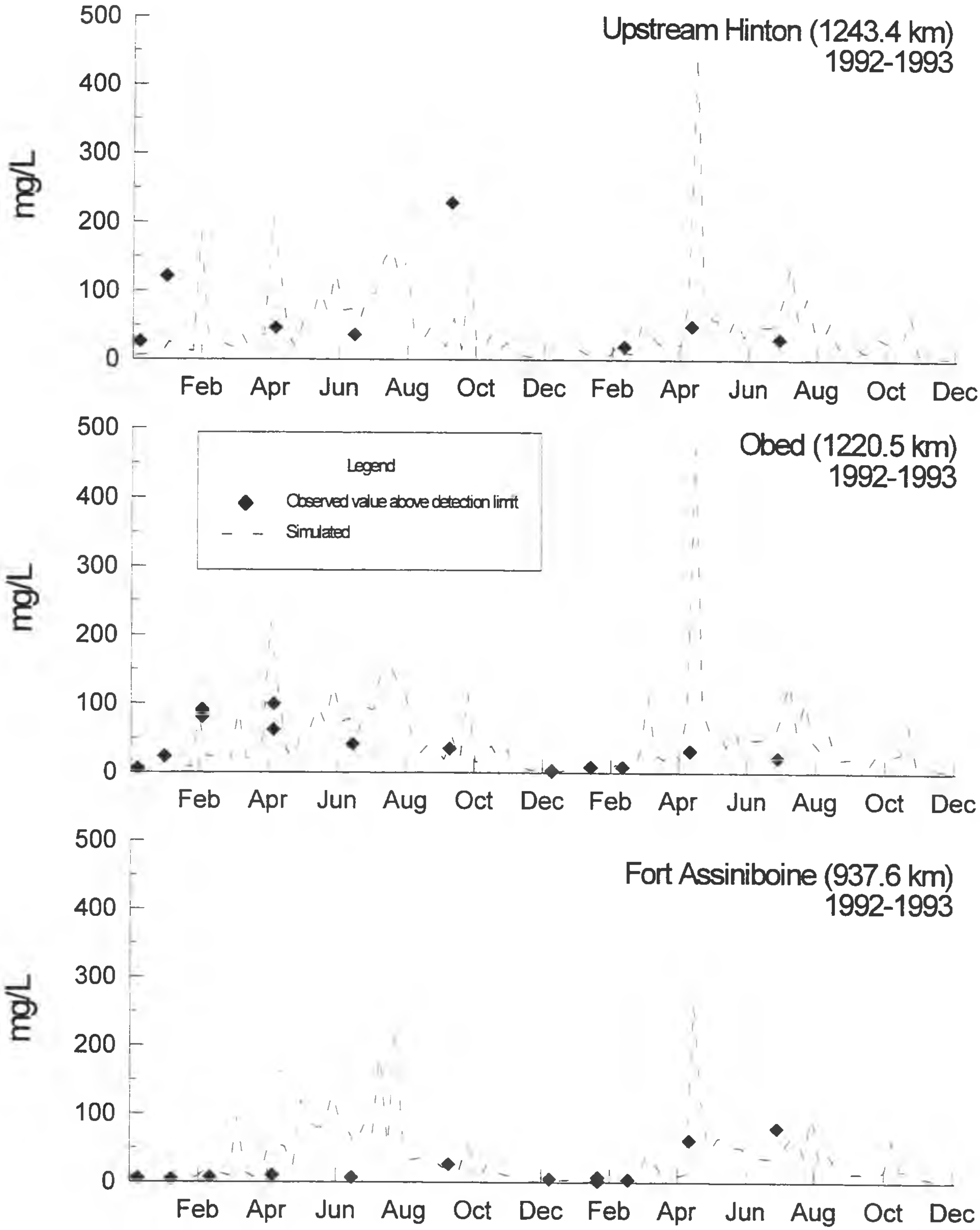


Figure 4.6a.
Athabasca River, Total Suspended Solids, Time Series

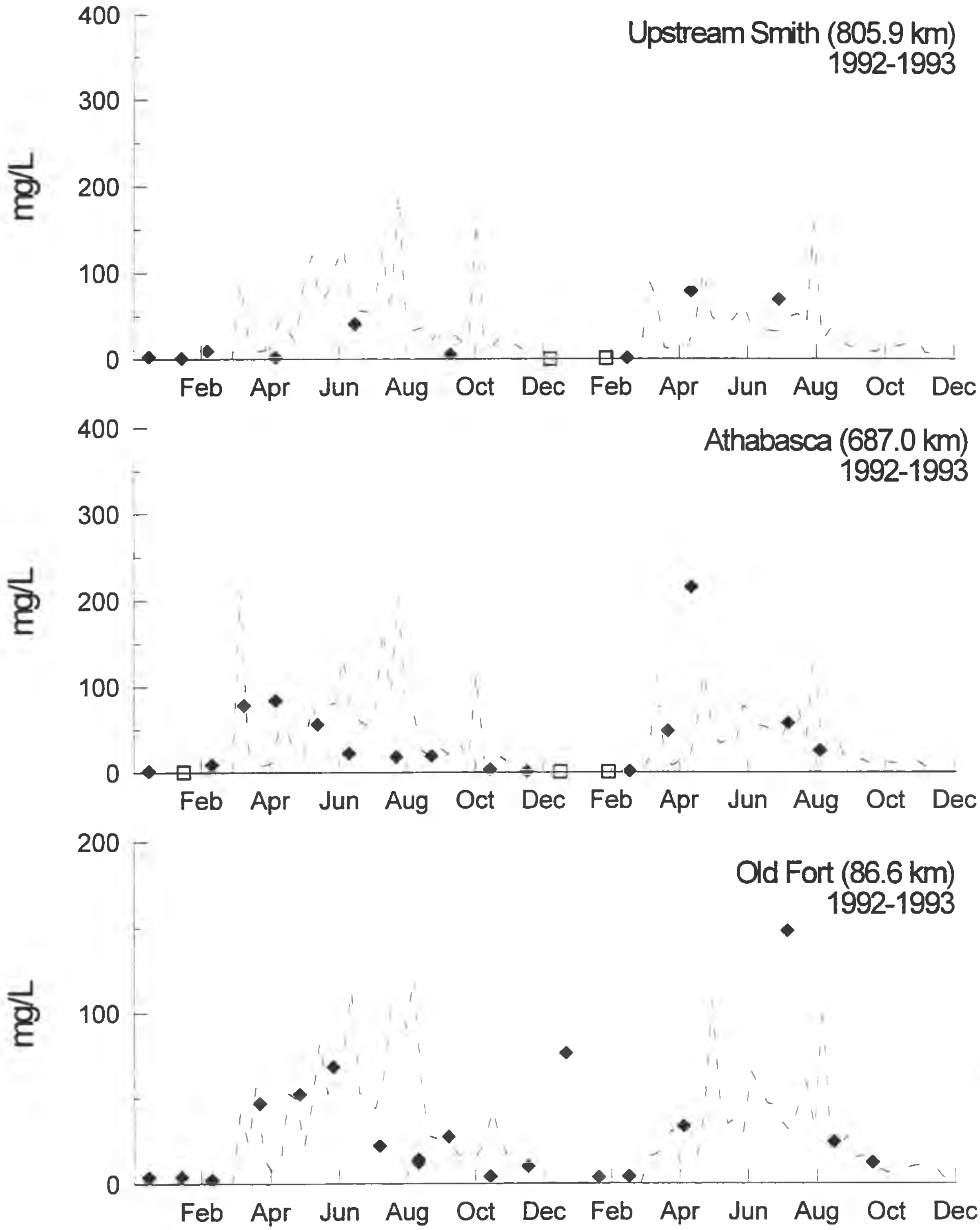


Figure 4.6b.
Athabasca River, Total Suspended Solids, Time Series

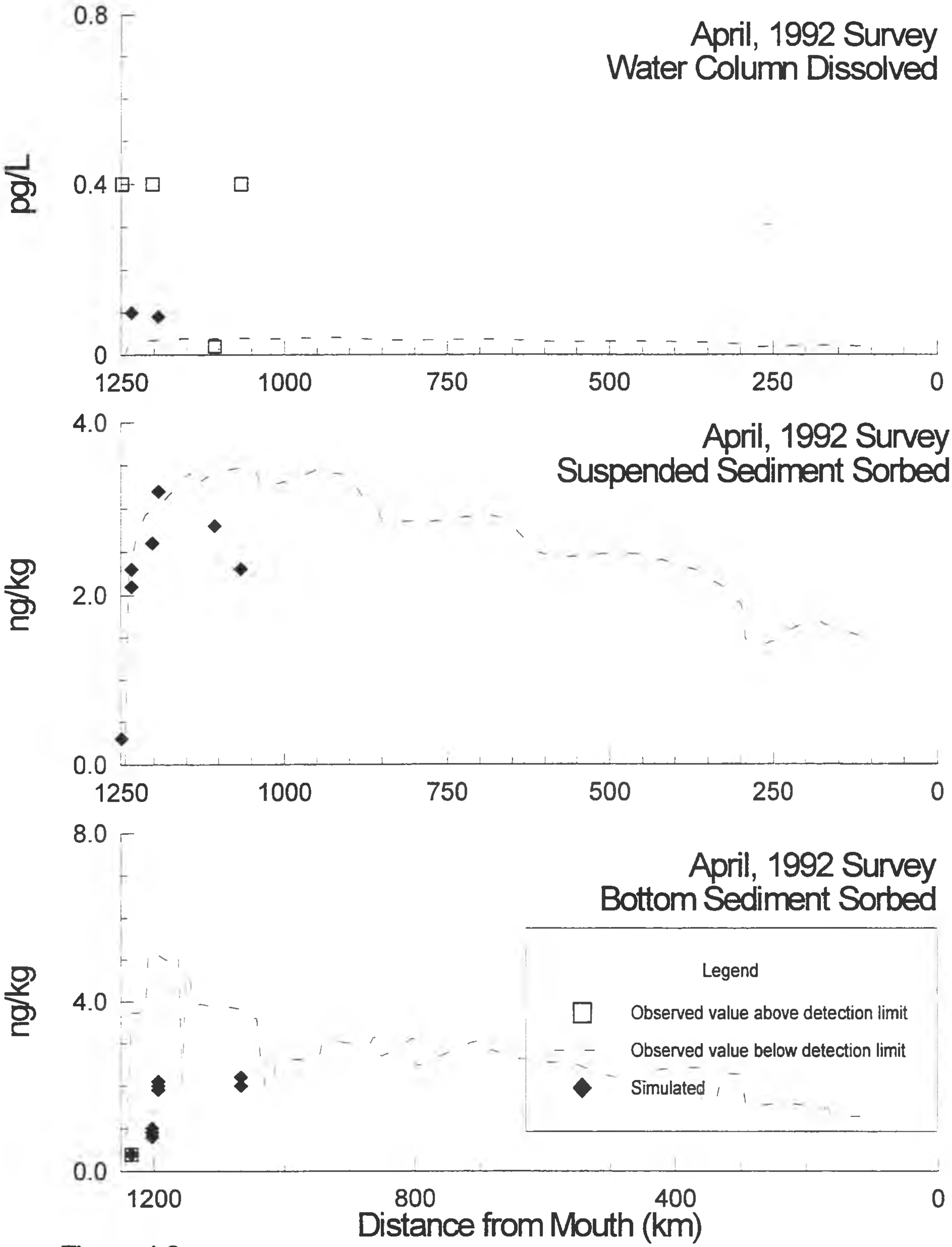


Figure 4.9a.
Athabasca River, 2,3,7,8-TCDF Calibration, Synoptic Surveys

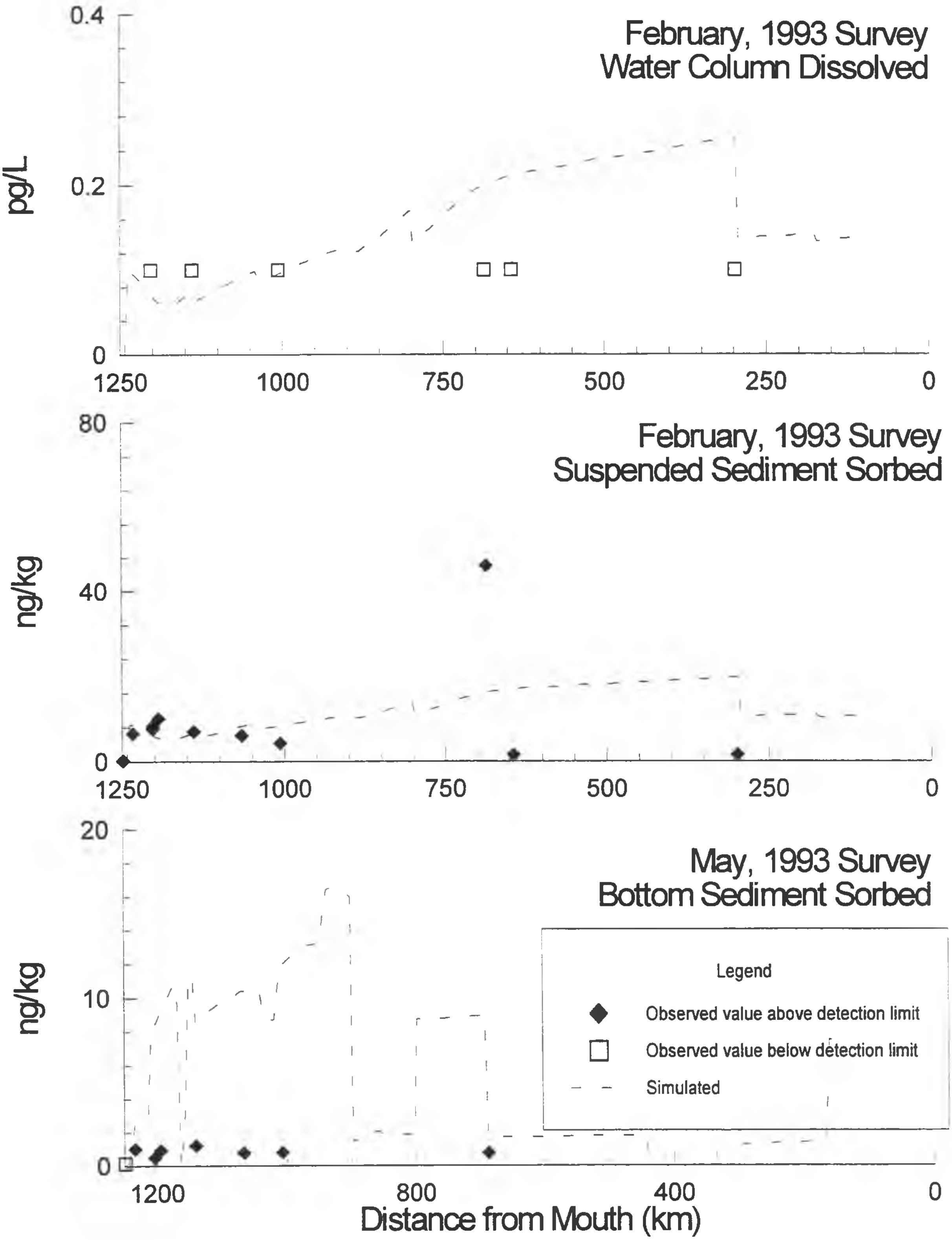


Figure 4.9b.
Athabasca River, 2,3,7,8 TCDF Calibration, Synoptic Surveys

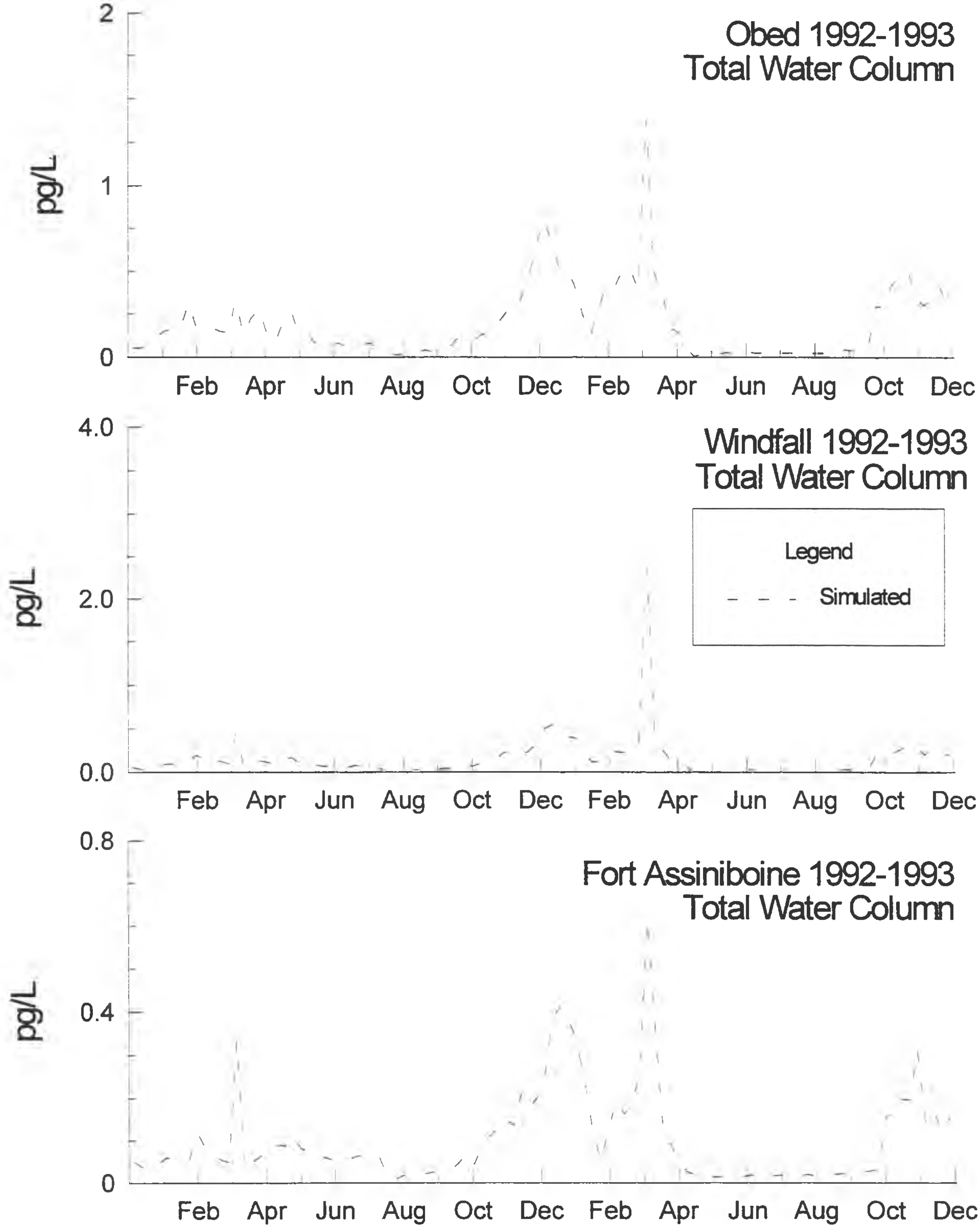


Figure 4.10a.
Athabasca River 2,3,7,8-TCDF Calibration, Time Series

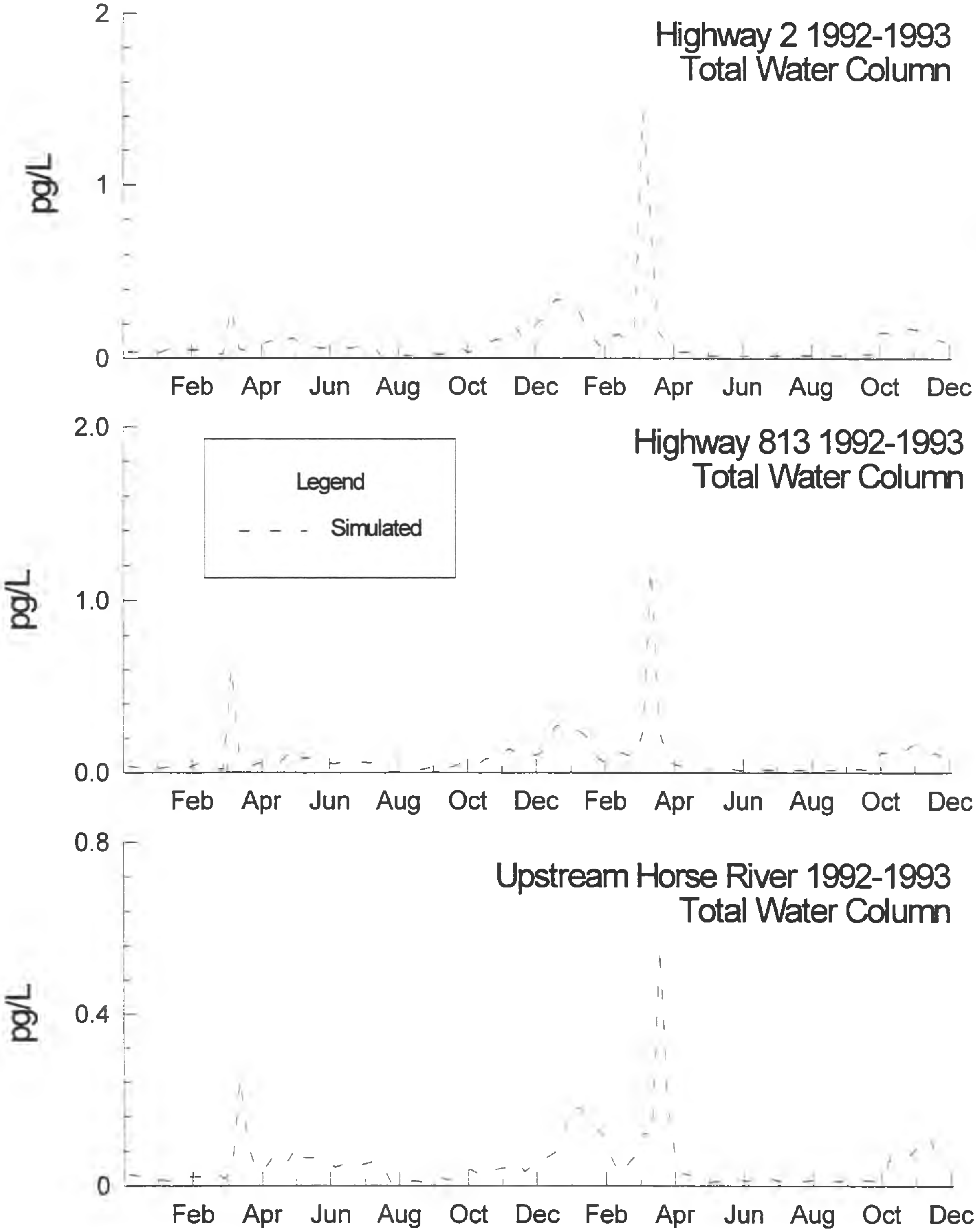


Figure 4.10b.
Athabasca River 2,3,7,8-TCDF Calibration, Time Series

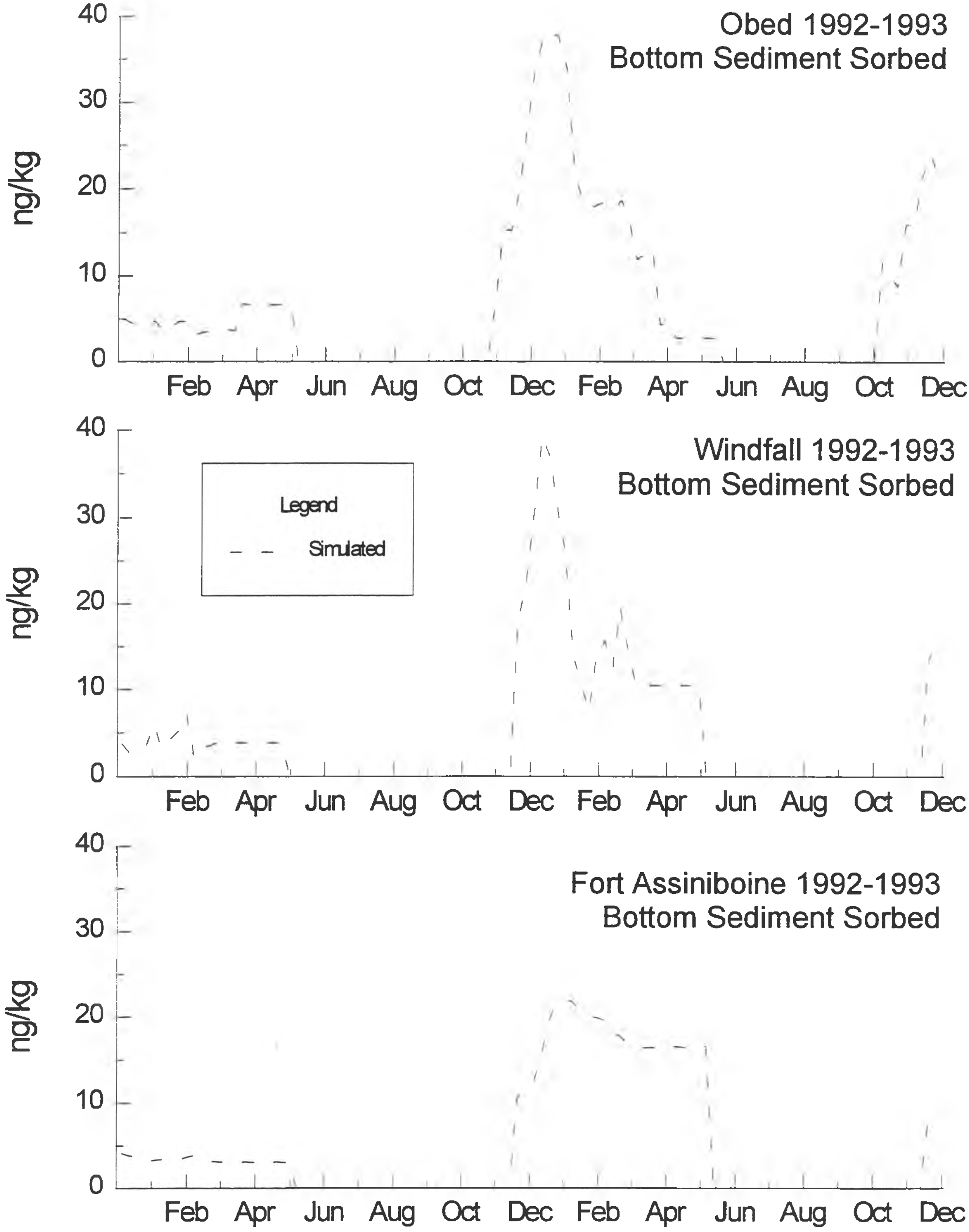


Figure 4.10c.
Athabasca River, 2,3,7,8-TCDF Calibration, Time Series

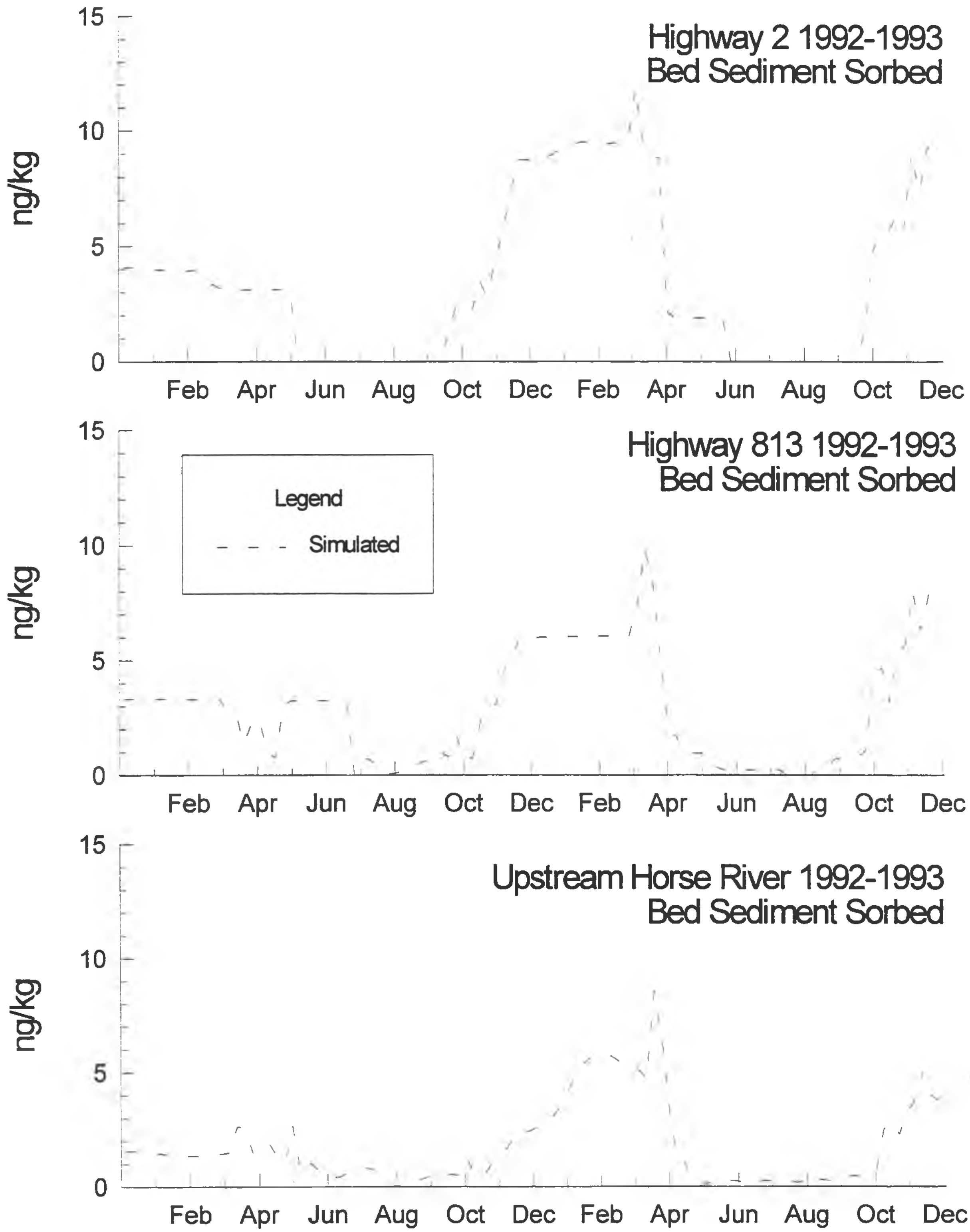


Figure 4.10d.
Athabasca River 2,3,7,8-TCDF Calibration, Time Series

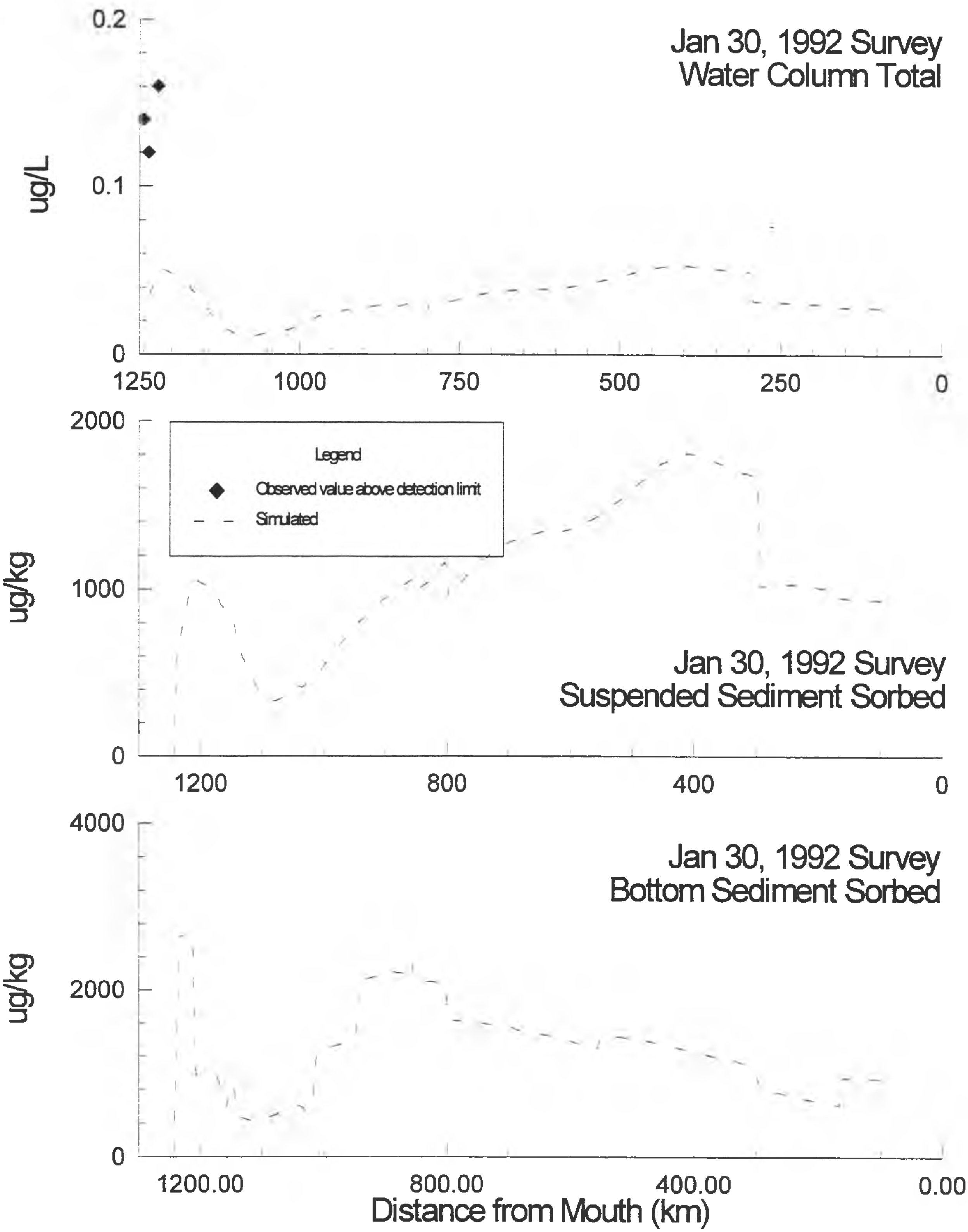


Figure 4.13a.
Athabasca River, DHA Calibration, Synoptic Surveys

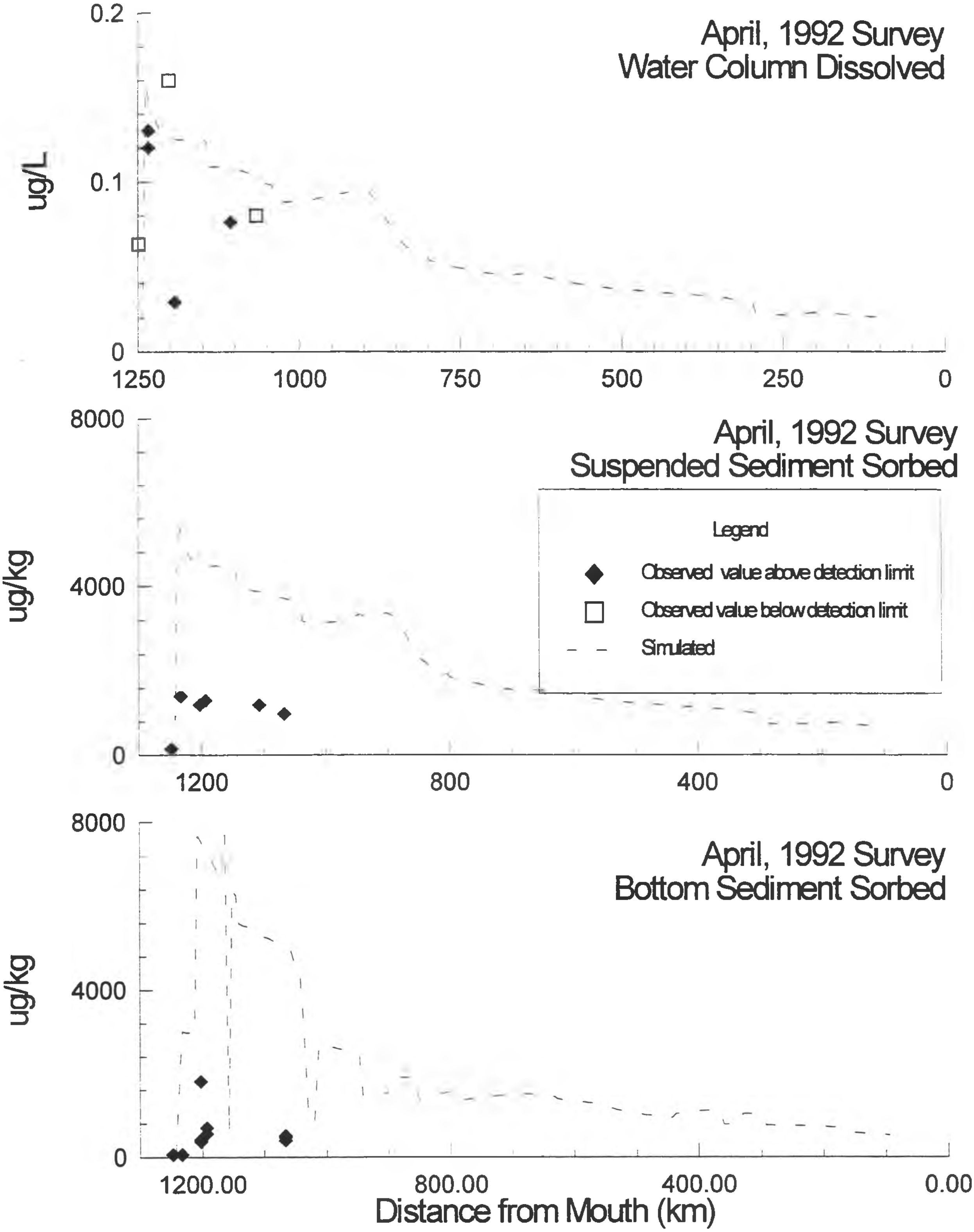


Figure 4.13b.
Athabasca River, DHA Calibration, Synoptic Surveys

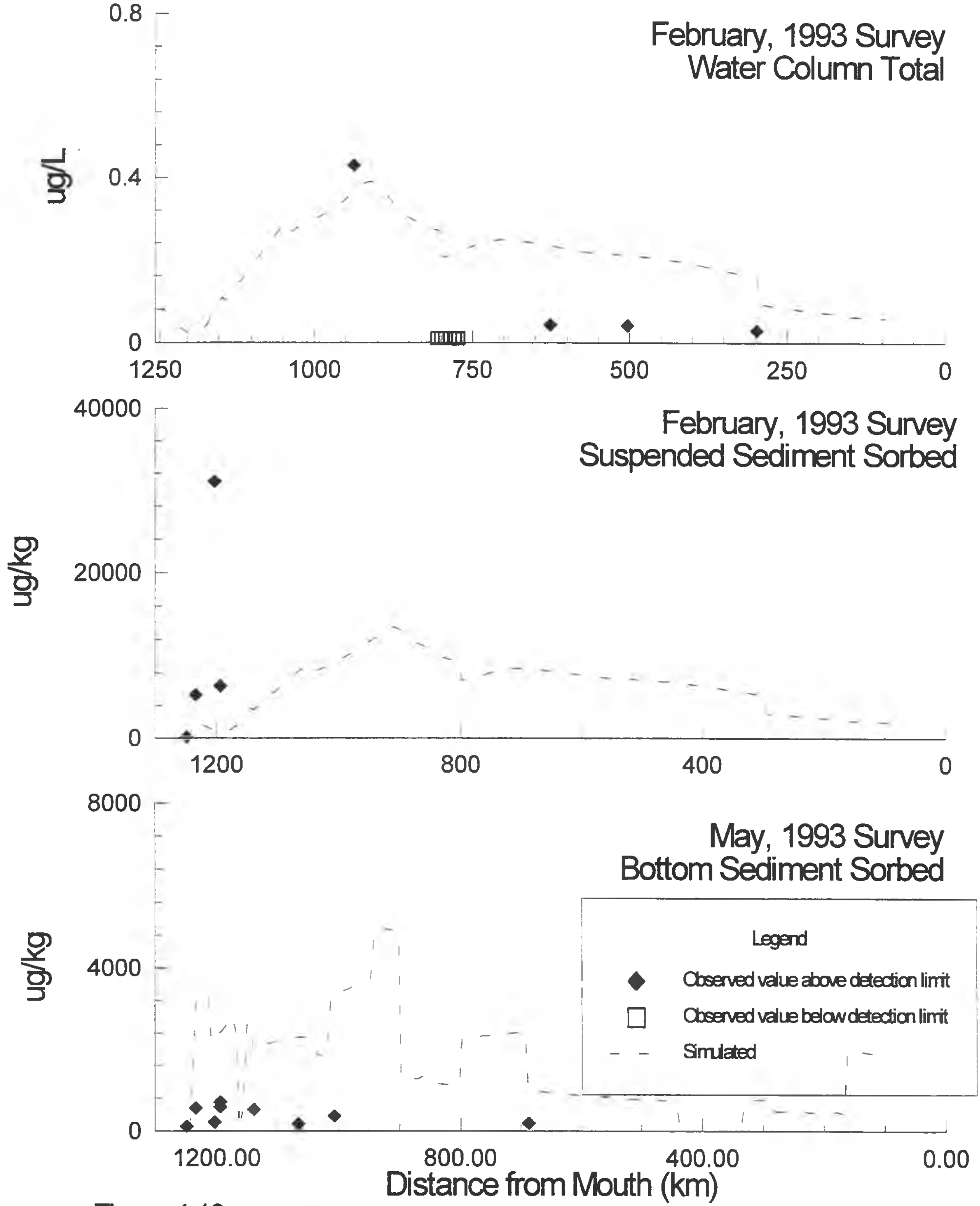


Figure 4.13c.
Athabasca River, DHA Calibration, Synoptic Surveys

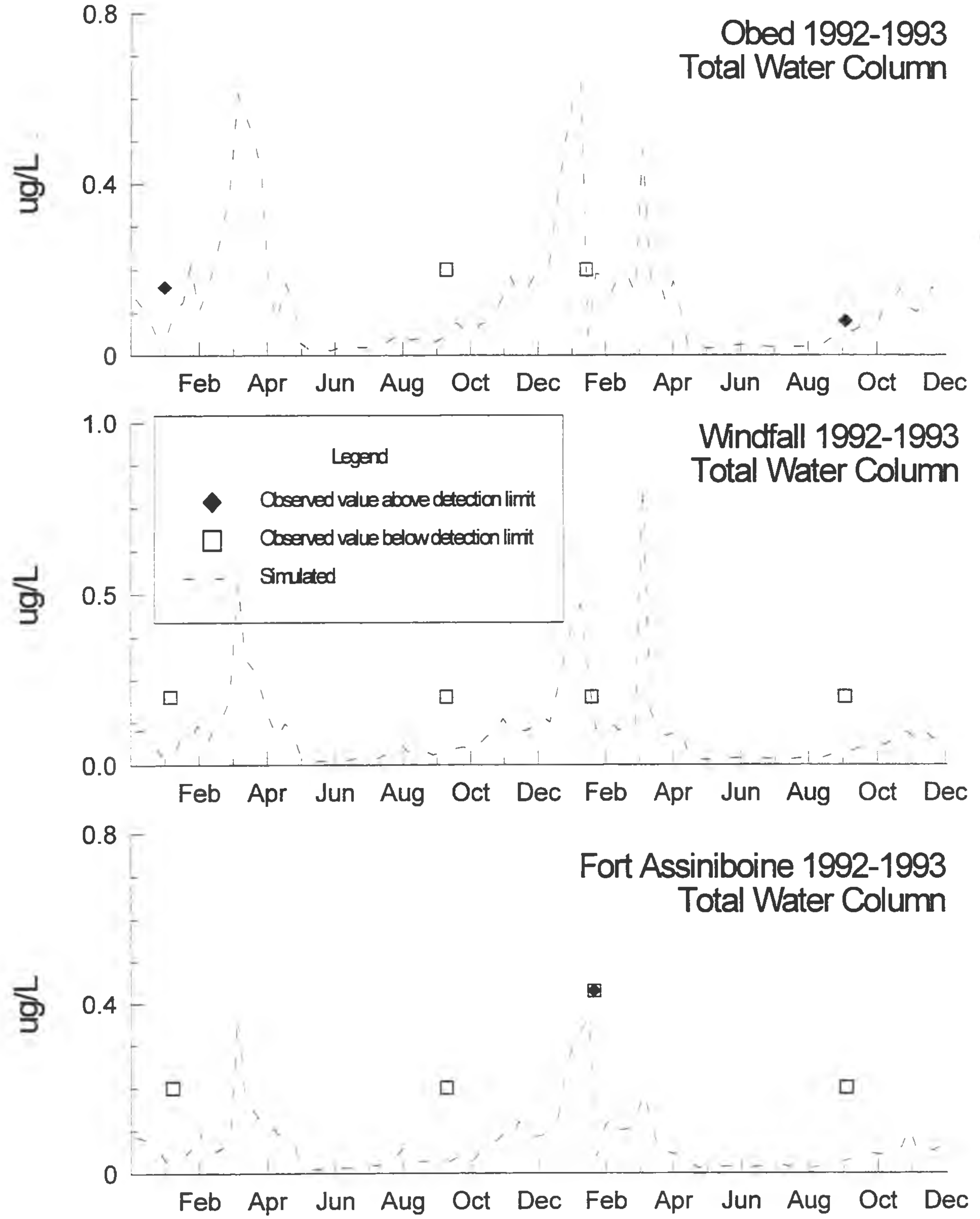


Figure 4.14a.
Athabasca River, DHA Calibration, Time Series

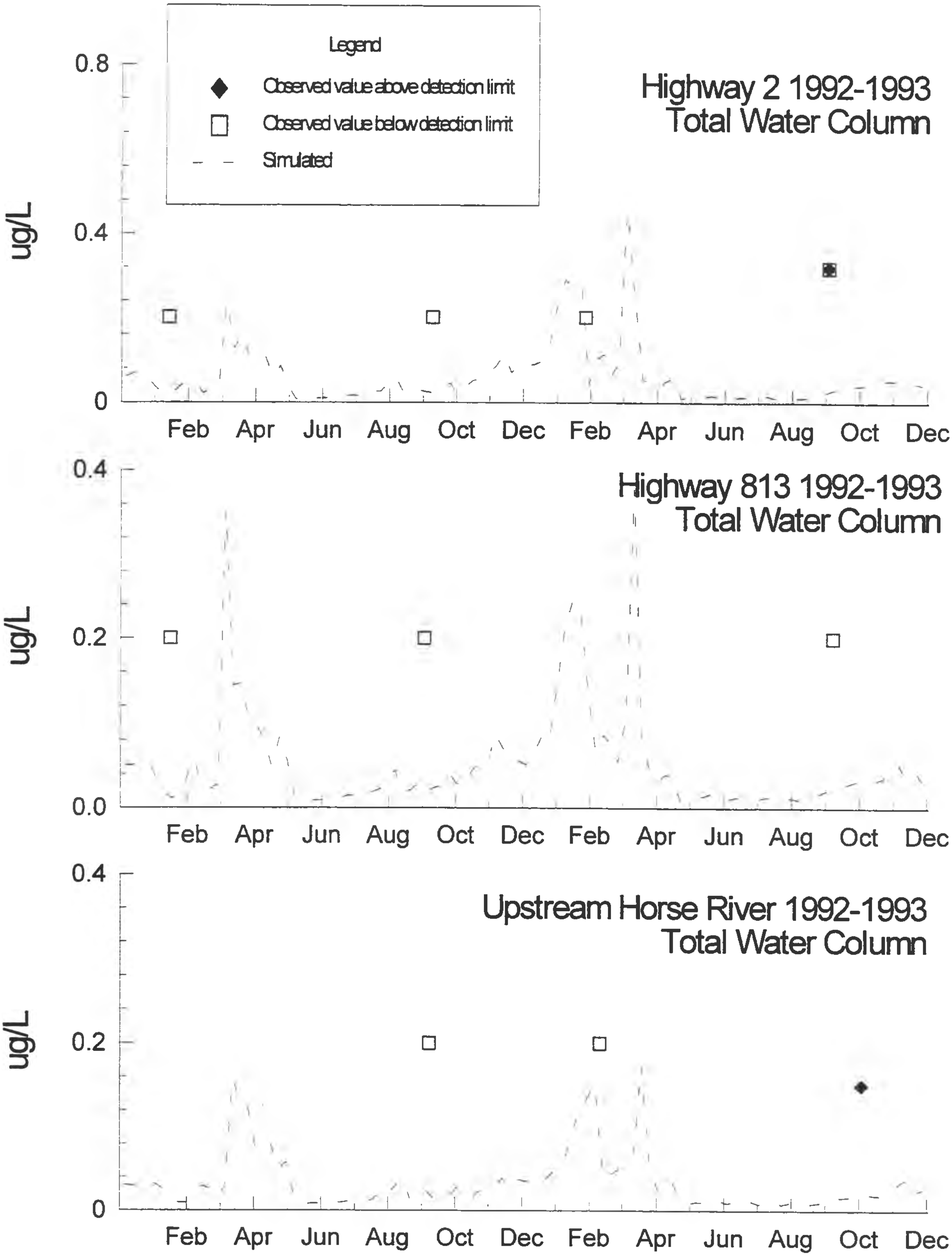


Figure 4.14b.
Athabasca River, DHA Calibration, Time Series

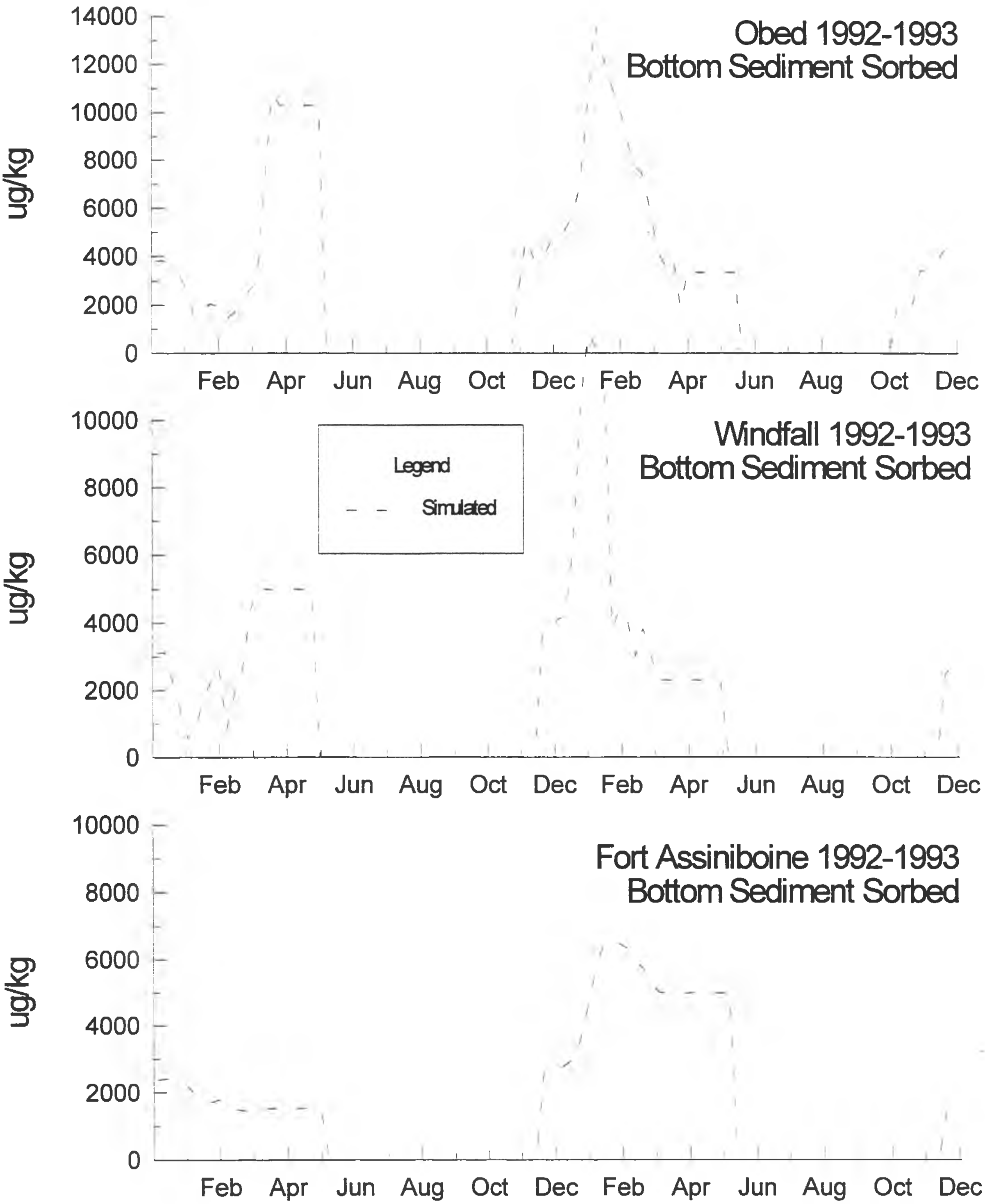


Figure 4.14c.
Athabasca River, DHA Calibration, Time Series

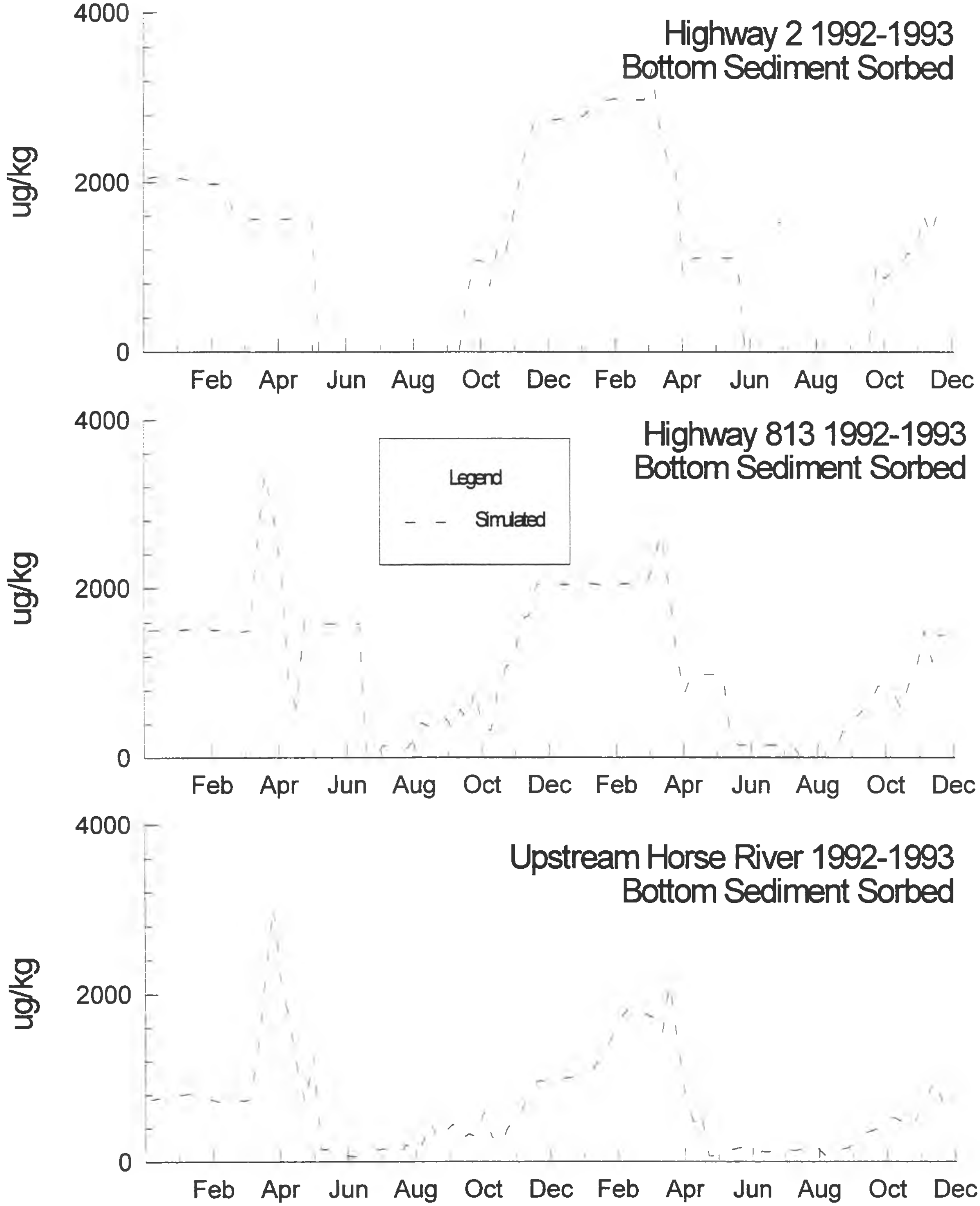


Figure 4.14d.
Athabasca River, DHA Calibration, Time Series

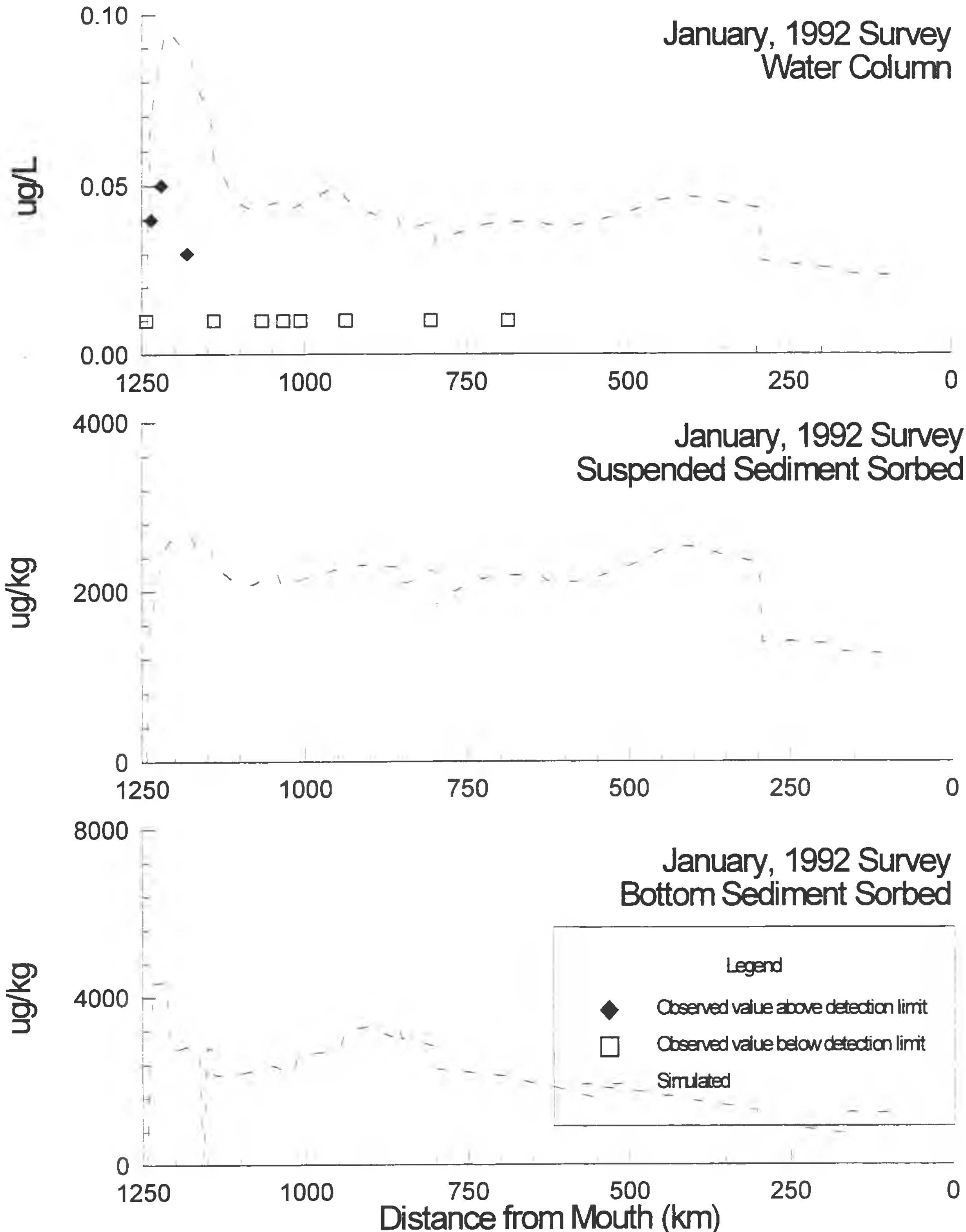


Figure 4.17a.
Athabasca River, 12,14-dichloro-DHA Calibration,
Synoptic Surveys

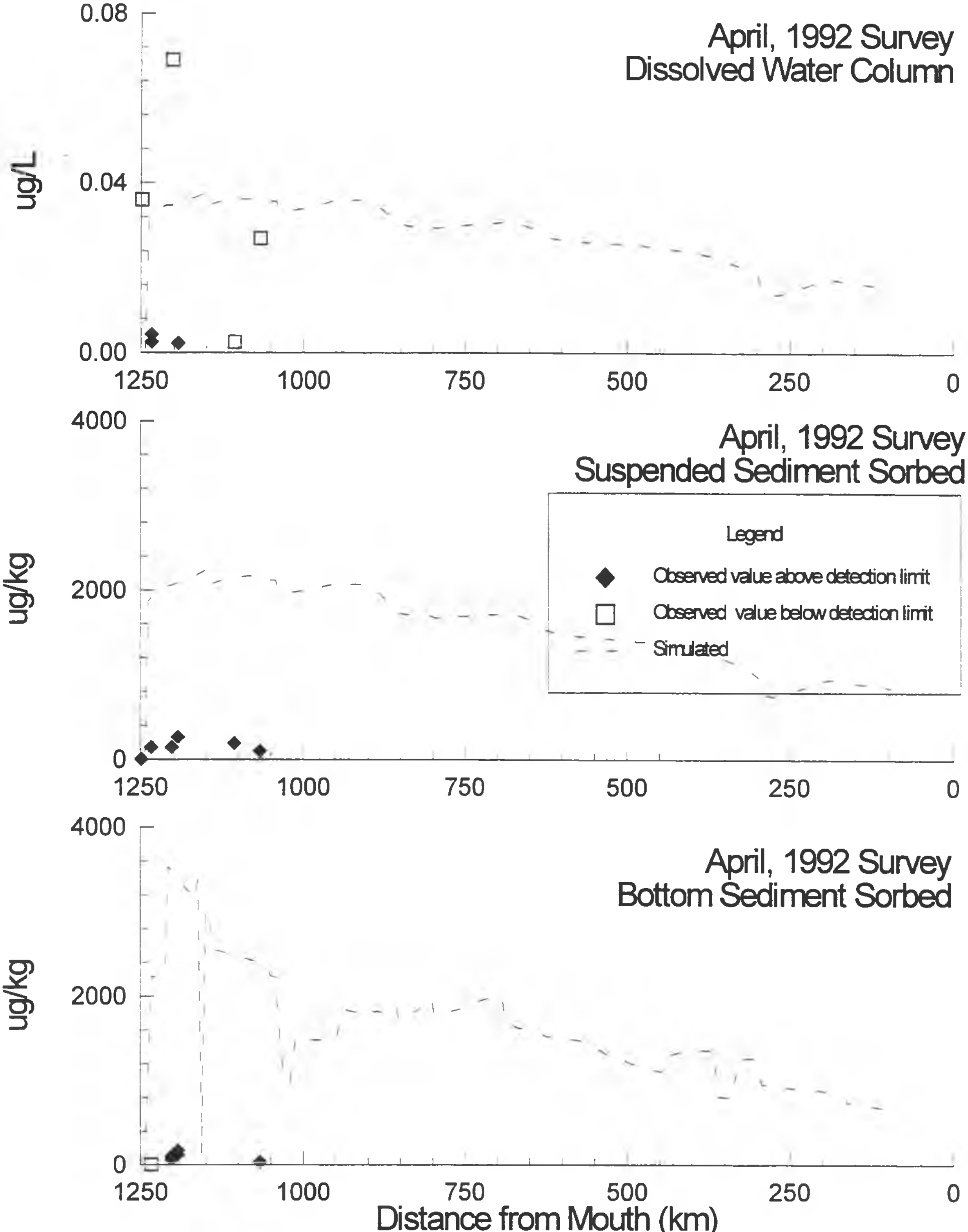


Figure 4.17b.
Athabasca River, 12,14-dichloro-DHA Calibration,
Synoptic Surveys

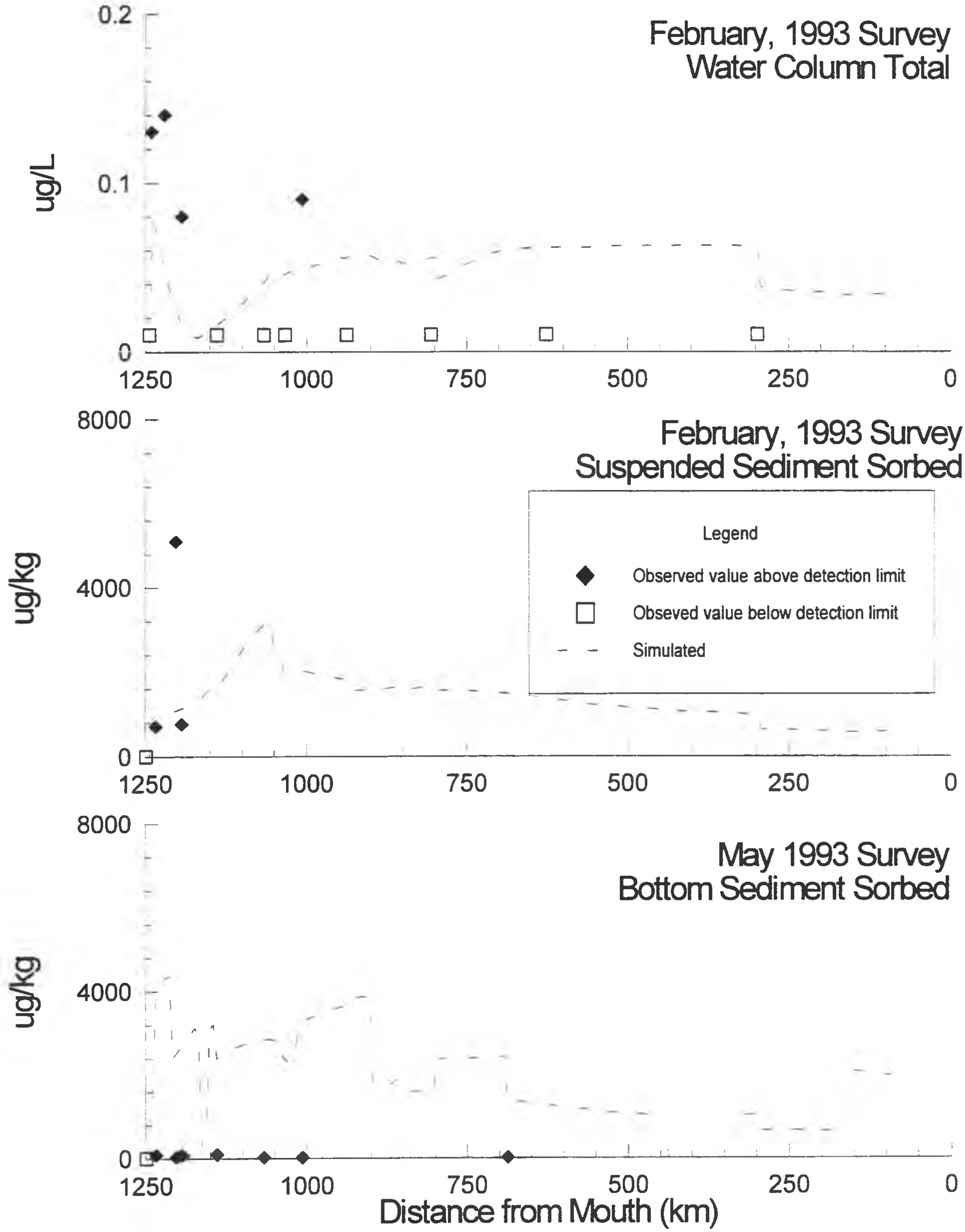


Figure 4.17c.
Athabasca River, 12,14-dichloro-DHA Calibration,
Synoptic Surveys

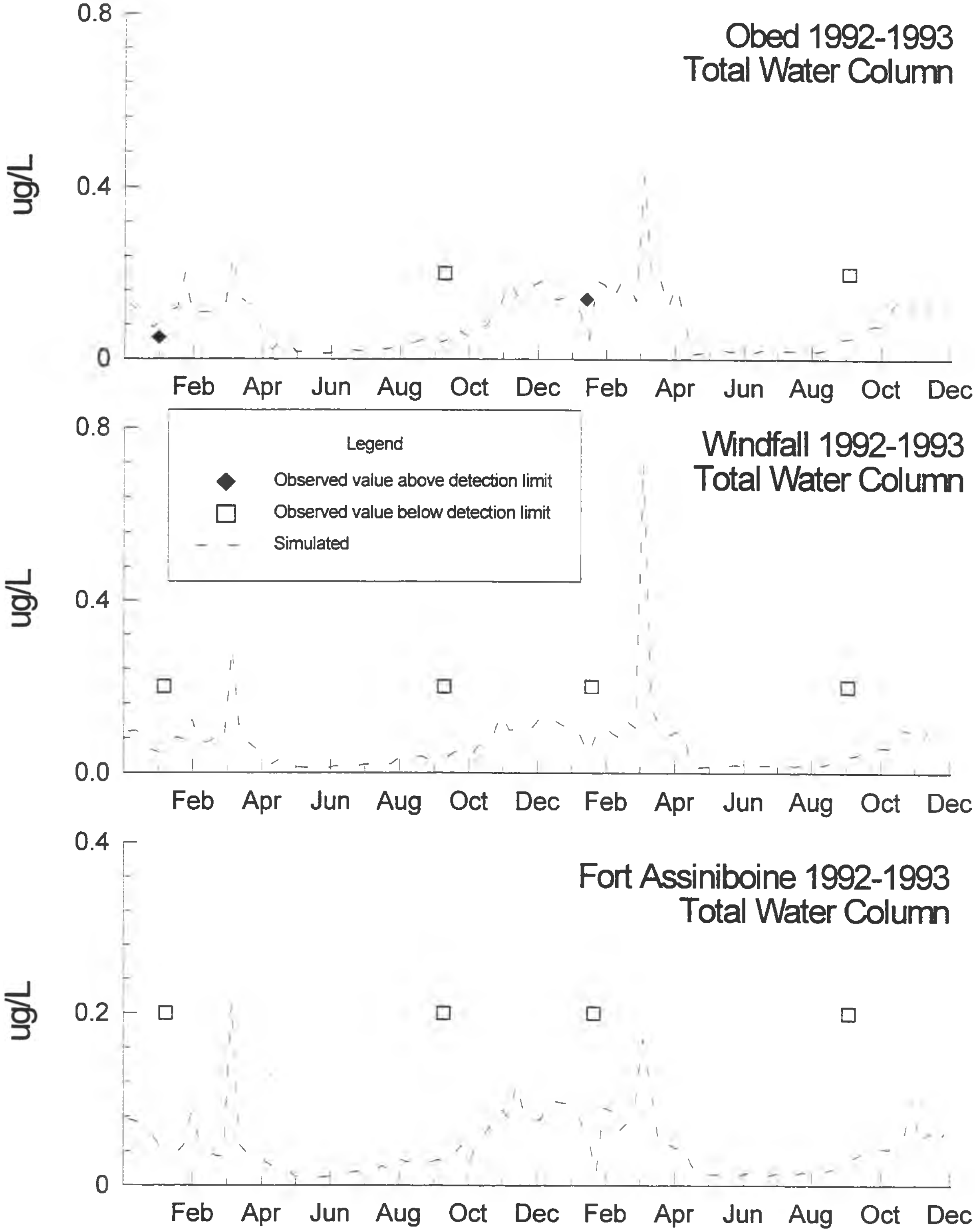


Figure 4.18a.
Athabasca River, 12,14-dichloro-DHA Calibration,
Time Series

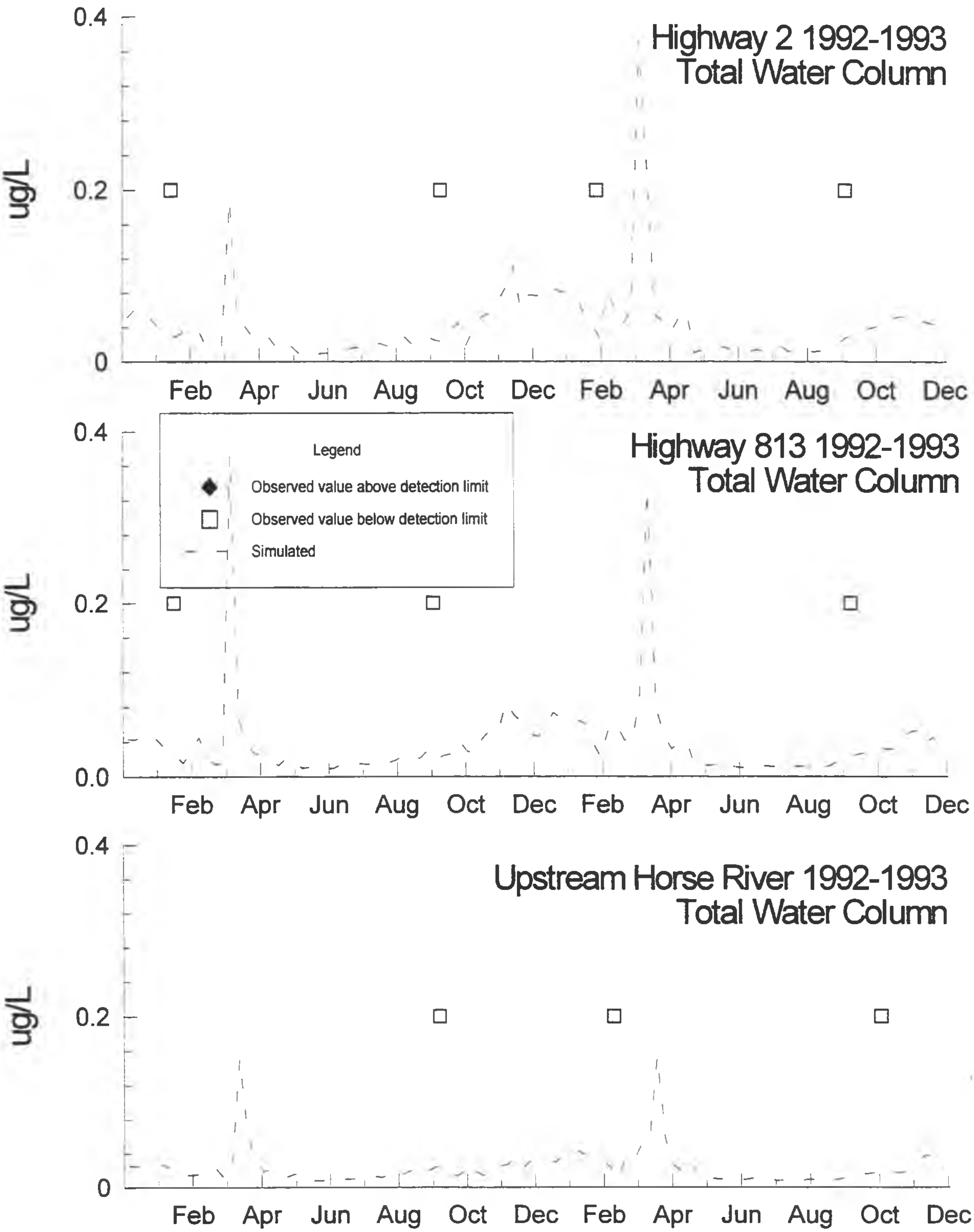


Figure 4.18b.
Athabasca River, 12,14-dichloro-DHA Calibration,
Time Series

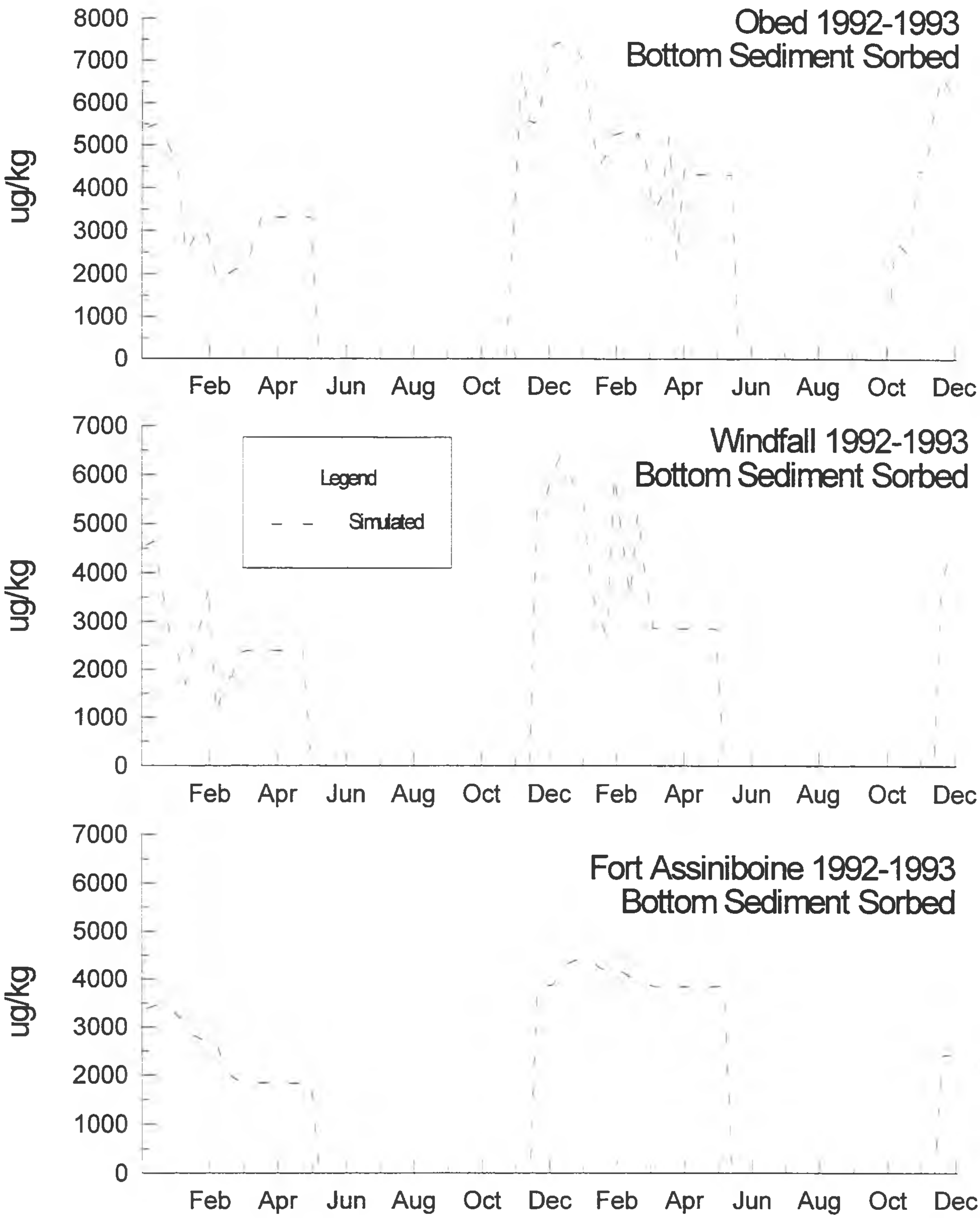


Figure 4.18c.
Athabasca River, 12,14-dichloro-DHA Calibration, Time Series

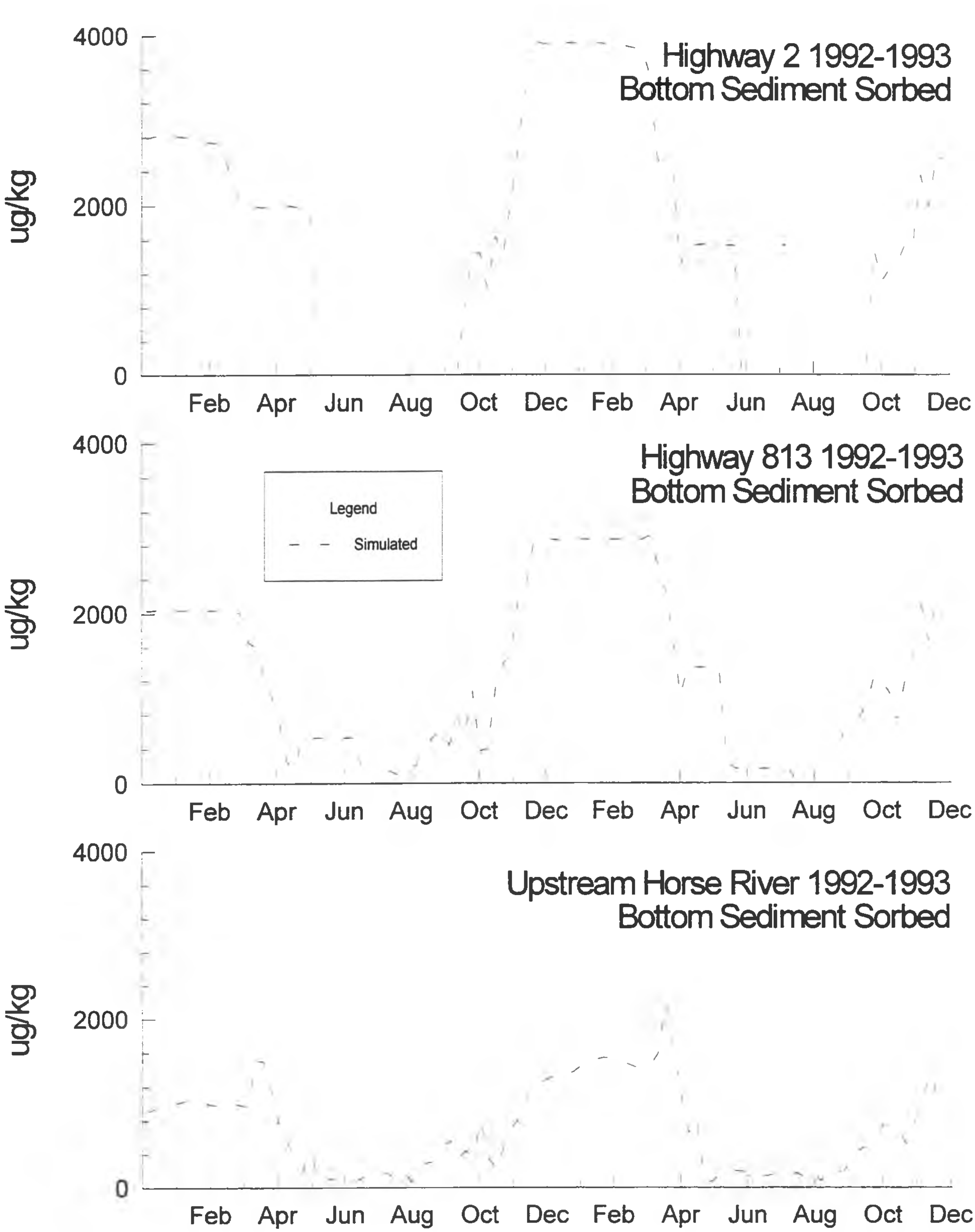


Figure 4.18d.
Athabasca River, 12,14-dichloro-DHA Calibration,
Time Series

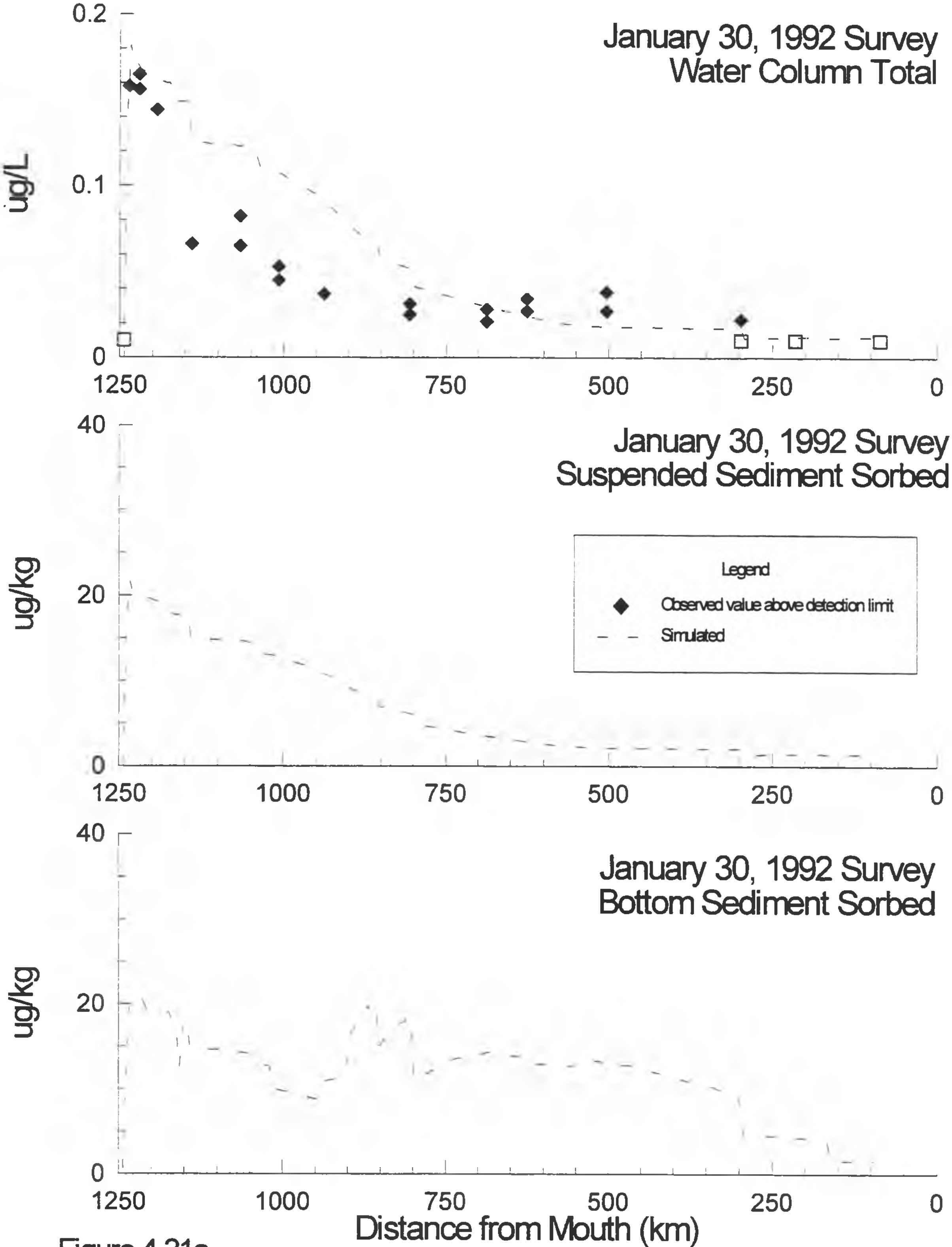


Figure 4.21a.
Athabasca River, 3,4,5-TCC Calibration, Synoptic Surveys

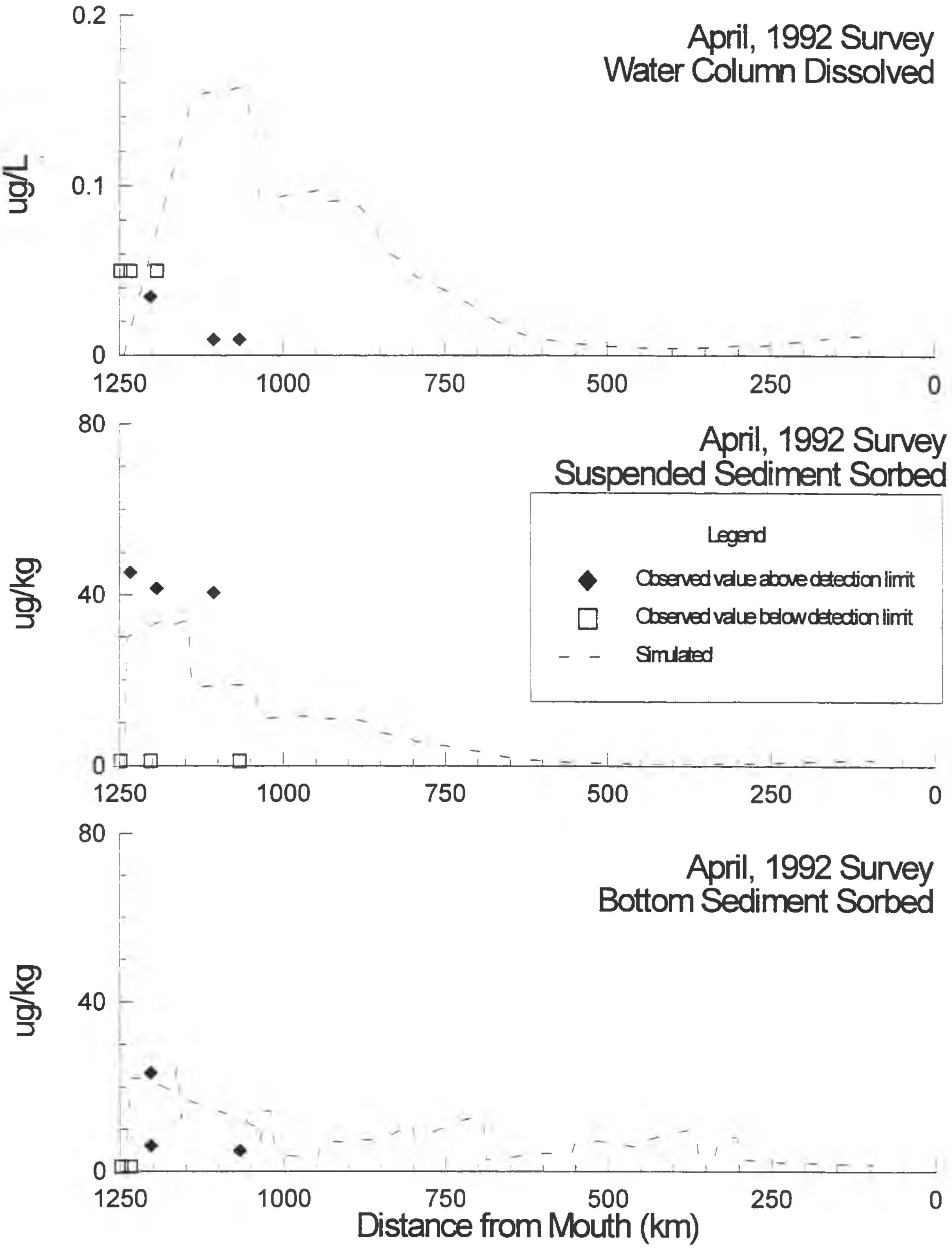


Figure 4.21b.
Athabasca River, 3,4,5-TCC Calibration, Synoptic Surveys

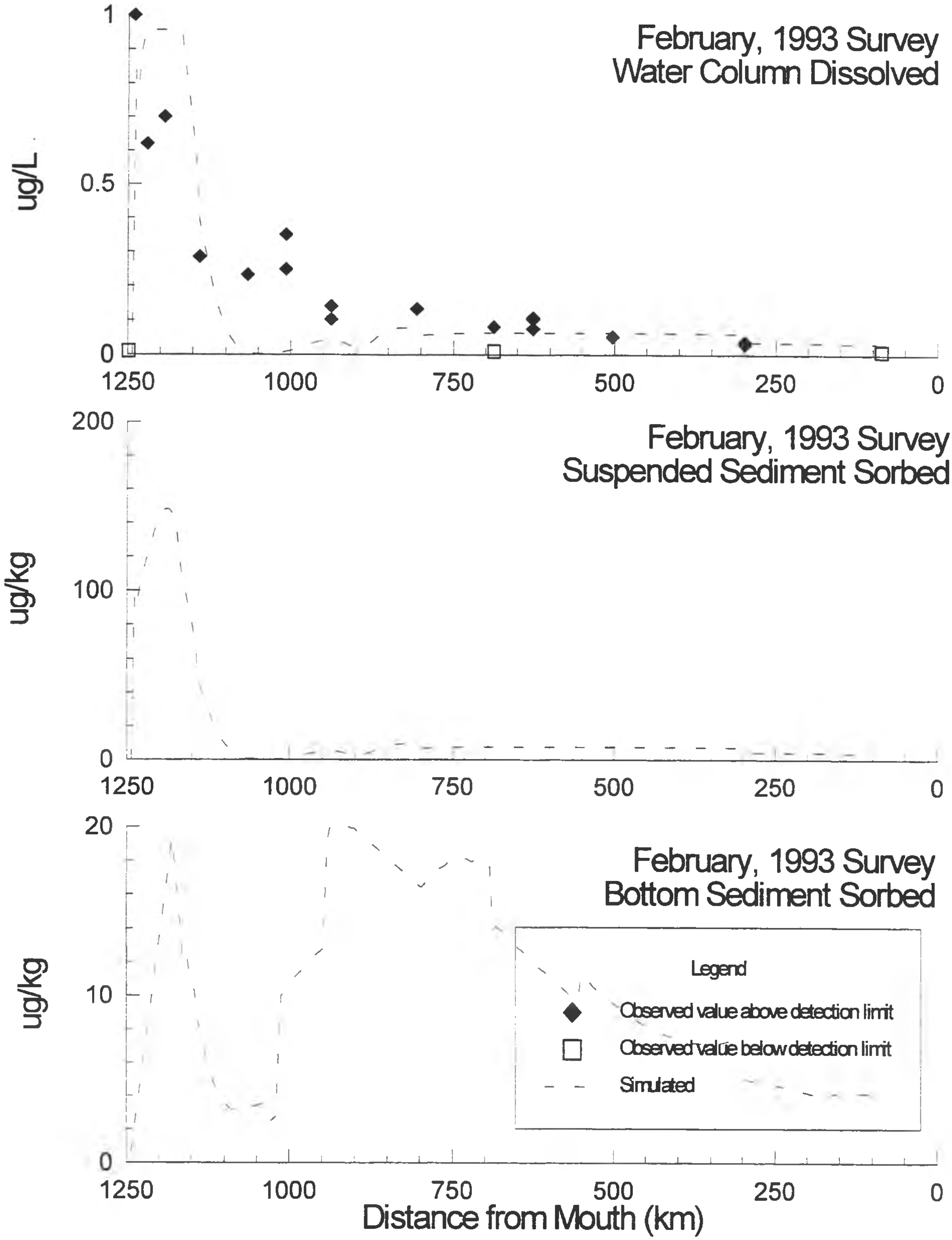


Figure 4.21c.
Athabasca River, 3,4,5-TCC (ug/L and ug/kg) Calibration, Synoptic Surveys

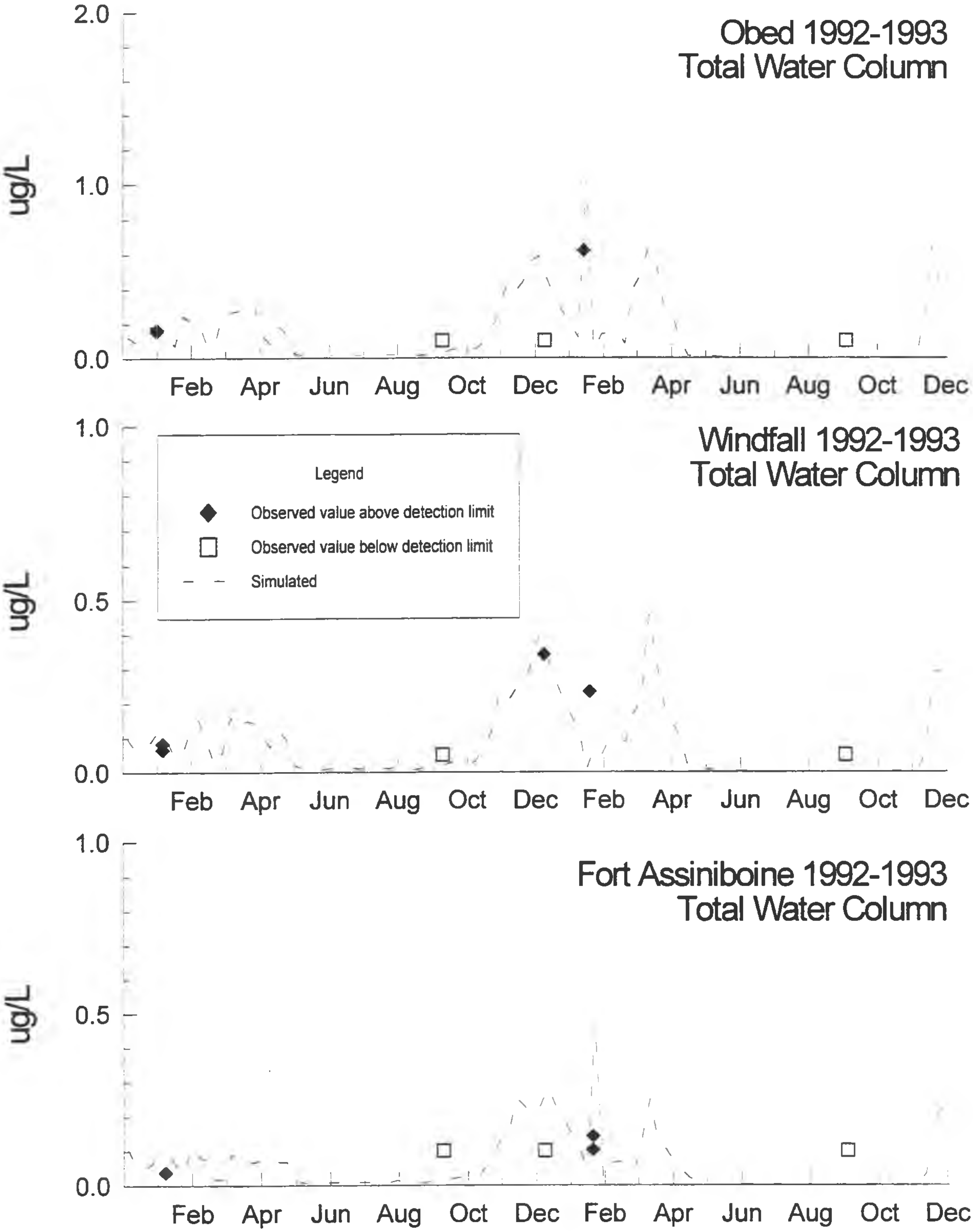


Figure 4.22a.
Athabasca River, 3,4,5-TCC Calibration, Time Series

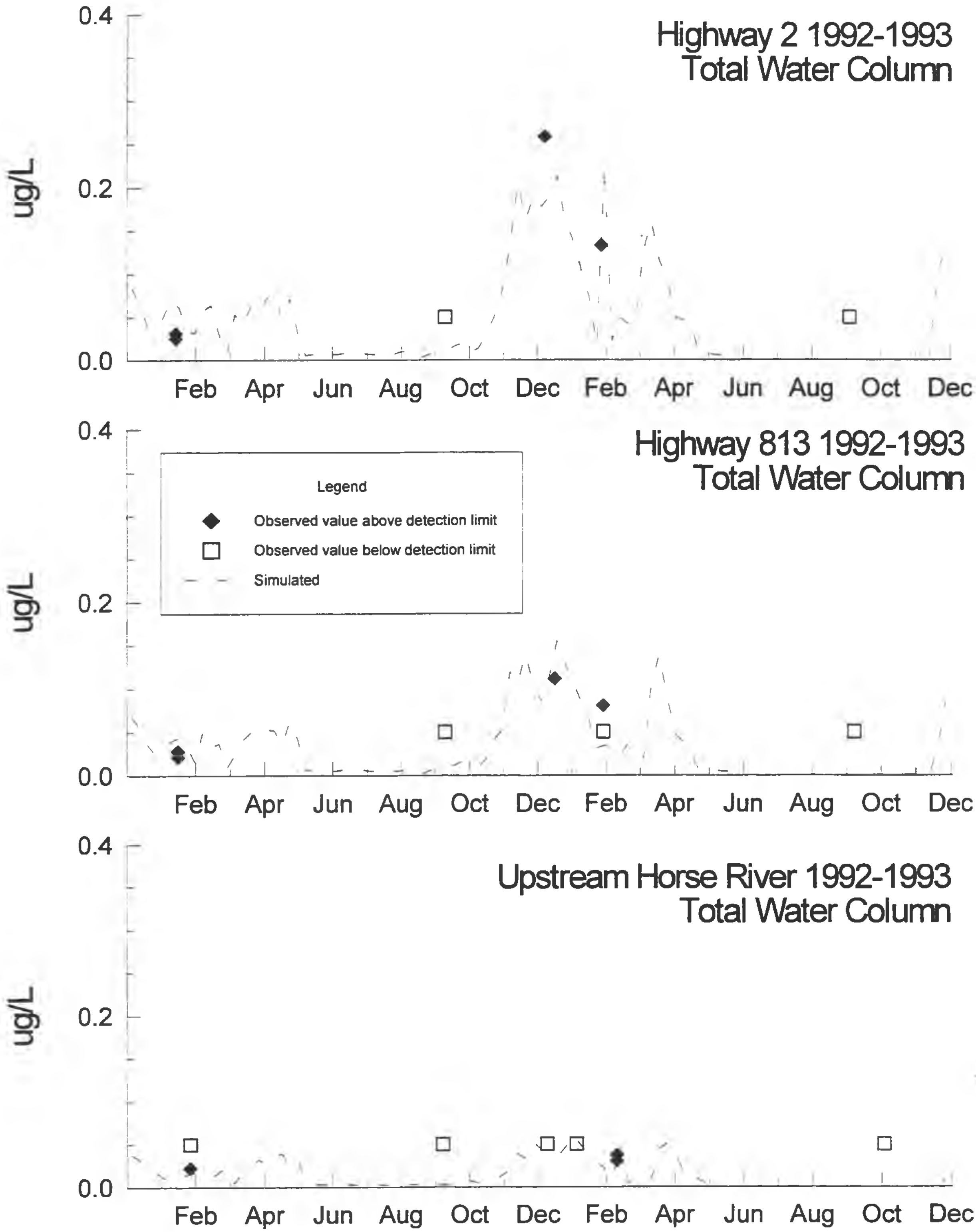


Figure 4.22b.
Athabasca River, 3,4,5-TCC Calibration, Time Series

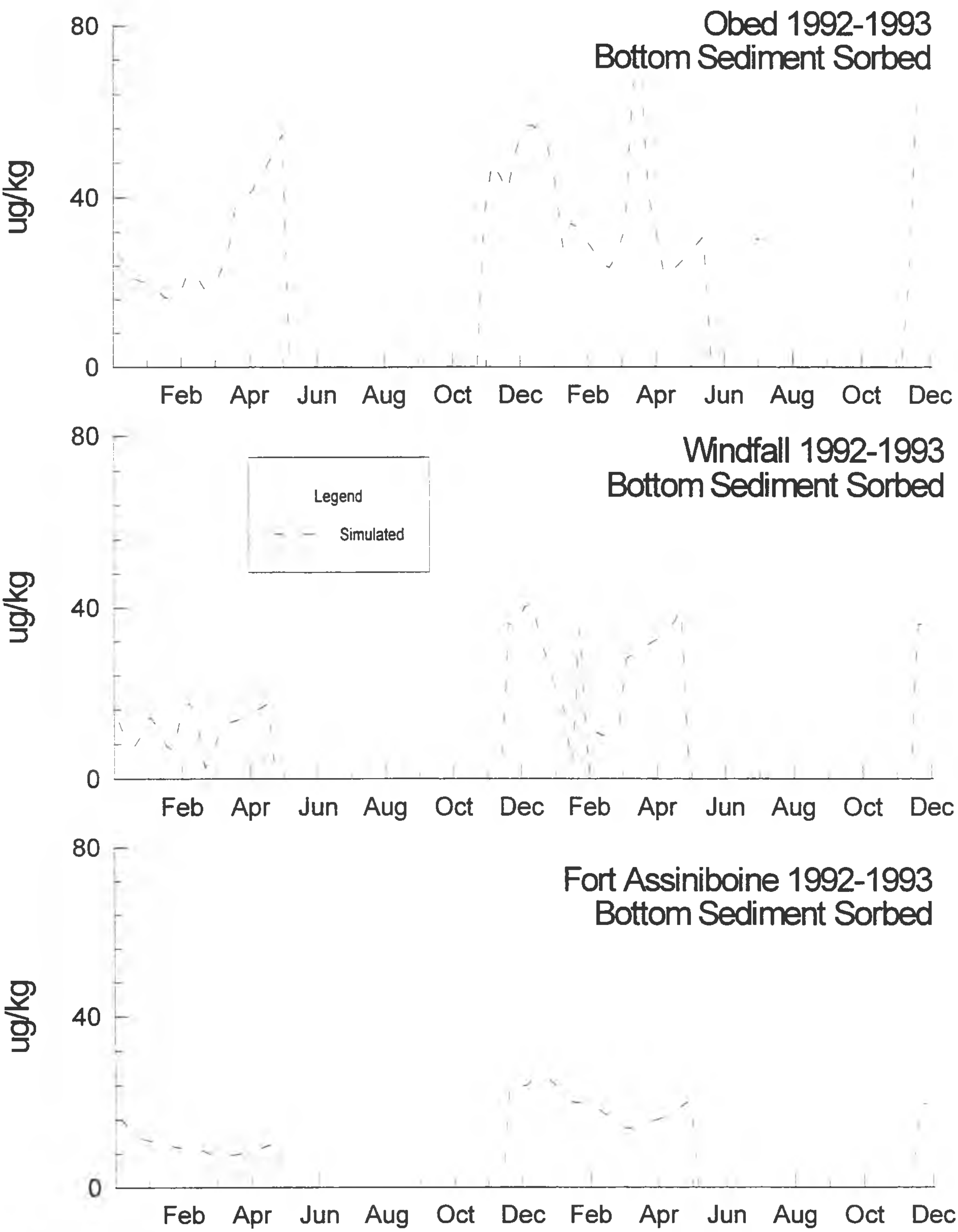


Figure 4.22c.
Athabasca River, 3,4,5-TCC Calibration, Time Series

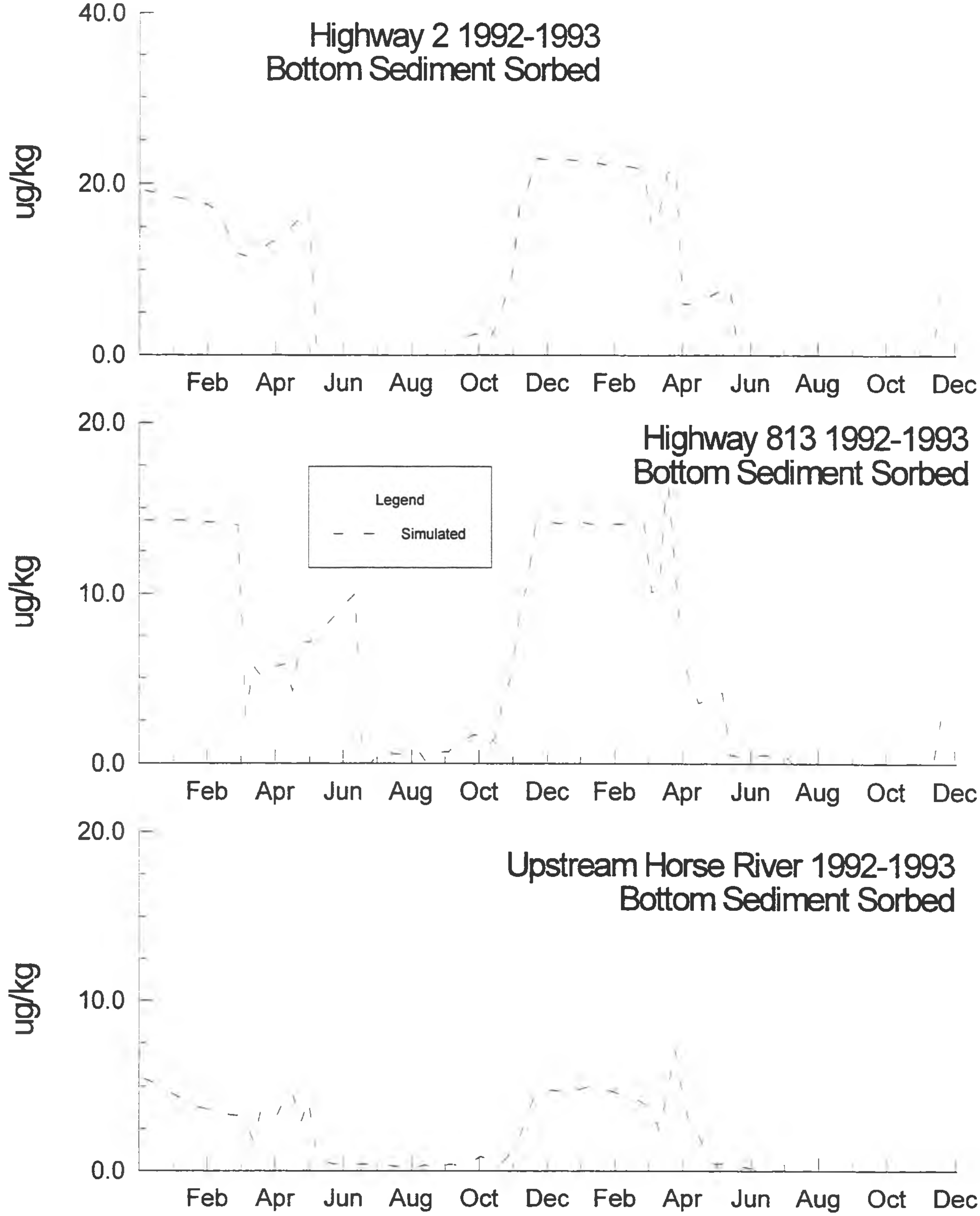


Figure 4.22d.
Athabasca River, 3,4,5-TCC Calibration, Time Series

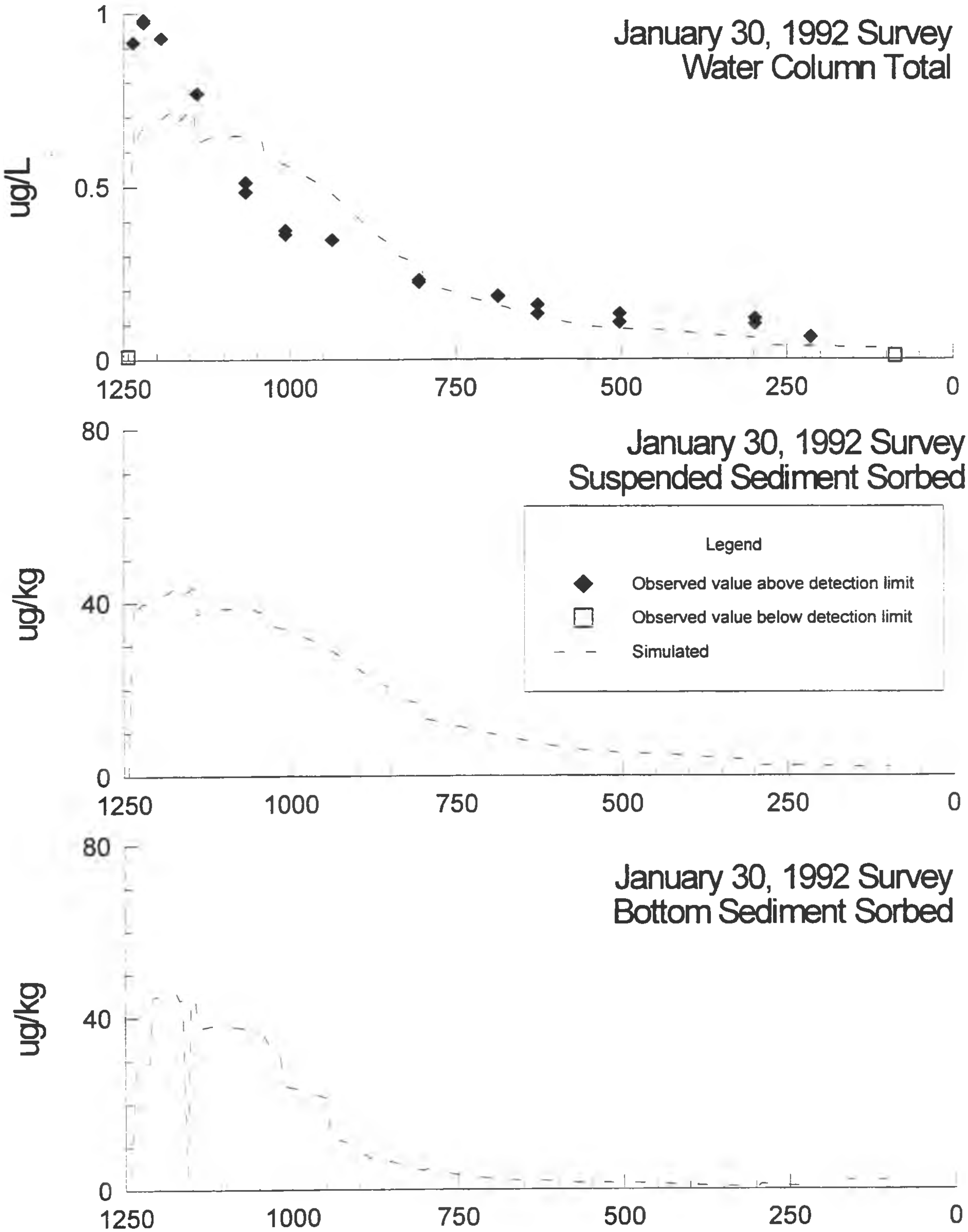


Figure 4.25a
Athabasca River, 3,4,5-TCG Calibration, Synoptic Surveys

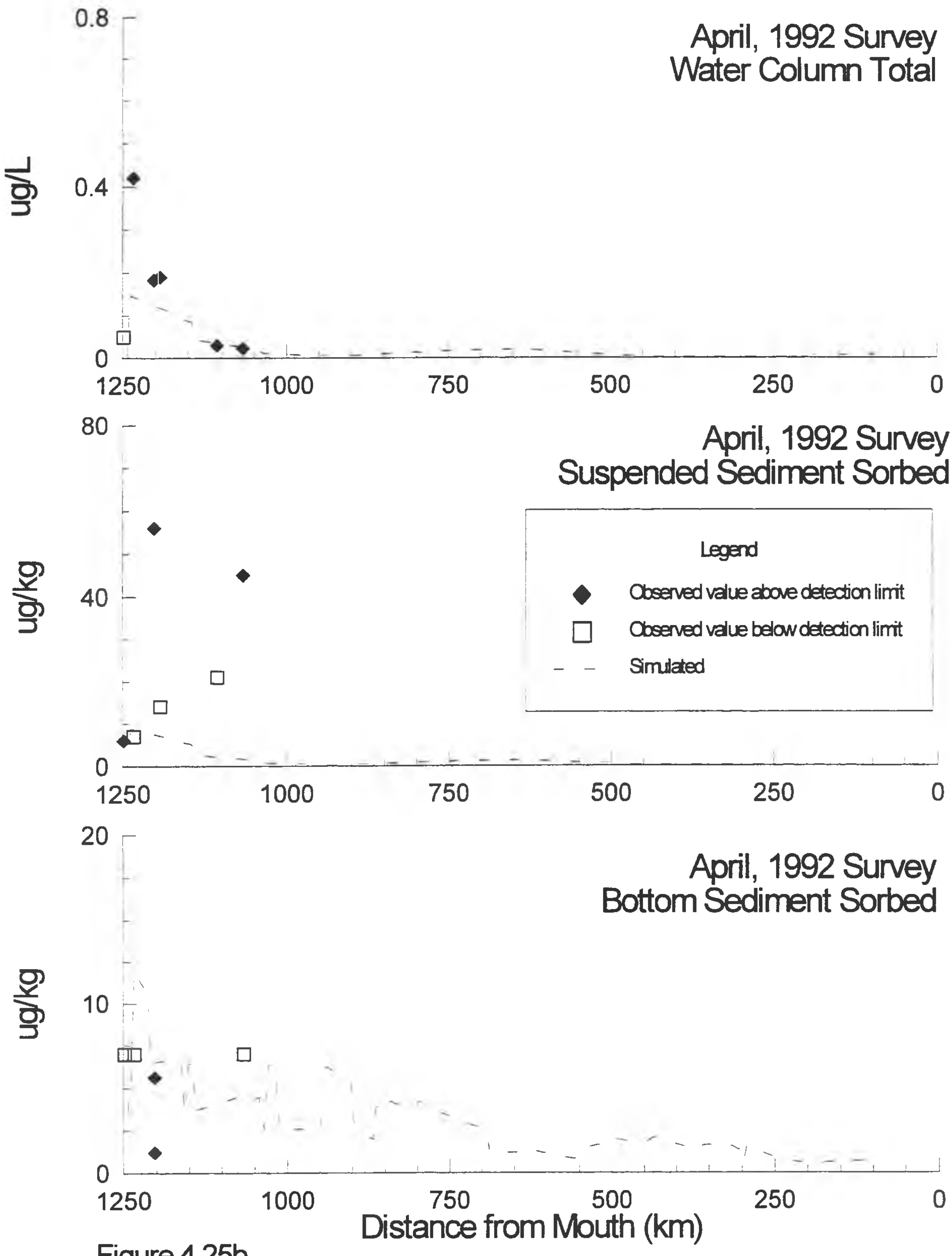


Figure 4.25b.
Athabasca River, 3,4,5-TCG Calibration, Synoptic Surveys

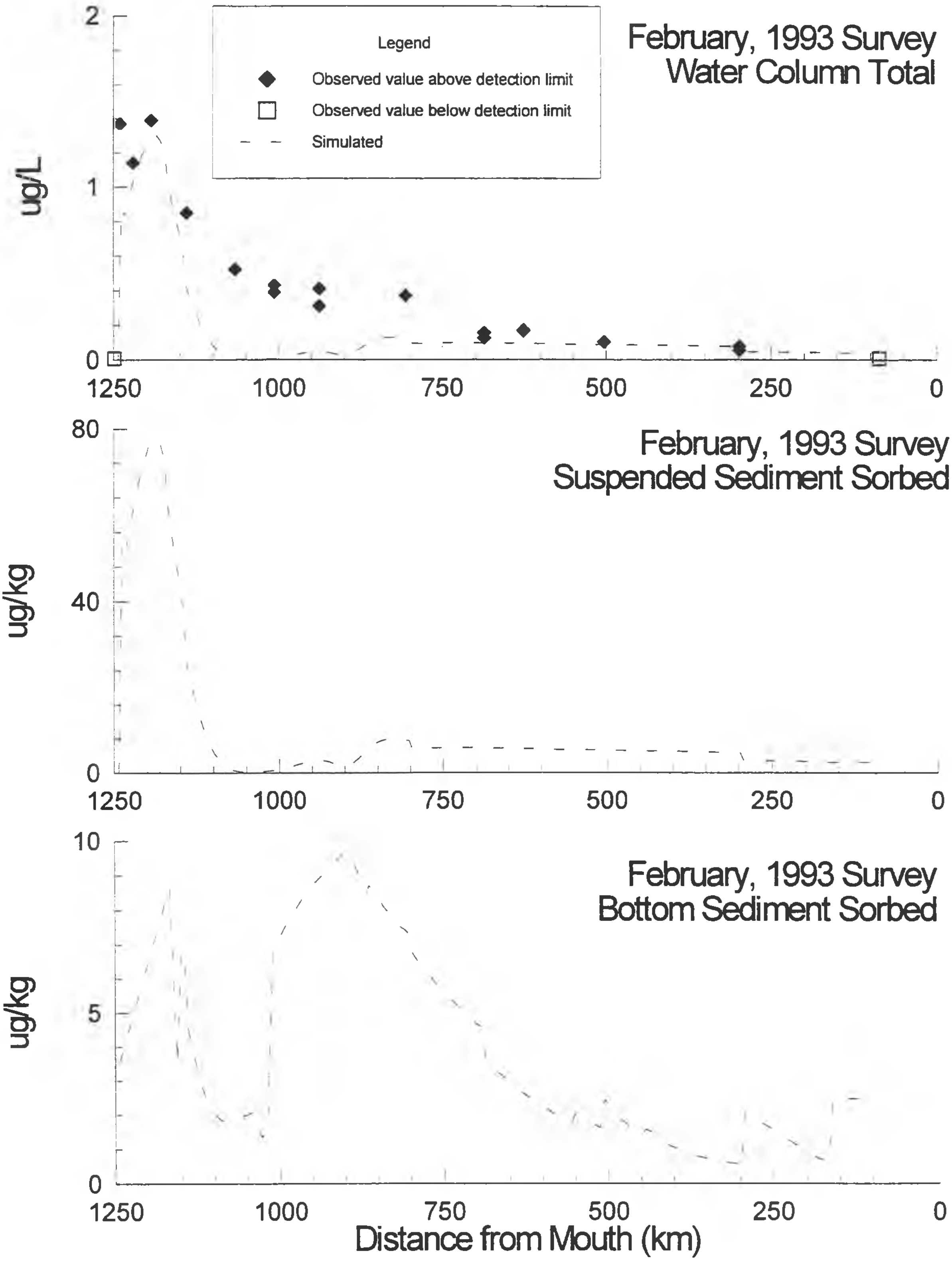


Figure 4.25c.
Athabasca River, 3,4,5-TCG Calibration, Synoptic Surveys

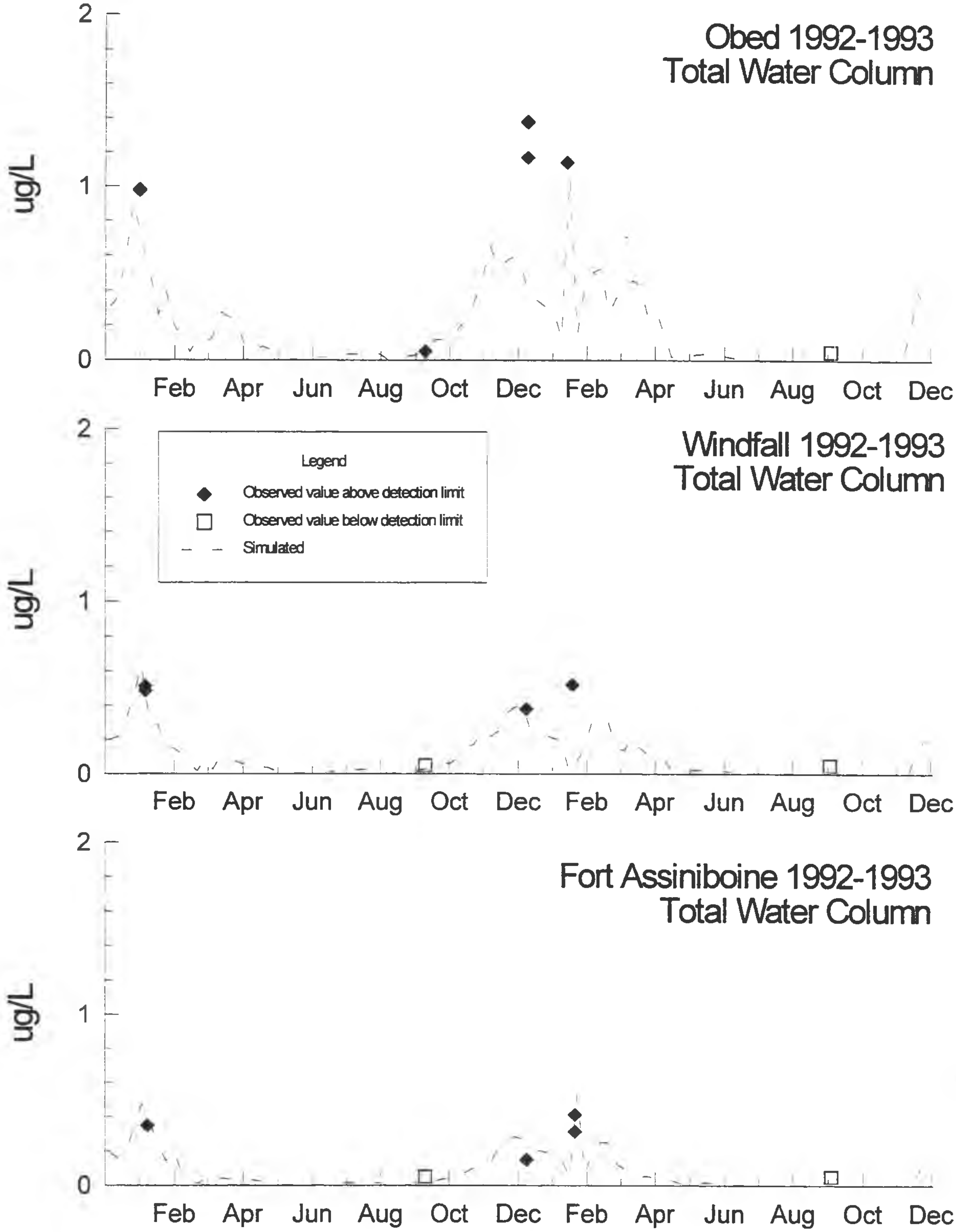


Figure 4.26a.
Athabasca River, 3,4,5-TCG Calibration, Time Series

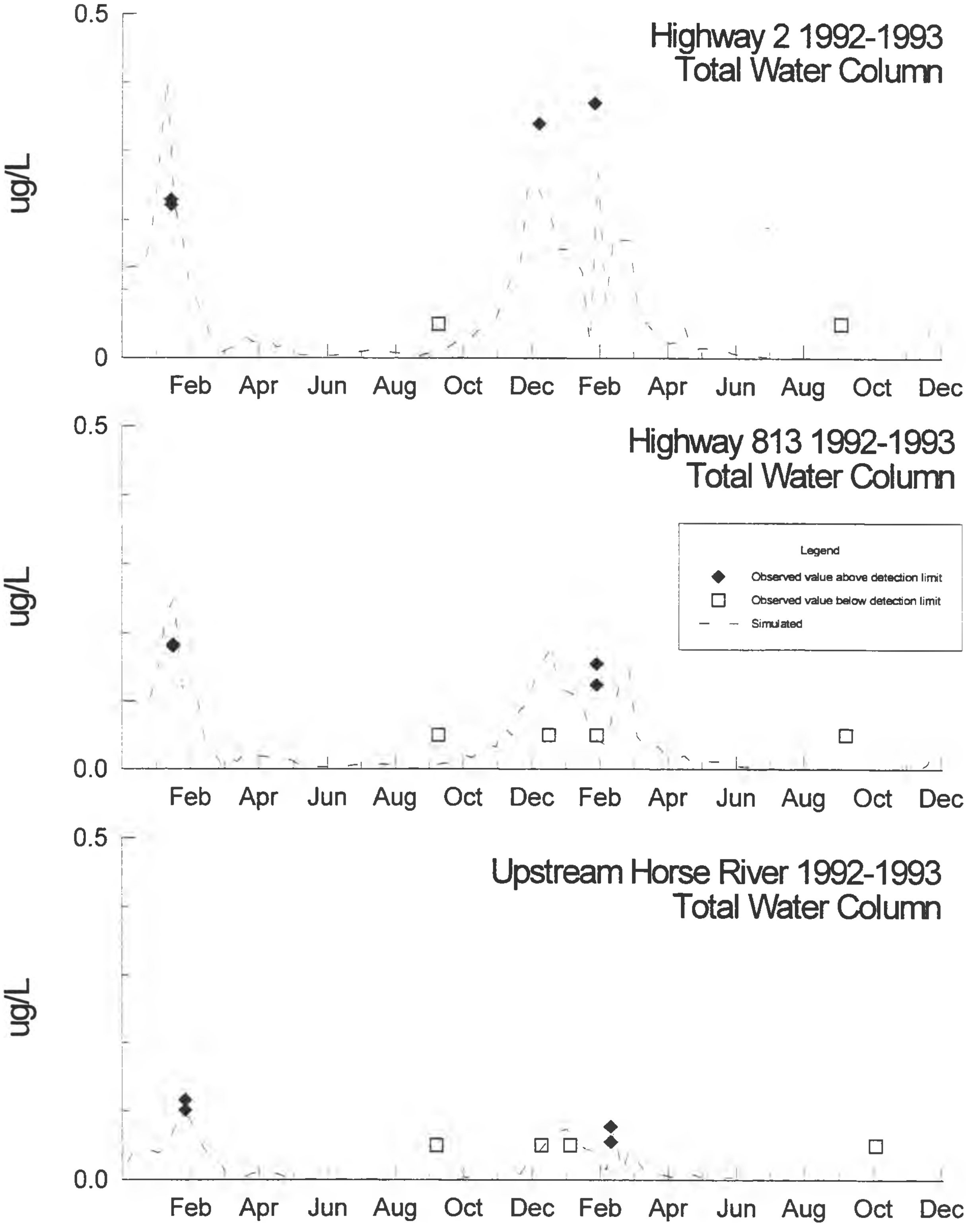


Figure 4.26b.
Athabasca River, 3,4,5-TCG Calibration, Time Series

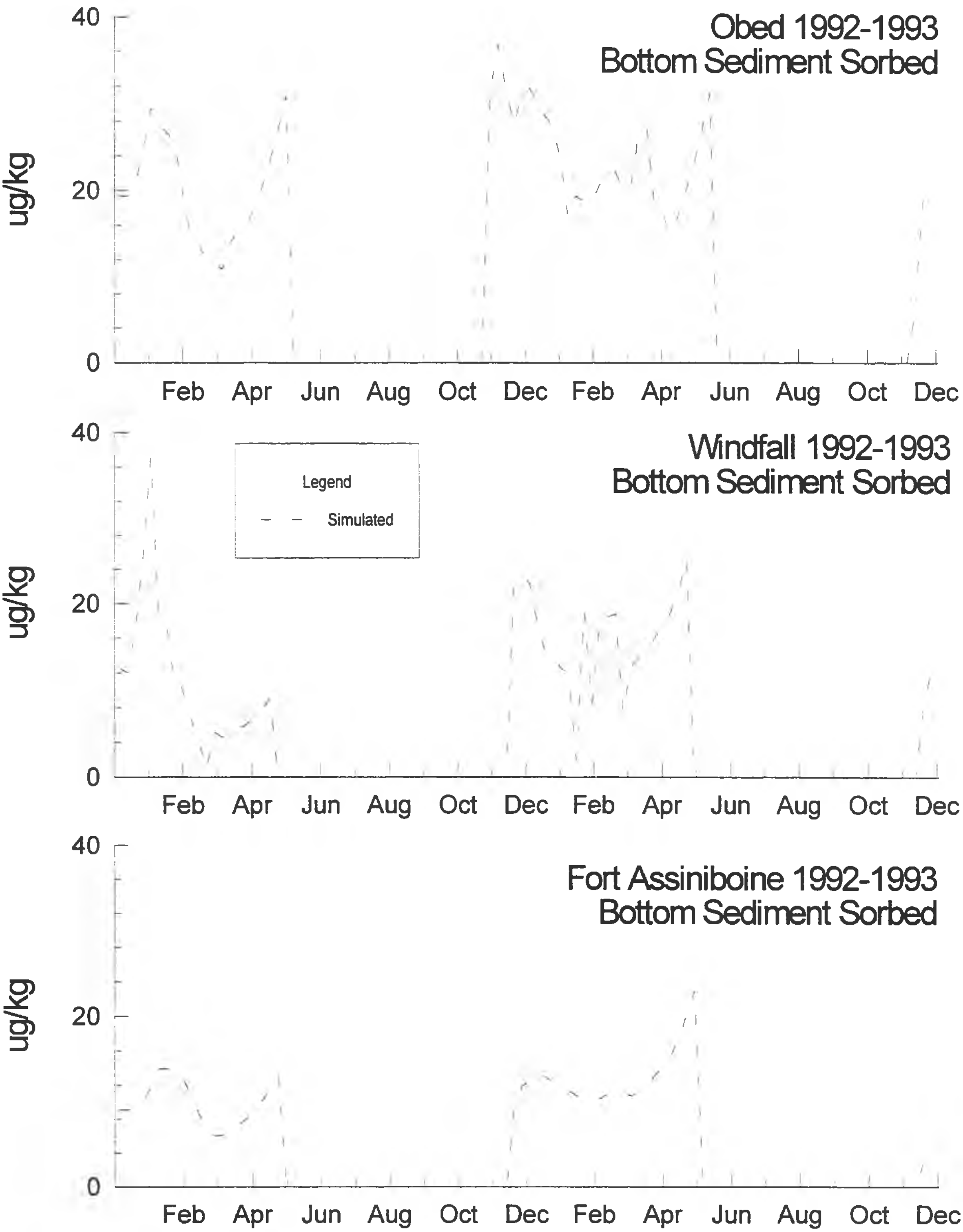


Figure 4.26c.
Athabasca River, 3,4,5-TCG Calibration, Time Series

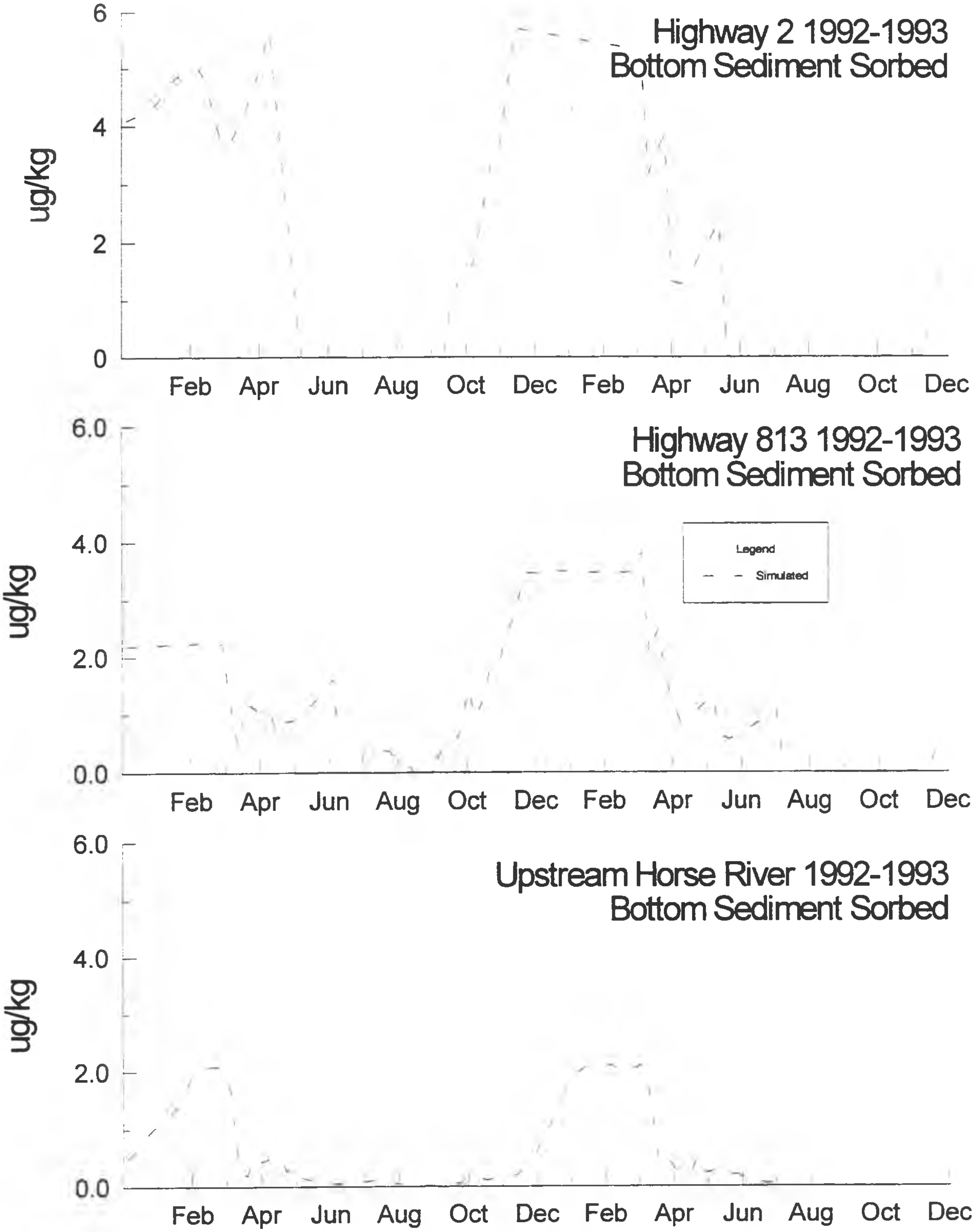


Figure 4.26d.
Athabasca River, 3,4,5-TCG Calibration, Time Series

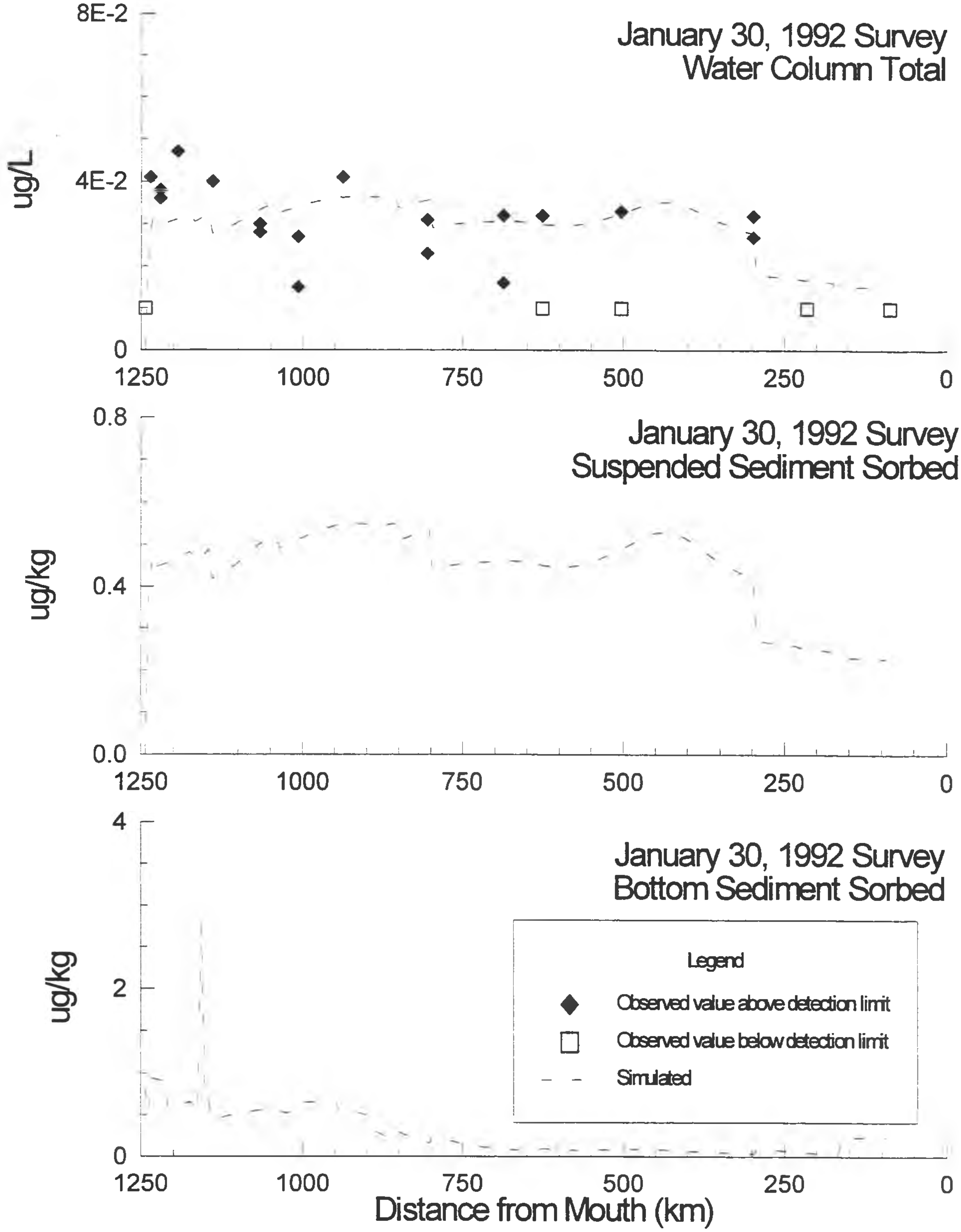


Figure 4.29a.
Athabasca River, 3,4,5-TCV Calibration, Synoptic Surveys

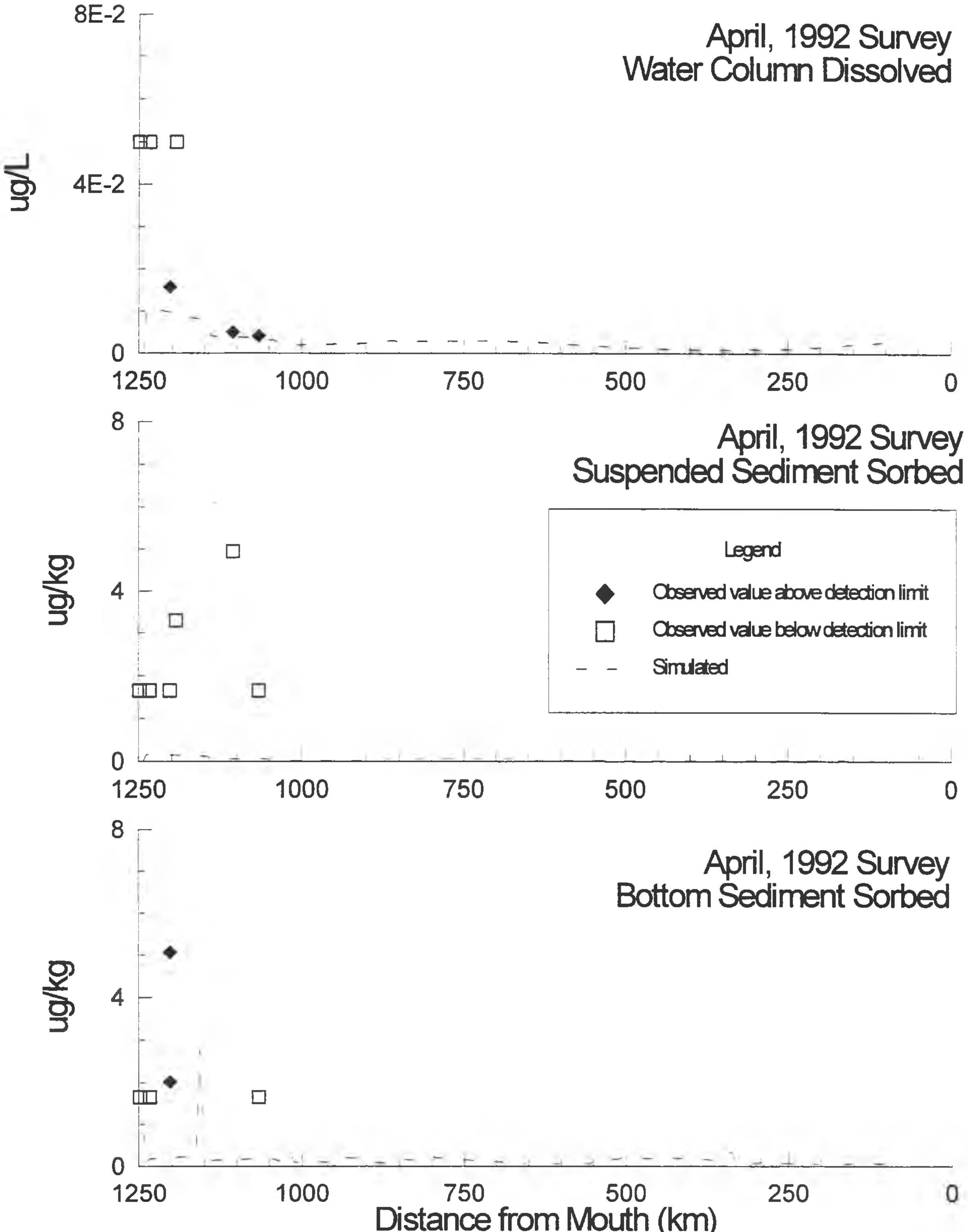


Figure 4.29b.
Athabasca River, 3,4,5-TCV Calibration, Synoptic Surveys

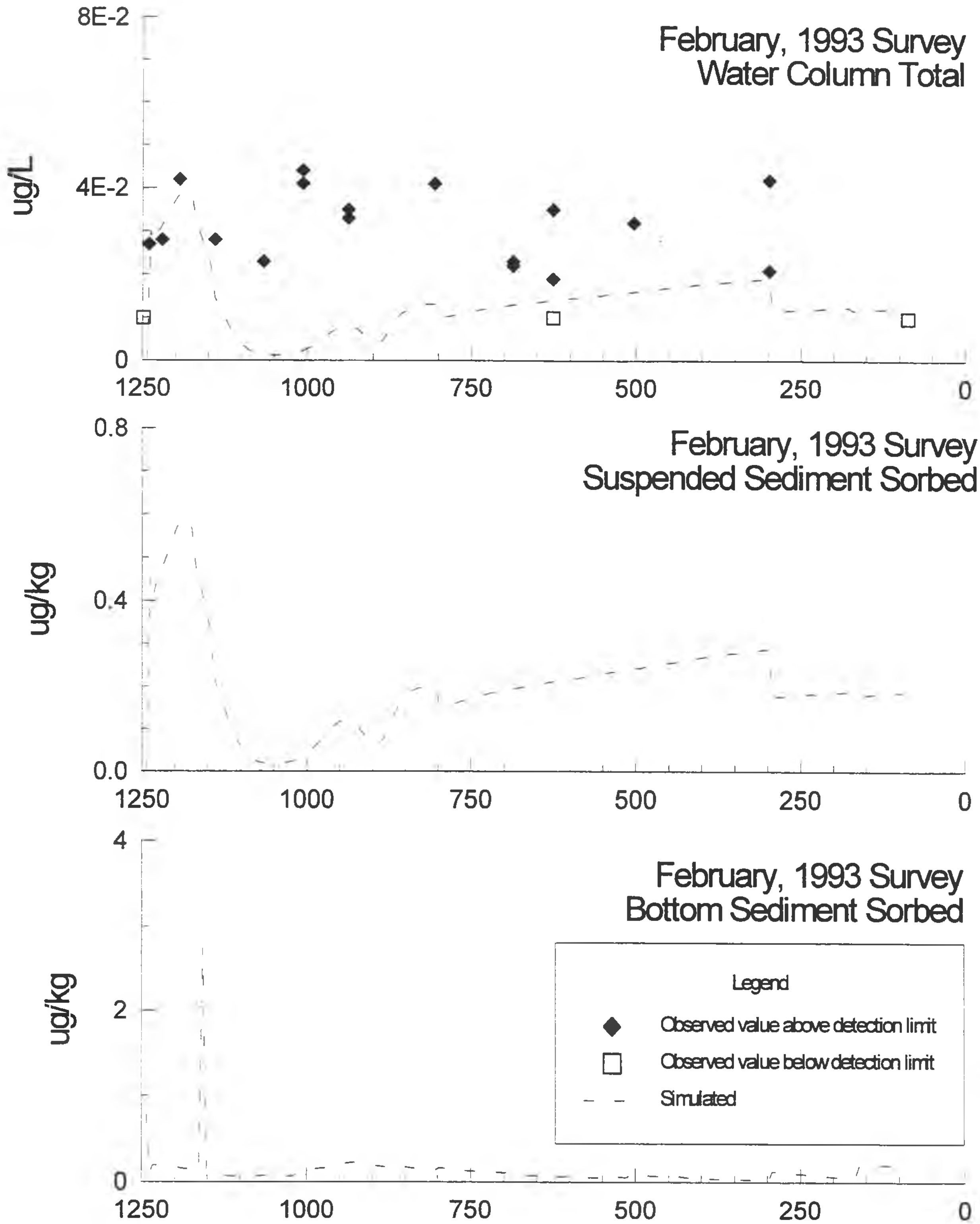


Figure 4.29c.
Athabasca River, 3,4,5-TCV Calibration, Synoptic Surveys

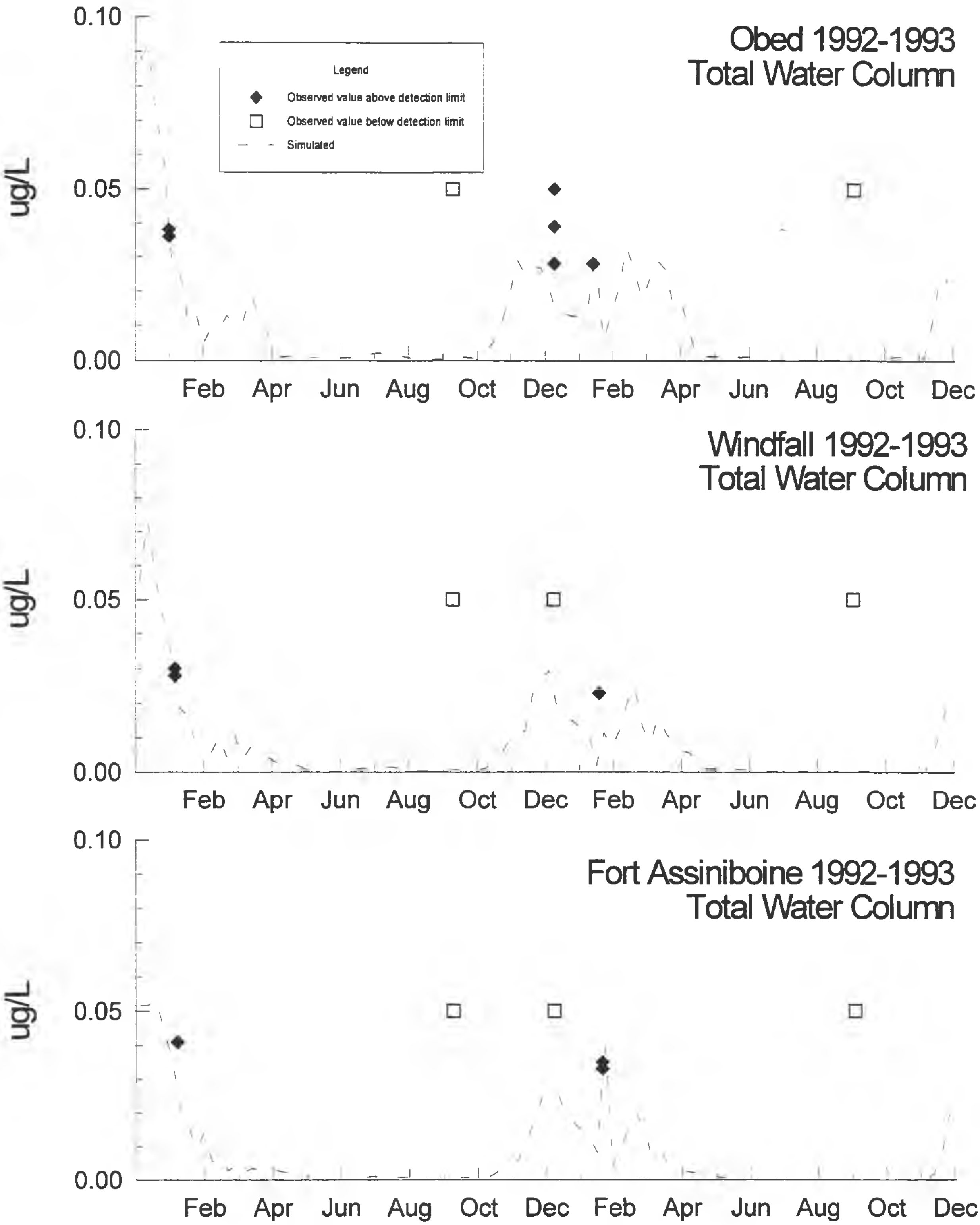


Figure 4.30a.
Athabasca River, 3,4,5-TCV Calibration, Time Series

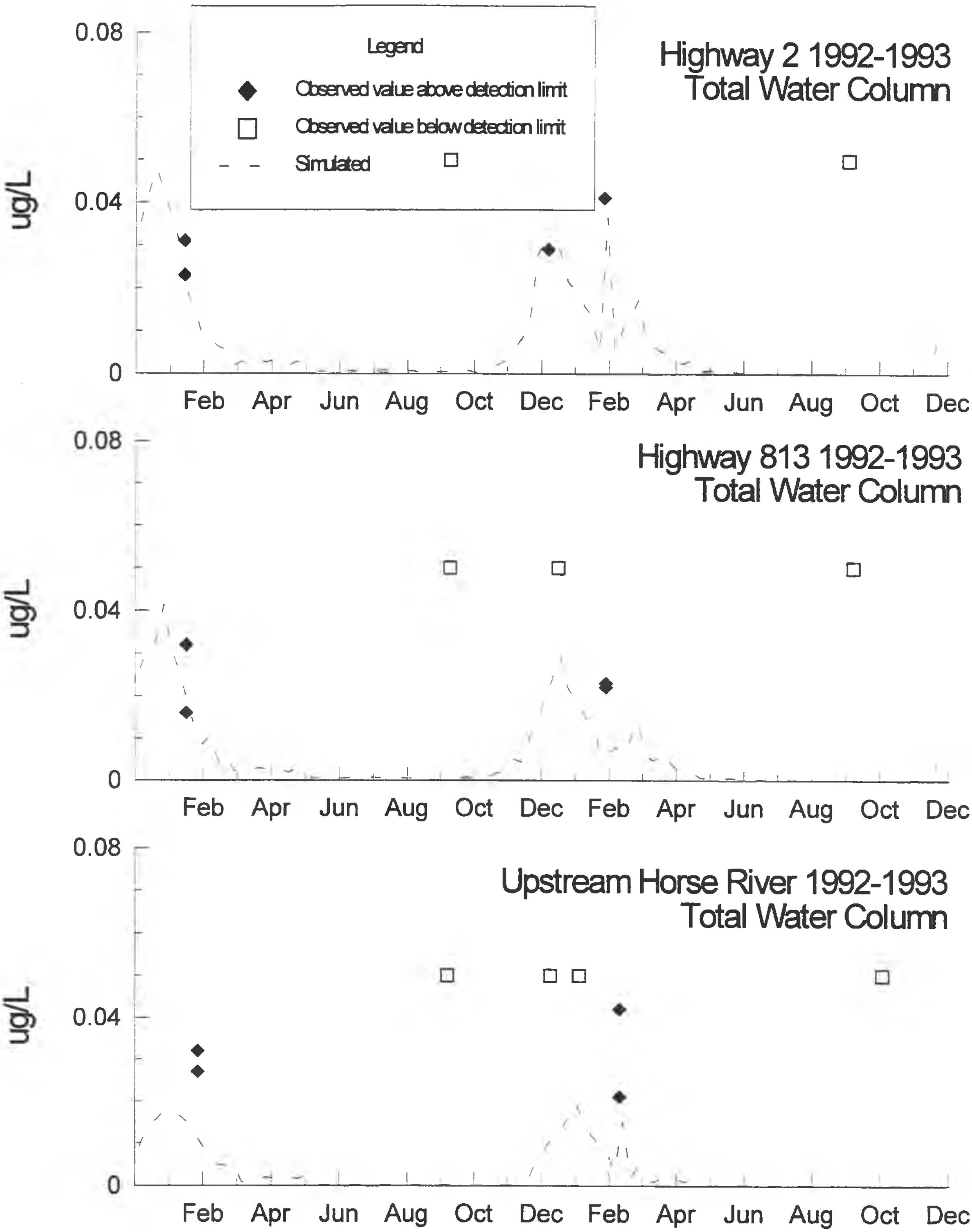


Figure 4.30b.
Athabasca River, 3,4,5-TCV Calibration, Time Series

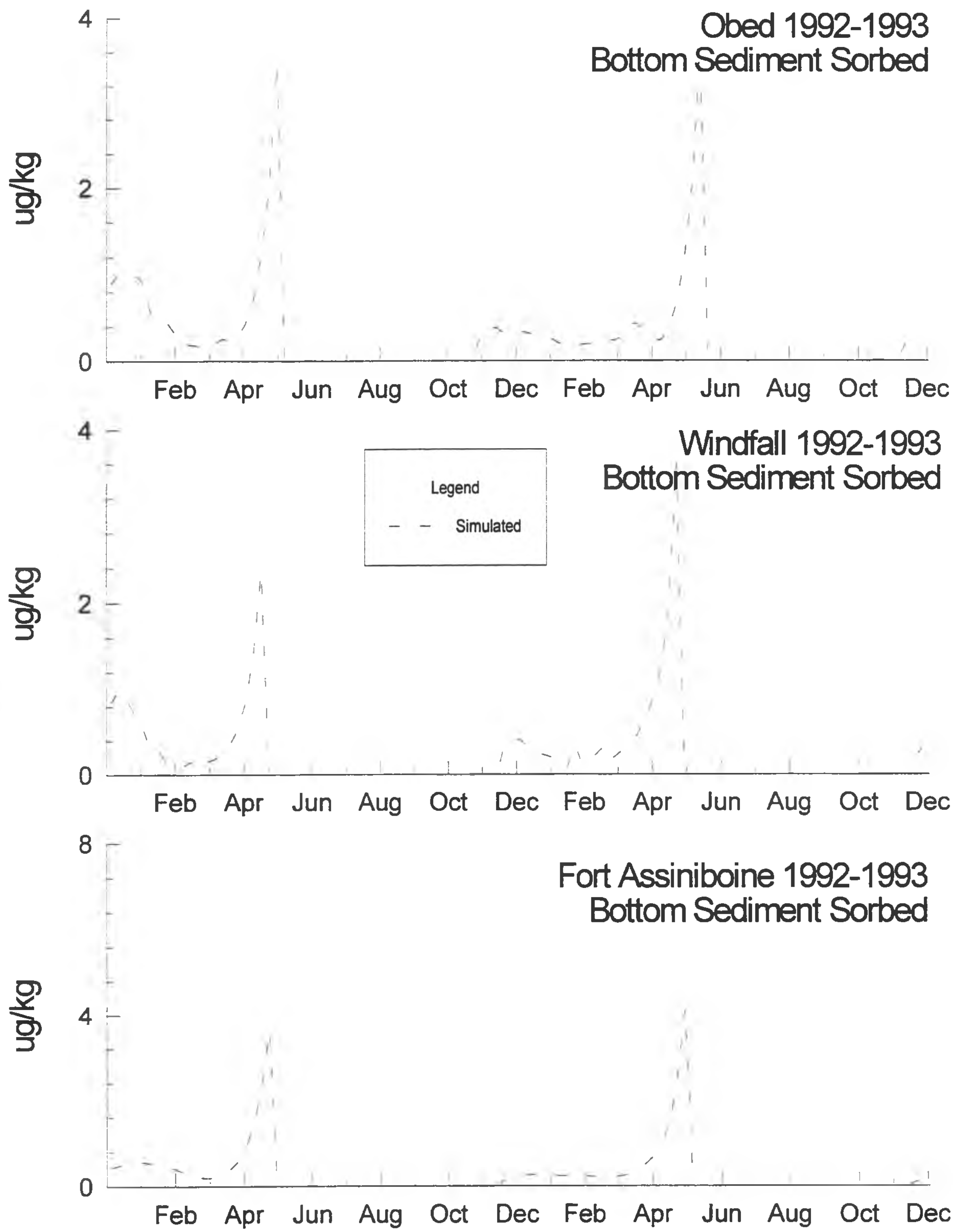


Figure 4.30c.
Athabasca River, 3,4,5-TCV Calibration, Time Series

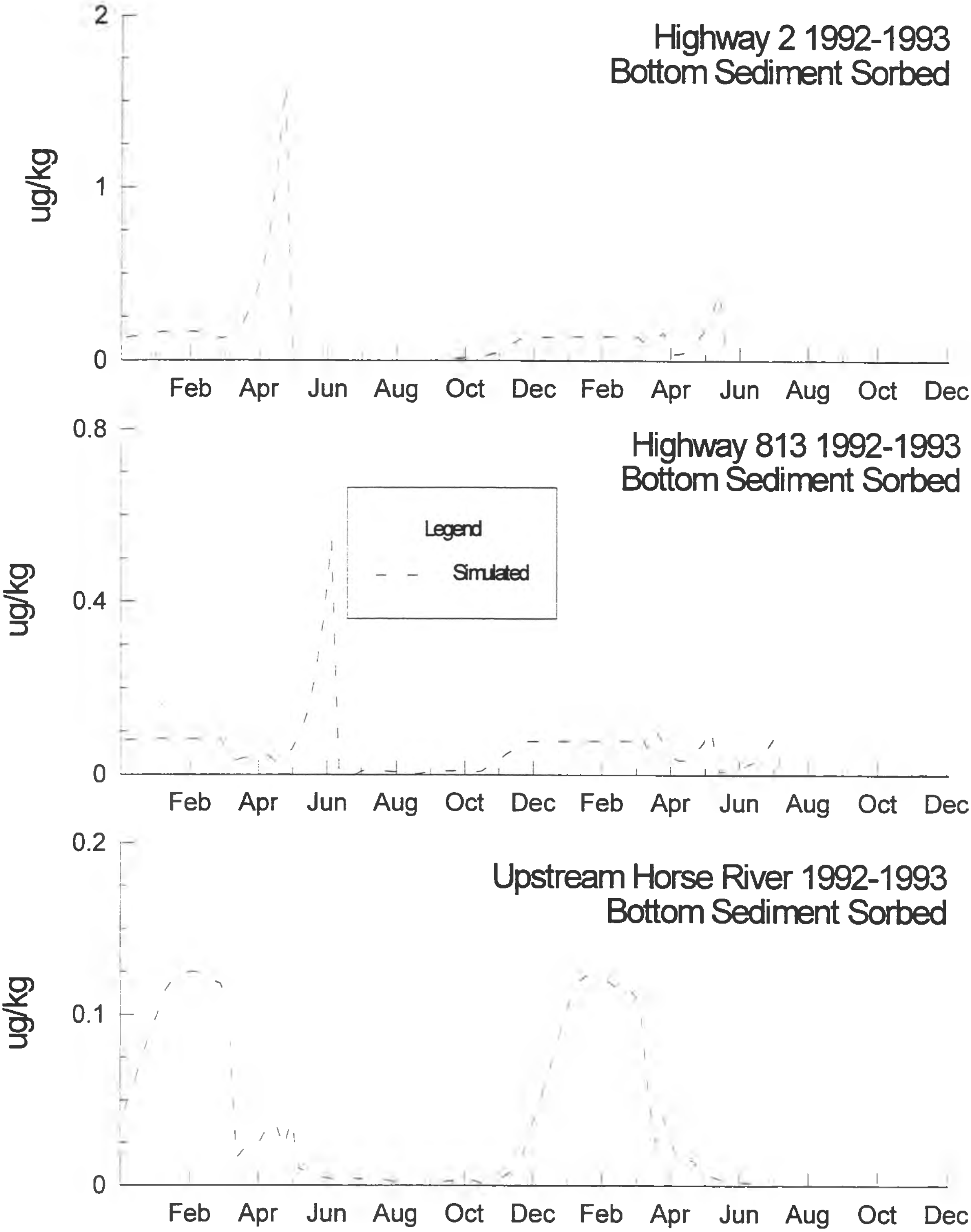


Figure 4.30d.
Athabasca River, 3,4,5-TCV Calibration, Time Series

NORTHERN RIVER BASINS STUDY

APPENDIX D - TERMS OF REFERENCE

Project 2381-E1: Contaminant Fate Model - Sediment Routine Development

I. BACKGROUND AND OBJECTIVES

One of the major objectives of the Northern River Basins Study (NRBS) is to develop predictive tools to determine the cumulative effects of man-made discharges on the aquatic environment (Study Board Question 13a) and predictive models to provide an ongoing assessment of the state of the aquatic ecosystem (Study Board Question 14). The Contaminants Component of the NRBS assumed the task of modelling the fate, accumulation and effects of contaminants released into the aquatic environment. A modelling sub-committee was formed and, in April 1993, the sub-committee hosted a contaminant fate and food chain modelling workshop (NRBS Projects 2381-C1-C4) to provide direction for future modelling initiatives (Brownlee and Muir 1994). The workshop was attended by government representatives, members of the academic community, environmental consultants, representative from resource-based industries in the northern river basins and NRBS-affiliated research scientists. Based on presentations and discussions at the workshop, the sub-committee decided to utilize the *WASP IV* model, developed by the U.S. Environmental Protection Agency, and the Thomann/Connolly and Gobas food chain models to model the fate and bioaccumulation of point-source contaminants entering the Athabasca River system.

Contaminant fate and food chain model development is to be based on previous contaminant fate modelling carried out in the Athabasca River Basin (Macdonald and Radermacher 1992) and Wapiti-Smoky rivers (HydroQual 1990). These models will also incorporate historic contaminants data collected by Alberta Environmental Protection, Environment Canada and industry in the Athabasca River and Wapiti-Smoky rivers, and recent data collected by the NRBS. Results from the 1992 and 1993 NRBS Reach Specific Study and the February/March 1993 NRBS/Alberta Environmental Protection winter synoptic survey will be of particular significance for contaminant fate and food chain modelling.

To date, the contractor has completed the following tasks:

- Information review and compilation - summary report including locations, mediums, chemical parameters, ranges of values, number of samples, etc, of the chemical information to be used in the model;
- Model configuration - modify reach structure of existing *WASP* configuration, simulate river hydrology, confirm mass balance calibration, calibrate water column concentrations of TSS;
- Rate coefficient compilation - a table of published physical and chemical rate coefficients and constants for use in the WASP and food chain models;
- Simulation and calibration of contaminant fate:

- Technical review meeting - meeting with members of the modelling sub-committee and the Contaminants Component Leader; and
- User interface and user training.

The existing *WASP IV* requires some adjustments to develop a more appropriate sediment transport routine. *WASP IV* handles sedimentation processes through a net flux. Sediment flows are input as velocities and areas. Sediment velocities are allowed to vary in time and may represent the net settling, sedimentation deposition and scour. Only solids and sorbed chemicals are transported by the *WASP IV* flow fields. Up to three sediment size fractions may be incorporated into the WASP model using all of the three principal constituent solid fields. Using *WASP* to model sediment processes requires formulating the velocity time function for each sedimentation zone in the river, prior to running the *WASP* simulation. However, if the sedimentation is a function of flocculation influenced by effluent concentrations, then the formulation of this pre-processed input deck is a function of the post-processed water column concentrations.

Based on the inadequacy of the *WASP IV* model discussed above, the objective of this project will develop a sediment flux routine and incorporate that routine into the model. The incorporated sediment flux routine will be based on a current study of critical sheer stresses for erosion and deposition of fine sediment (Krishnappan and Stephens 1995). The *WASP IV* model will then be able to calculate automatically the sediment flux velocities based on the input values for river reach hydraulics. The sediment routines will do this by estimating reach averaged shear velocities and predicting settling rates, scour rates and these will then be converted to a net settling velocity for internal use in *WASP IV* by taking into account the flocculation mechanism.

II. GENERAL REQUIREMENTS

The contractor will proceed with the sediment development project in three phases, with input from B. Krishnappan, NWRI.

1. Model Development

   a) Development of the empirical/theoretical sedimentation processes will be conducted by B. Krishnappan, based on his work to date (NRBS Project 1332-D1). He will supply the contractor with a sedimentation model suitable for coding into computer programs. This model will be an explicit formulation of mathematical expressions for estimating settling rates, scour rate and flocculation as a function of river shear stress, river sediment composition and effluent quality affecting flocculation.. The basis for estimating the reach averaged river shear stress using available hydraulic information used in *WASP IV* will also be required from B. Krishnappan based on his current knowledge of sedimentation in the Athabasca River and river hydraulics in general.

b) Development of new computer codes for sedimentation flux will be developed by the contractor, based on the expressions developed by B. Krishnappan. The new routines will use as input the reach averaged velocity, effluent load, river background sedimentation concentration, and fixed inputs describing the bed slope and roughness which would be required to estimate bed shear stress. These routines will be developed as stand-alone routines for testing and QA/QC. Additionally, the contractor will include hydraulic calibration of the existing Athabasca River information to estimate reach averaged shear velocities as a function of the flow information available.

2. Incorporate the new sediment routines into *WASP IV* and provide documentation limited to the technical basis and practical use of the new sediment routines. The new sediment velocity calculation routines will be merged into *WASP IV* by intercepting the sedimentation velocity in the appropriate routines. At this point in the *WASP IV* program, either the current time-step or the past time-step contaminant water column and effluent concentration, will be visible and available for use in calculation flocculation processes as specified by B. Krishnappan.

3. Re-simulation of the existing NRBS contaminant fate model for the Athabasca River. The re-simulation will include minor changes to the existing calibration as necessary. The re-simulation will include simulation of suspended solids and each of the chemicals considered in the existing model under the current contract (NRBS #95-F-G-98-3)

III. REPORTING REQUIREMENTS

1. Ten bound copies of a Draft Report which incorporates the new sedimentation flux routines into a re-calibrated *WASP IV* contaminant fate model will be submitted to the Component Coordinator, including an electronic disk version, by **October 15, 1995**.

   Five copies of the computer software and User's Manual to be distributed as follows:

   a) National Water Research Institute - B. Brownlee/B. G. Krishnappan
   b) Freshwater Institute - D. Muir
   c) Alberta Environmental Protection - L. Noton
   d) Environment Canada - R. Crosley
   e) Northern River Basins Study

2. Three weeks after receipt of review comments, the contractor is to submit ten cerlox bound copies, two unbound camera ready copies, and an electronic disk version of the final project report to the Component Coordinator.

3. The Contractor is to provide draft and final reports in the style and format outlined in the NRBS document, "A Guide for the Preparation of Reports," which will be supplied upon execution of the contract.

The final report is to include the following: an acknowledgement section that indicates any local involvement in the project, Report Summary, Table of Contents, List of Tables, List of Figures and an Appendix with the Terms of Reference for this project.

Text for the report should be set up in the following format:

a) Times Roman 12 point (Pro) or Times New Roman (WPWIN60) font.
b) Margins; are 1" at top and bottom, 7/8" on left and right.
c) Headings; in the report body are labelled with hierarchical decimal Arabic numbers.
d) Text; is presented with full justification; that is, the text aligns on both left and right margins.
e) Page numbers; are Arabic numerals for the body of the report, centred at the bottom of each page and bold.

- If photographs are to be included in the report text they should be high contrast black and white.
- All tables and figures in the report should be clearly reproducible by a black and white photocopier.
- Along with copies of the final report, the Contractor is to supply an electronic version of the report in Word Perfect 5.1 or Word Perfect for Windows Version 6.0 format.
- Electronic copies of tables, figures and data appendices in the report are also to be submitted to the Project Liaison Officer along with the final report. These should be submitted in a spreadsheet (Quattro Pro preferred, but also Excel or Lotus) or database (dBase IV) format. Where appropriate, data in tables, figures and appendices should be geo-referenced.

4. All figures and maps are to be delivered in both hard copy (paper) and digital formats. Acceptable formats include: DXF, uncompressed E⌀⌀, VEC/VEH, Atlas and ISIF. All digital maps must be properly geo-referenced.

5. All sampling locations presented in report and electronic format should be geo-referenced. This is to include decimal latitudes and longitudes (to six decimal places) and UTM coordinates. The first field for decimal latitudes / longitudes should be latitudes (10 spaces wide). The second field should be longitude (11 spaces wide).

6. Ten to twenty-five 35 mm slides that can be used at public meetings to summarize the project, methods and key findings. The package of slides is to be comprised of one original and four duplicates of each slide.

IV. DELIVERABLES

1. A draft report submitted to the Study Office by October 15, 1995.
2. An electronic interface program for the re-simulated and re-calibrated *WASP IV* model, and installation instructions and users manual for the model.
3. A final project report.

4. A package of 35 mm slides (originals plus four duplicate copies) for presentations public presentations .

V. CONTRACT ADMINISTRATION

This project is being coordinated by the modelling sub-committee of the Contaminants Component of the Northern River Basins Study (Component Leader - Dr. John Carey, NWRI, Burlington). The Scientific Authority for this project is:

Dr. Brian Brownlee
National Water Research Institute
867 Lakeshore Road,
P.O. Box 5050
Burlington, Ontario
L7R 4A6
phone: (905) 336-4706 fax: (905) 336-4972

Questions of a technical nature should be directed to him.

Members of the modelling sub-committee include:
Dr. Brian Brownlee, National Water Research Institute, Burlington - Contaminant fate
Dr. Anne-Marie Anderson, Alberta Environmental Protection, Edmonton - Benthos
Bob Crosley, Environment Canada, Calgary - Water and sediment
Dr. Mike MacKinnon, Syncrude Research, Edmonton - Oil sands
Dr. Derek Muir, Fisheries and Oceans Canada, Winnipeg - Food chain
Leigh Noton, Alberta Environmental Protection, Edmonton - Pulp mills

They will have direct input with the contractor in the development of the model. The leaders of other Northern River Basins Study components will also have direct input into the development of the model. These include: Dr. Terry Prowse - Hydrology/Hydraulics Component; Dr. Patricia Chambers - Nutrients Component; Mr. Tom Mill - Food Chain Component.

The Component Coordinator for this project is:

Richard Chabaylo
Northern River Basins Study
690 Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta
T5J 3M4
phone: (403) 427-1742 fax: (403) 422-3055

Questions of an administrative nature should be directed to him.

VI. LITERATURE CITED

Brownlee, B. and D. Muir. 1994. Proceedings of the Contaminants Fate and Food Chain Modelling Workshop. Draft report submitted to the Northern River Basins Study.

HydroQual Canada Limited. 1990. Implementation of Water Quality Models for the Wapiti-Smoky and Peace River Systems. Report prepared for Alberta Environment, Standards and Approvals Division, Edmonton.

Krishnappan, B.G. and R. Stephens. 1995. Critical sheer stresses for erosion and deposition of fine suspended sediment from the Athabasca River. Draft Report prepared for the Northern River Basins Study, Edmonton. 17 pp.

Macdonald, G. and A. Radermacher. 1992 (May). Athabasca River Water Quality Modelling - 1990 Update. Prepared for: Standards and Approvals Division, Alberta Environment, Edmonton. Prepared by: Environmental Management Associates, Calgary.