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Sediment and Radionuclide Transport in Rivers

Radionuclide Transport Modeling for Cattaraugus and Buttermilk Creeks, New York

Prepared by Y. Onishi, S.B. Yabusaki, C. T. Kincaid
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ABSTRACT

SERATRA, a transient, two-dimensional (laterally-averaged) computer model of sediment-contaminant transport in rivers, satisfactorily resolved the distribution of sediment and radionuclide concentrations in the Cattaraugus Creek stream system in New York. By modeling the physical processes of advection, diffusion, erosion, deposition, and bed armoring, SERATRA routed three sediment size fractions, including cohesive soils, to simulate three dynamic flow events. In conjunction with the sediment transport, SERATRA computed radionuclide levels in dissolved, suspended sediment, and bed sediment forms for four radionuclides (^{137}Cs, ^{90}Sr, ^{239,240}Pu, and ^{3}H). By accounting for time-dependent sediment-radionuclide interaction in the water column and bed, SERATRA is a physically explicit model of radionuclide fate and migration. Sediment and radionuclide concentrations calculated by SERATRA in the Cattaraugus Creek stream system are in reasonable agreement with measured values.

SERATRA is in the field performance phase of an extensive testing program designed to establish the utility of the model as a site assessment tool. The model handles not only radionuclides but other contaminants such as pesticides, heavy metals and other toxic chemicals. Now that the model has been applied to four field sites, including the latest study of the Cattaraugus Creek stream system, we recommend a final model validation through comparison of predicted results with field data from a carefully controlled tracer test at a field site. We also recommend a detailed laboratory flume testing to study cohesive sediment transport, deposition and erosion characteristics. The lack of current understanding of these characteristics is one of the weakest areas hindering the accurate assessment of the migration of radionuclides sorbed by fine sediments of silt and clay.

SUMMARY

The migration and fate of radionuclides in surface waters are controlled by four complex mechanisms. These mechanisms are radionuclide transport due to water and sediment movements; intermedia transfer due to adsorption/desorption, precipitation/dissolution, and volatilization; decay and degradation due to radionuclide decay or chemical and biological degradation (where applicable); and transformation due to the yield of daughter, degradation, or chemical-reaction products (where applicable). SERATRA, a two-dimensional (laterally-averaged) finite element model of sediment-radionuclide transport, was formulated to account for these mechanisms in a physically explicit manner.

SERATRA predicts time-varying longitudinal and vertical distributions of sediments and radionuclides in nontidal rivers and some impoundments. The model consists of three coupled transport submodels, sediment transport, dissolved radionuclide transport, and particulate radionuclide transport, which are capable of time-dependent sediment-radionuclide interaction in the riverbed and water column.

The potential of SERATRA as a site assessment tool has led to a lengthy testing program designed to validate the model over a variety of field conditions. Initially, numerical experiments, i.e., mass balance checks and comparisons with analytical solutions, were performed to confirm the accuracy of the model. Next, SERATRA was taken to the field where it was applied to large rivers with steady flow conditions under several previous projects. SERATRA is currently in the final stage of the testing program where smaller rivers with dynamic flow events are being modeled.

Hence under this study, SERATRA was applied to a system of two small, highly dynamic streams in New York: Cattaraugus and Buttermilk Creeks. Radionuclides found in this system are due in part to a radioactive waste burial site near Franks Creek, a tributary of Buttermilk Creek. An extensive field data collection program provided time- and space-dependent measurements of discharges, sediments, and radionuclides for the modeling of three flow events. Particular attention in the field sampling program was given to the behavior of radionuclides associated with the various size fractions of bed and suspended sediment. Laboratory analyses of collected samples under separate projects yielded data on 30 radionuclides including equilibrium distributions of dissolved and sorbed radionuclide forms. The depths and discharges required as input to SERATRA were obtained by hydrodynamic models with measured and synthesized flow data. Radionuclide information for an application of SERATRA was sufficient in four cases: ^{137}Cs, ^{90}Sr, ^{239,240}Pu, and ^{3}H.

Sediment and radionuclide concentrations predicted by SERATRA on the three flow events were in reasonable agreement with values measured in the field. SERATRA performed best where the most field data were available, underscoring the importance of complete and accurate input data when describing a complex modeling system.

SERATRA has now been tested on four field sites of widely varying flow and topographic characteristics. We recommend a comparison of predicted results with field data from a carefully controlled tracer test as the final validation of SERATRA. Since the confidence of radionuclide transport modeling is severely impaired by the general lack of the understanding of cohesive sediment transport characteristics, we strongly recommend that detailed laboratory flume testing be performed to increase the understanding of the basic mechanisms of transport, deposition and erosion of cohesive sediment in fresh and saline waters.

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Most of the measured radionuclide activities used in this study were counted by the University of Washington, Laboratory of Radiation Ecology for radiological analyses under a separate project.

1.0 INTRODUCTION

Four complex mechanisms govern the migration and fate of contaminants in surface waters: 1) transport, 2) intermedia transfer, 3) decay and degradation, and 4) transformation.

Transport refers to the mixing and advection of contaminants by the water flow. This includes the transport of sorbed and precipitated contaminants by the movement of solids entrained in the flow. Intermedia transfer involves the exchange of contaminant across the solid-liquid and liquid-gas interfaces. In the bed and water column, particulate-contaminant interaction occurs through precipitation/dissolution and adsorption/desorption. At the water surface, contaminants are volatilized to the atmosphere. Decay and degradation mechanisms attenuate the contaminant severity. Processes included in this category are radionuclide decay, and degradation due to hydrolysis, oxidation, photolysis, and biological activities. Transformation, on the other hand, creates new forms of potentially hazardous substances through the yield of daughter, degradation, or chemical-reaction products.

Historically, contaminant modeling in surface waters has been performed without considering the nonaqueous forms a contaminant may exist in or evolve to. Although a contaminant may be substantially precipitated, volatilized, or sorbed to a solid matrix, the aqueous-only modeling approach remains popular because of the conservative concentrations predicted for dissolved contaminants in most cases. Recent concern for the accumulation of contaminants in the environment in addition to the dissolved contaminant levels has prompted the development of more sophisticated surface water models.

SERATRA, a computer model of sediment-contaminant (e.g., radionuclides, pesticides, heavy metals) transport was developed in response to the need for a site assessment methodology which realistically addresses the governing mechanisms of contaminant migration and fate in surface waters. SERATRA uses the finite element computational approach to predict time-varying longitudinal and vertical distributions of sediments and contaminants in rivers and some impoundments.

The model consists of the following three coupled submodels, which describe sediment-contaminant interactions and migration:

- a sediment transport submodel
- a dissolved contaminant transport submodel
- a particulate contaminant transport submodel.

The sediment transport submodel simulates transport, deposition, scouring and armoring for three size fractions of cohesive and noncohesive sediments. The transport of particulate contaminant (i.e., contaminants adsorbed by sediment) is also simulated for each sediment size. Dissolved contaminants are linked by the adsorption/desorption process to the particulate contaminants. The contaminant submodels account for 1) advection and dispersion of dissolved and particulate contaminants; 2) radionuclide decay and chemical and biological degradation resulting from hydrolysis, oxidation, photolysis, biological activities where applicable; 3) volatilization; 4) adsorption/desorption; and 5) deposition and scouring of particulate contaminants. SERATRA also computes changes in riverbed conditions for sediment and contaminant distributions.

In an effort to prepare SERATRA for dissemination, a lengthy program of testing has been followed. Initially, numerical experiments were performed to confirm the accuracy of the model. These experiments consisted of simulating problems which have analytical solutions to compare against, and checking the mass balance by isolating the various mechanisms in the model formulation. Upon the successful completion of these experiments, SERATRA was then applied to actual field sites.

Prior to this study, sediment and radionuclide transport in the Columbia River in Washington and the Clinch River in Tennessee, were simulated by SERATRA under steady flow conditions (Onishi and Wise 1979, Onishi et al. 1980). The reasonably good results produced by SERATRA in these two applications paved the way for the final phase of model testing: unsteady flow conditions.

In an ensuing study, contamination in Four Mile and Wolf Creeks in Iowa was simulated over a three year period during which highly dynamic runoff events occurred (Onishi et al. 1979). Although the concentrations of alachlor (a pesticide) predicted by SERATRA were reasonable, no measured data were available for comparison.

SERATRA had now been successfully applied to three diverse stream systems, modeling both radionuclides and pesticides. Despite the satisfactory performance of SERATRA in the field, the time-dependent computation of particulate radionuclide transport remained unverified because of data limitations in these earlier studies.

In an effort to investigate the importance of fluvial sediment in the transport of radionuclides, the U.S. NRC requested PNL to conduct a comprehensive data collection program to provide SERATRA with suitable information for the verification study. The field site selected by the U.S. NRC is located within the watershed of Cattaraugus Creek in rural western New York. Radionuclides found in Cattaraugus Creek and its tributary, Buttermilk Creek, have originated in part from the past operation of a low-level radioactive waste disposal facility at West Valley, New York (Ecker and Onishi 1978, Walters et al. 1982, Ecker et al. 1982).

During each of the years 1977 to 1979, Pacific Northwest Laboratory (PNL) monitored one, week-long flow event on Cattaraugus and Buttermilk Creeks for discharges, sediments, and radionuclides. Hydrodynamics on these three phases of data collection were extremely varied, from a high, unsteady flow in Phase 1 to a low, steady flow in Phase 2 with an intermediate flow in Phase 3. PNL determined the physical characteristics of the water and sediment samples, e.g., temperature, concentrations, sediment size fractions, densities, etc., before sending the samples mostly to the University of Washington where the radiochemical analyses were performed. A total of 30 radionuclides were analyzed, of which ^{137}Cs, ^{90}Sr, ^{239,240}Pu, and ^{3}H had adequate data bases for a reasonable modeling effort. Fortunately, these four radionuclides have distinctly different geochemical attributes allowing the full breadth of model capability to be tested.

Complex models such as SERATRA have extensive data requirements to be properly applied in a predictive mode. Inadequate data sets have the effect of reducing the analysis to an exercise in curve fitting due to the number of model parameters which can be adjusted. In this study of the Cattaraugus Creek watershed, all parameters were predetermined prior to the model application except for the cohesive sediment transport parameters and vertical dispersion coefficient. To avoid the danger of curve fitting, these latter parameters were calibrated on one flow event and applied unchanged to the other two flow events.

This report discusses the performance testing of SERATRA on three flow events in Cattaraugus and Buttermilk Creeks where four radionuclides are simulated. Included in the report is a model description, summary of previous SERATRA applications, results from the application to Cattaraugus and Buttermilk Creeks, hypothetical case studies and the computer print out of SERATRA code.

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2.0 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The sediment-radionuclide transport model SERATRA is undergoing a testing program which will lead to its distribution as a site assessment tool. The final phase of this testing program is the field verification of the model. In the latest of a series of field applications, the Cattaraugus Creek stream system in New York was modeled to simulate the transport, deposition and resuspension of sediment and particulate radionuclides; the transport of dissolved radionuclides; and sediment-radionuclide interactions. Radionuclides simulated by SERATRA were ^{137}Cs, ^{90}Sr, ^{239,240}Pu, and ^{3}H. Results from this modeling study indicate that SERATRA can reproduce with reasonable accuracy the mechanisms which affect the migration and fate of radionuclides in rivers.

SERATRA generated the best results where known boundary conditions and verification values were both time- and space-dependent. This study emphasizes the importance of providing an adequate data set to model a complex phenomenon.

RECOMMENDATIONS

1. SERATRA has now been tested at four sites (Columbia River; Clinch River; Four Mile and Wolf Creeks; and Buttermilk and Cattaraugus Creeks) where its ability to handle a wide range of flow, sediment, and contaminant behavior has been demonstrated under current and previous studies. As a final step in the validation of SERATRA, we recommend that SERATRA be applied to a field site where a carefully controlled tracer test (e.g., a neutron activation test) can be performed.

2. Due to the radiochemical nature of the radionuclide transport problem, a critical dependence on laboratory analyses is unavoidable. Radionuclide distribution coefficients are, to a certain extent, affected by factors which cannot always be accounted for in the laboratory. In particular, the dynamics of field phenomena are impossible to duplicate. We recommend additional research into the present method of modeling a dynamic adsorption phenomenon.

3. We also recommend coupling a geochemical model with the transport model, SERATRA, so that adsorption mechanisms and precipitation are more accurately estimated by a geochemical model to obtain more accurate concentrations and forms of radionuclides in surface waters.

4. Basic characteristics of transport, deposition and erosion of cohesive sediment (e.g., silt and clay) should be investigated in a carefully controlled laboratory flume. The current lack of understanding of these characteristics inhibits a reliable prediction of particulate and dissolved radionuclides in surface waters.

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4. Basic characteristics of transport, deposition and erosion of cohesive sediment (e.g., silt and clay) should be investigated in a carefully controlled laboratory flume. The current lack of understanding of these characteristics inhibits a reliable prediction of particulate and dissolved radionuclides in surface waters.

3.0 FORMULATION OF MODEL, SERATRA

The SERATRA code uses the finite element computation method with the Galerkin weighted residual technique. It consists of three submodels coupled to include the effects of sediment-contaminant interaction. The submodels are: 1) a sediment transport submodel, 2) a dissolved contaminant transport submodel, and 3) a particulate contaminant (contaminants adsorbed by sediment) transport submodel. SERATRA not only calculates distributions of sediment and contaminant concentrations in water, but also predicts river bed conditions, including bed elevation change, sediment size distribution within the bed, and distribution of particulate contaminant concentration in the river bed. The detailed model formulation is discussed below:

3.1 SEDIMENT TRANSPORT SUBMODEL

Since the movements and adsorption capacities of sediments vary significantly with sediment sizes, the sediment transport submodel solves the migration of sediment (transport, deposition and scouring) for three size fractions of cohesive and non-cohesive sediments.

The model includes the mechanisms of:

1. Advection and dispersion of sediments
2. Fall velocity and cohesiveness
3. Deposition on the river bed
4. Resuspension from the river bed (bed erosion and armoring)
5. Sediment contributions from tributaries and point/nonpoint sources into the system and subsequent mixing.

Sediment mineralogy and water quality effects are implicitly included through the above mentioned mechanisms 2, 3, and 4.

Mass conservation of sediment passing through the control volume leads to the following expression for the transport of sediments:

$$\underbrace{\frac{\partial}{\partial t}(C_j B\ell)}_{\text{rate of accumulation}} + \underbrace{(U_\circ C_j B - U_i C_{ij} B)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial z}\left\{C_j (W - W_{sj}) B\ell\right\}}_{\text{vertical advection}}$$

$$= \underbrace{\frac{\partial}{\partial z}\left(\varepsilon_z \frac{\partial C_j}{\partial z} B\ell\right)}_{\text{vertical diffusion}} + \underbrace{\frac{1}{h}(S_{Rj} - S_{Dj})}_{\text{sediment erosion or deposition}} \qquad j = 1, 2, \ldots, N \qquad (1)$$

where(a)

B = river width

C_j = concentration of sediment of jth size fraction

C_{ij} = sediment concentration of horizontal inflow for jth size fraction

h = water depth

ℓ = longitudinal distance

N = number of sediment size fractions considered. Currently, $N = 3$ (i.e., sand, silt and clay)

S_{Dj} = sediment deposition rate per unit area for jth sediment size fraction

S_{Rj} = sediment erosion rate per unit area for jth sediment size fraction

t = time

U_i = horizontal inflow velocity

U_o = horizontal outflow velocity

W = vertical flow velocity

W_{sj} = fall velocity of sediment particle of jth size fraction

z = vertical direction

ε_z = vertical diffusion coefficient

The model neglects longitudinal diffusion and assumes lateral sediment concentrations to be uniform. However, the model does handle vertical variations of longitudinal velocity to cause some longitudinal spread of sediment.

Boundary conditions at the water surface ($z = h$) and river bed ($z = 0$) are:

$$\left(W - W_{sj}\right) C_j - \varepsilon_z \frac{\partial C_j}{\partial z} = 0 \qquad \text{at } z = h \tag{2}$$

$$-(1 - \gamma) W_{sj} C_j - \varepsilon_z \frac{\partial C_j}{\partial z} = 0 \qquad \text{at } z = 0 \tag{3}$$

(a) The symbols defined above remain the same throughout the report.

where

γ = coefficient, i.e., probability that particle settling to the bed is deposited.

Sediment erosion and deposition rates, S_{Rj} and S_{Dj}, are also evaluated separately for each sediment size fraction because erosion and deposition characteristics are significantly different for cohesive and noncohesive sediments.

Erosion and deposition of noncohesive sediments are affected by the amount of sediment the flow is capable of carrying. For example, if the amount of sand being transported is less than the flow can carry for given hydrodynamic conditions, the river will scour sediment from the stream bed to increase the sediment transport rate. This occurs until the actual sediment transport rate becomes equal to the carrying capacity of the flow or until the available bed sediments are all scoured, whichever occurs first. Conversely, the river deposits sand if its actual sediment transport rate is above the flow's capacity to carry sediment. Sediment transport capacity of flow, Q_T in this model, was calculated by either the Toffaleti or the Colby formulas (Vanoni 1975), whichever a user assigns. The computer program of the Colby method used in SERATRA was that developed by Mahmood and Ponce (Mahmood and Ponce 1975). The sediment transport capacity of flow, Q_T, was then compared with the actual amount of sand, Q_{Ta}, being transported in a river water. Hence:

$$S_{Rj} = \frac{Q_T - Q_{Ta}}{A} \tag{4}$$

$$S_{Dj} = \frac{Q_{Ta} - Q_T}{A} \tag{5}$$

where

A = the river bed surface area.

The availability of bed sediments to be resuspended was also examined to determine the actual amount of sediment erosion.

For sediment erosion and deposition rates of cohesive sediments (silt and clay), the following Partheniades (1962) and Krone (1962) formulas, respectively, were adoped in this study:

$$S_{Rj} = M_j\left(\frac{\tau_b}{\tau_{cRj}} - 1\right) \tag{6}$$

$$S_{Dj} = W_{sj}C_j\left(1 - \frac{\tau_b}{\tau_{cDj}}\right) \tag{7}$$

where

M_j = erodibility coefficient for sediment of jth size fraction

τ_b = bed shear stress

τ_{cDj} = critical shear stress for sediment deposition for jth sediment size fraction

τ_{cRj} = critical shear stress for sediment erosion for jth sediment size fraction.

Values of M_j, τ_{cDj} and τ_{cRj} must be determined by field and/or laboratory tests for a particular river regime. The model examines the availability of cohesive sediments in the river bed to determine the actual amount of sediment erosion.

When the fall velocity, W_{sj}, depends on sediment concentration and no aggregation occurs, Krone (1962) recommends:

$$W_{sj} = K_j'' C_j^{4/3} \tag{8}$$

where

K_j''= an empirical constant depending on the sediment type.

3.2 DISSOLVED CONTAMINANT TRANSPORT SUBMODEL

The dissolved contaminant transport submodel includes the mechanisms of:

1. Advection and dispersion of dissolved contaminants (pesticides, radionuclides, and other toxic substances) within the river
2. Adsorption (uptake) of dissolved contaminants by sediments (suspended and bed sediments) or desorption from sediments into water
3. Radionuclide decay
4. Degradation of dissolved contaminants due to hydrolysis, oxidation, photolysis and biological activities
5. Volatilization
6. Contributions of dissolved contaminants from tributaries and point/nonpoint sources into the system, and subsequent mixing.

Effects of water quality (e.g., pH, water temperature, salinity, etc.) and clay minerals are indirectly taken into account through changes in the distribution coefficients for adsorption and desorption, K_{dj}, K'_{dj}, respectively. In this model, distribution coefficients for adsorption can be assigned to a value different from that of desorption to be able to handle not-completely-reversible adsorption/desorption processes. Mass conservation of dissolved contaminants may be expressed as:

$$\underbrace{\frac{\partial}{\partial t}(G_w B\ell)}_{\text{rate of accumulation}} + \underbrace{(U_o G_w B - U_i G_{wi} B)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial z}(W G_w B\ell)}_{\text{vertical advection}}$$

$$= \underbrace{\frac{\partial}{\partial z}\left(\varepsilon_z \frac{\partial G_w}{\partial z} B\ell\right)}_{\text{vertical diffusion}} - \underbrace{\lambda G_w B\ell}_{\text{radionuclide decay}} - \underbrace{\sum_{i=1}^{5} K_{Ci} G_w B\ell}_{\text{chemical and biological degradation and volatilization}}$$

$$- \underbrace{\sum_j K_j (K_{dj} C_j G_w - G_j) B\ell}_{\text{adsorption to moving sediment}} - \underbrace{\sum_j K'_j (K'_{dj} C_j G_w - G_j) B\ell}_{\text{desorption from moving sediment}}$$

$$- \underbrace{\sum_j \gamma_j (1\text{-}POR) D_j K_{bj} (K_{dj} G_w - G_{Bj})}_{\text{adsorption to sediment in bed}} - \underbrace{\sum_j \gamma_j (1\text{-}POR) D_j K'_{bj} (K'_{dj} G_w - G_{Bj})}_{\text{desorption from sediment in bed}}$$

$$j = 1, 2, 3 \qquad (9)$$

It was assumed that a contaminant has the same distribution coefficient values K_{dj} or K'_{dj}, for the moving (suspended and bed load sediments) and non-moving (bed sediment without any motion) jth sediment. However, these two types of sediments have two different transfer rates, K_j or K'_j and K_{bj} or K'_{bj}, as expressed in Equation 9.

In addition to the previously defined symbols:

D_j = diameter of jth sediment

G_{Bj} = particulate contaminant concentration per unit weight of sediment in jth sediment size fraction in river bed

γ_j = specific weight of jth sediment

G_w = dissolved contaminant concentration per unit volume of water

G_{wi} = dissolved contaminant concentration in horizontal inflow

G_j = particulate contaminant concentration per unit volume of water

K_{Ci} = the first order reaction rate of contaminant degradation due to hydrolysis, oxidation, photolysis, biological activities, and volatilization

K_{bj}, K'_{bj} = transfer rates of contaminants for adsorption and desorption, respectively, with jth non-moving sediment in bed

K_{dj}, K'_{dj} = distribution coefficients rate of adsorption and desorption, respectively, between dissolved contaminant and moving sediment (suspended and bed load sediments) of jth size fraction, respectively

K_j, K'_j = transfer rates of contaminants for adosprtion and desorption, respectively, with jth sediment in motion

λ = decay rate of radioactive material.

POR = porosity of bed sediment

The distribution coefficients, K_{dj} and K'_{dj}, are defined by:

$$K_{dj} \text{ and } K'_{dj} = \frac{f_{sj} \, M'_j}{f_w / V_w} = \frac{f_{sj}}{f_w C_j} \tag{10}$$

where

f_{sj} = fraction of contaminant sorbed by jth sediment

f_w = fraction of contaminant left in solution

M'_j = weight of jth sediment

V_w = volume of water

$$\frac{f_{sj}}{f_w} = \frac{G_j}{G_w}$$

Hence Equation 10 may be rewritten as:

$$G_j = K_{dj} \, C_j \, G_w \qquad \text{or} \qquad G_j = K'_{dj} \, C_j \, G_w \tag{11}$$

The adsorption of contaminant by sediments or desorption from the sediments is assumed to occur toward an equilibrium condition with the transfer rate, K_j or K'_j (with the unit of the reciprocal of time), if the particulate contaminant concentration differs from its equilibrium values as expressed in Equation 11. Longitudinal dispersion of dissolved contaminant is considered to be negligible when compared to convection. Longitudinal spread of contaminants due to vertical variation of longitudinal velocity is, however, simulated in this study.

Boundary conditions at the water surface and river bed are:

$$WG_w - \varepsilon_z \frac{\partial G_w}{\partial z} = 0 \qquad \text{at } z = h \tag{12}$$

$$\varepsilon_z \frac{\partial G_w}{\partial z} = 0 \qquad \text{at } z = 0 \tag{13}$$

One of the important mechanisms of transport and fate of contaminants is the degradation and volatilization of contaminants in an aquatic environment. The contaminant degradation includes both chemical and biological reactions. Major mechanisms of chemical degradation are due to reactions of: 1) hydrolysis, 2) oxidation, and 3) photolysis (Smith et al. 1977). Due to the present lack of knowledge on degradation and volatilization of particulate contaminants (Smith et al. 1977), these degradation mechanisms were considered only for the dissolved contaminants. These degradation and volatilization rates are included in Equation 9 as the first order kinetic reaction rates, K_{Ci}; i=1, 2, 3, 4 and 5. Actual formulations of chemical and biological degradation, and volatilization were obtained from pesticide studies conducted by Smith et al. 1977, Zepp and Cline 1977 and Falco et al. 1976. These formulations will be discussed below:

<u>Chemical Degradation Due to Hydrolysis</u>:

The fundamental concept of chemical reactivity is based on the quest to improve stability in the configuration of the outer shells. A contaminant in solution will react with other species in solution and form a complex if there is a large increase in stability. Hydrolysis reactions are a specialized type of complex formation in which the $[OH^-]$ anion acts as the ligand. They are quite sensitive to pH changes. The rate of change of dissolved contaminant concentration due to hydrolysis is expressed by the following equation (Smith et al. 1977):

<u>Hydrolysis</u>

$$-\frac{dG_w}{dt} = K_A[H^+]G_w + K_B[OH^+]\ GW + K_N G_w$$

$$= (K_A[H^+] + \frac{K_B K_w}{[H^+]} + K_N)G_w$$

$$= (K_A \cdot 10^{-pH} + K_B \cdot 10^{pH-14} + K_N)G_w$$

$$= K_{C1} G_w \tag{14}$$

where

$$K_{C1} = K_A \cdot 10^{-pH} + K_B \cdot 10^{pH-14} + K_N$$

$$K_w = [H^+] \cdot [OH^-] = 10^{-14}$$

$$pH = -\log [H^+]$$

K_A, K_B, K_N = acid, base and neutral hydrolysis rates; respectively.

Rate coefficients, K_A, K_B and K_N can be determined from laboratory tests (Smith et al. 1977).

Chemical Degradation Due to Oxidation

Oxidation of contaminants by free radical processes may become important under some environmental conditions. The rate of oxidation of contaminant may be expressed by the second order reactions depending on the concentration, of free and radical oxygen, and dissolved contaminant as shown below (Smith et al. 1977):

$$-\frac{dG_w}{dt} = K_{ox}[RO_2\cdot]G_w + K_{AB}[RO\cdot]G_w \tag{15}$$

It is assumed that only a small concentration of dissolved contaminants is oxidized, and that the second term in the right hand side may be deleted (Smith et al. 1977). Hence:

$$-\frac{dG_w}{dt} = K_{ox}[RO_2\cdot]G_w = K_{C2}G_w \tag{16}$$

where

K_{ox}, K_{AB} = oxidation rates of free radical oxygen of $[RO_2\cdot]$ and $[RO\cdot]$, respectively

$RO_2\cdot$ = free radical oxygen

$RO\cdot$ = free radical oxygen

The rate constant, K_{ox} can be obtained from laboratory tests outlined by Smith et al. (1977).

Chemical Degradation Due to Photolysis

Some contaminants can be photochemically transformed by absorbing light, especially ultraviolet light. The rate of contaminant concentration change due to photolysis reactions may be expressed by (Zepp and Cline 1977, Smith et al. 1977, and Stanford Research Institute 1979):

$$-\frac{dG_w}{dt} = \frac{2.303}{J} \phi \sum_{\lambda} \varepsilon_{\lambda} I_{\lambda} G_w$$

$$I_{\lambda} = I_{o\lambda} \exp \left\{-(K_1 + K_2 \bar{C})\ (h - z)\right\} \tag{17}$$

where

$\bar{C}$ = average sediment concentration above water depth Z

$I_{o\lambda}$ = incident light intensity of wave length λ

I_{λ} = light intensity of wave length λ at water depth Z

J = conversion constant

K_i = light attenuation coefficient for water

K_Z = light attenuation coefficient due to suspended sediment in water

ε_{λ} = molar extinction coefficient of light with the wave length λ

ϕ = quantum yield.

Since each computational cell has a vertical finite element thickness, the above equation was averaged over the element thickness for each element in this study. Hence:

$$-\frac{dG_w}{dt} = \frac{2.303}{J} \phi \sum_{\lambda} \varepsilon_{\lambda} I_{o\lambda} \exp \left[\left\{-(K_1 + K_2\bar{C})(n - i)\Delta z\right\} \cdot \left\{\frac{1 - \exp\left(-(K_1 + K_2\bar{C})\Delta z\right)}{(K_1 + K_2\bar{C})\ z}\right\} G_w\right] \tag{18}$$

$$= K_{C3} G_w$$

where

i = element's number counted from the river bottom

n = total number of elements

Δz = element thickness.

Various parameters and coefficients can be measured by conducting laboratory tests and/or field measurements (Zepp and Cline 1977, Smith et al. 1977, and Stanford Research Institute 1979).

Biodegradation

A contaminant compound may be degraded by microbial activities in an aquatic environment. In this study it is assumed that microbial degradation can be expressed by the second order reaction (Falco et al. 1976, Smith et al. 1977) depending on concentrations of biomass and contaminant in water, as shown below:

$$-\frac{dG_w}{dt} = K_{B1}[B]G_w = K_{C5}G_w \tag{19}$$

where

$[B]$ = biomass per unit volume

K_{B1} = the second order rate constant for biodegradation.

Volatilization

The volatilization of a contaminant occurs at the air-water interface. The change of contaminant concentration due to volatilization may be expressed by the following first order reaction (Smith et al. 1977):

$$-\frac{dG_w}{dt} = K_{C3}G_w \tag{20}$$

where

K_{C3} = volatilization rate of the contaminant

K_{C3} can be estimated by the following relationship:

$$(K_{C3})_{\text{water body}} = (K_o)_{\text{water body}}\left(\frac{K_{C3}}{K_o}\right)_{\text{laboratory test condition}}$$

$$= (K_o)_{\text{water body}}\left(\frac{d_o}{d_s}\right)$$

where

d_o, d_s = molecular diameters of oxygen and contaminant, respectively

(K_{C3}) laboratory test conditions = volatilization rate through any substances measure at a laboratory

(K_O) water = oxygen reaeration rate through water-air interface

3.3 PARTICULATE CONTAMINANT TRANSPORT SUBMODEL

The transport model of contaminants attached to sediment includes the mechanisms of:

1. Advection and dispersion of particulate contaminants
2. Adsorption of dissolved contaminants by sediments or desorption from sediments into water
3. Radionuclide decay
4. Deposition of particulate contaminants to the river bed or resuspension from the river bed
5. Contributions of particulate contaminants from tributaries and point/nonpoint sources into the system, and subsequent mixing.

As in the transport of sediments and dissolved contaminants, the conservation of contaminants adsorbed by each sand, silt and clay sediment may be expressed as:

$$\underbrace{\frac{\partial}{\partial t}(G_j\ B\ell)}_{\text{rate of accumulation}} + \underbrace{(U_\circ G_j\ B - U_i G_{ij}\ \ B)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial z}\left\{(W - W_{sj})G_j\ B\ell\right\}}_{\text{vertical advection}} \tag{21}$$

$$= \underbrace{\frac{\partial}{\partial z}\left(\varepsilon_z \frac{\partial G_j}{z} B\ell\right)}_{\text{vertical diffusion}} \underbrace{- \lambda G_j\ B\ell}_{\text{radionuclide decay}} + \underbrace{K_j\ (K_{dj} C_j G_w - G_j)\ B\ell}_{\text{adsorption}} + \underbrace{K_j'\ (K_{dj}' C_j G_w - G_j)\ B\ell}_{\text{desorption}} + \underbrace{\frac{1}{h}\ (G_{Bj} S_R - G_j S_D)}_{\text{contaminated sediment erosion and deposition}}$$

where

G_{ij} = particulate concentration per unit volume of water associated with the j_{th} sediment size fraction in horizontal inflow.

Longitudinal dispersion of particulate contaminant was assumed to be negligible, as compared to longitudinal advection. However, as noted before, the longitudinal spread of particulate contaminant due to nonuniform vertical distribution of longitudinal velocity is simulated in the model. It is also assumed that chemical and biological degradation of particulate contaminants, except radionuclide decay, is not significant. However, if it is necessary to include these mechanisms, the radionuclide decay term may include them.

The boundary conditions at the water surface and bed are:

$$G_j \ (W - W_{sj}) - \varepsilon_z \frac{\partial G_j}{\partial z} = 0 \qquad \text{at } z = h \text{ and } 0 \qquad (22)$$

The finite element technique with the Galerkin weighted residual method was used to solve the transport equations of sediments, dissolved contaminants and particulate contaminants.

3.4 FINITE ELEMENT TECHNIQUE

Because of its increased solution accuracy and ready accommodation to various boundary geometries (Desai and Abel 1972, Norton et al 1973, Onishi and Wise 1978) this method was used for this study. To apply the finite element method to a partial differential equation, an alternate integral equation is developed. The finite element method employing a Galerkin weighted residual was used to solve Equations 1, 9, and 21 with the associated boundary conditions of Equations 2, 3, 12, 13, and 22. Since the governing equations of sediment and contaminant transport have similar forms, the finite element technique is described here for the following advection-diffusion equation of the general form:

$$L\,[\phi] = \frac{\partial \phi}{\partial t} + \frac{\partial}{\partial z}\,(v\phi) - \frac{\partial}{\partial z}\,(\varepsilon_z \frac{\partial \phi}{\partial z}) + \alpha\phi - \beta \qquad (23)$$

The coefficients v, ε_Z, α, β are defined to accommodate the specific forms of the sediment and contaminant transport equations.

Galerkin Weighted Residual Method

The governing partial differential equation can be recast in an integral form employing the weighted residual method. This integral is formed by taking the product of L[ϕ] with some arbitrary set of weighting functions, W_j, which yields:

$$\chi = \int_R L[\phi] W_j \, dz \qquad (24)$$

where

R = a domain of interest.

If ϕ is approximated by some polynomial:

$$\tilde{\phi} = \sum_{i=1}^{n} \phi_i W_i \qquad (25)$$

where

W_i = approximating functions then the quantity $L[\tilde{\phi}]$ represents the residual error.

For the Galerkin weighted residual method, the approximating function W_i is chosen to be the same as the weighting function W_j. The integral term becomes an error distribution principle by which the nodal values ϕ_i can be determined so that the residual error over the domain R is orthogonal to the polynomial selected for weight and interpolation functions.

By expanding the equation and integrating by parts, the reduced functional results:

$$\chi = \int_R W_j\frac{\partial\phi}{\partial t} + W_j\left[\frac{\partial}{\partial z}(v\phi) + \frac{\partial W}{\partial z}j\ \epsilon\ \frac{\partial\phi}{z\partial z} + W_j\alpha\phi - W_j\beta\right]dz - W_j\epsilon\frac{\partial\phi}{z\partial z}\bigg|_0^h = 0 \qquad (26)$$

$$j = 1, 2 \ldots n + 1$$

Note that Equation 26 was derived by assuming no net flux across the boundary. In cases where the boundary has positive or negative net flux across it, this flux was incorporated as a source or sink term in the governing equation.

The above integral can be partitioned so that:

$$\chi = \chi_e 1 + \chi_e 2 + \chi_e 3 + \ldots + \chi_e n = \sum_{i=1}^{n} \chi_e i \qquad (27)$$

where

n = the number of subdomains.

This may be expanded to give:

$$\chi = \int_{z_1}^{z_2} [\ ]\,dz + \int_{z_2}^{z_3} [\ ]\,dz + \ldots + \int_{z_n}^{z_{n+1}} [\ ]\,dz \qquad (28)$$

The contents in brackets in Equation 28 are the same as those in Equation 26. Equation 28 will yield a set of n+1 ordinary differential equations in terms of the ϕ_{n+1}.

Finite-Element Equations

The contributions from any typical subregion or finite element can be developed by substituting a particular polynomial approximation for ϕ into Equation 26. For simplicity, a linear approximation was chosen: i.e.,

$$\phi \simeq \tilde{\phi} = \frac{Z_{i+1} - Z}{\Delta z} \tilde{\phi}_i + \frac{Z - Z_i}{\Delta z} \tilde{\phi}_{i+1} \tag{29}$$

where

$$\Delta z = z_{i+1} - z_i .$$

In vector notation, one has:

$$\tilde{\phi}(z,t) = W_i, W_{i+1} \begin{Bmatrix} \tilde{\phi}_i \\ \tilde{\phi}_{i+1} \end{Bmatrix} \tag{30}$$

where weighting functions are given by:

$$W_i = \frac{1}{\Delta z} (z_{i+1} - z) \tag{31}$$

$$W_{i+1} = \frac{1}{\Delta z} (z - z_i) \tag{32}$$

The individual terms in the functional are approximated by:

$$\frac{\partial}{\partial t} = W_1, W_2 \begin{Bmatrix} \frac{\partial \phi_i}{\partial z} \\ \frac{\partial \phi_{i+1}}{\partial z} \end{Bmatrix} \tag{33}$$

$$\frac{\partial \phi}{\partial z} = \frac{\partial W_i}{\partial z}, \frac{\partial W_{i+1}}{\partial z} \begin{Bmatrix} \tilde{\phi}_i \\ \tilde{\phi}_{i+1} \end{Bmatrix} = - \left[- \frac{1}{\Delta z}, \frac{1}{\Delta z} \right] \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} \tag{34}$$

Substituting these quantities into Equation 26 for a typical subdomain, a set of algebraic equations is obtained.

The results for individual terms are given below.

1. Time Dependent Term:

$$\int_{R_{ei}} W_j \frac{\partial \phi}{\partial t} dz = \int_{z_i}^{z_{i+1}} W_i W_j dz \left\{ \partial \phi \right\} \quad dz = \frac{\Delta z}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{Bmatrix} \frac{d\phi_i}{dt} \\ \frac{d\phi_{i+1}}{dt} \end{Bmatrix} \tag{35}$$

2. Advective Term:

$$\int_{R_{ei}} W_j \frac{\partial v\phi}{\partial z} dz = \int_{R_{ei}} W_j \frac{\partial v}{\partial z}\phi \, d_z + \int_{R_{ei}} W_j \, v\frac{\partial \phi}{\partial z} \, d_z =$$

$$= \begin{bmatrix} -\frac{2}{3}v_i + \frac{1}{6}v_{i+1} & \frac{1}{6}v_i + \frac{1}{3}v_{i+1} \\ -\frac{1}{3}v_i - \frac{1}{6}v_{i+1} & -\frac{1}{6}v_i + \frac{2}{3}v_{i+1} \end{bmatrix} \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} \tag{36}$$

3. Diffusion Term:

$$\int_{R_{ei}} \frac{\partial W_j}{\partial z} \epsilon_z \frac{\partial \phi}{\partial z} dz = \frac{\epsilon_z}{\Delta z^2} \int_{z_i}^{z_{i+1}} \begin{bmatrix} 1 & -1 \\ 1 & -1 \end{bmatrix} \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} dz = \frac{\epsilon_z}{\partial z} \begin{bmatrix} 1 & -1 \\ 1 & -1 \end{bmatrix} \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} \tag{37}$$

4. Decay Term:

$$\int_{R_{ei}} W_j \alpha \phi_i dz = \alpha \int_{z_i}^{z_{i+1}} W_j W_i dz \phi_i = \frac{\alpha \Delta z}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} \tag{38}$$

5. Sink/source Term:

$$\int_{R_{ei}} W_j \beta dz = \beta \int_{z_i}^{z_{i+1}} W_j dz = \beta \Delta z \begin{Bmatrix} 1/2 \\ 1/2 \end{Bmatrix} \tag{39}$$

Where β is assumed independent of z. However, many sink/source terms in Equations 1, 9, and 21 are not independent of z and these terms are integrated according to their dependency of z. Summing up and gathering terms, one can write the element contributions to the matrix equation as finite element:

$$\sum_{j=1}^{n} [P]_{ej} \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} + [S]_{ej} \begin{Bmatrix} \phi_i \\ \phi_{i+1} \end{Bmatrix} = \sum_{j=1}^{n} \{R\}_{ej} \tag{40}$$

where

$$[P]_{ej} = \Delta z \begin{bmatrix} 1/3 & 1/6 \\ 1/6 & 1/3 \end{bmatrix} \tag{41}$$

$$\left\{R\right\}_{ej} = \frac{\beta \Delta z}{2} \left\{ \begin{matrix} 1 \\ 1 \end{matrix} \right\} \qquad \text{(if } \beta \text{ is independent of z)} \qquad (42)$$

$$[S]_{ej} = \begin{bmatrix} \left(D - \frac{2}{3} V_i + \frac{1}{6} V_{i+1} + \frac{\alpha \Delta z}{3}\right) & \left(- D - \frac{1}{6} V_i - \frac{1}{3} V_{i+1} - \frac{\alpha \Delta z}{6}\right) \\ -\left(D + \frac{1}{3} V_i + \frac{1}{6} V_{i+1} + \frac{\alpha \Delta z}{6}\right) & \left(+ D - \frac{1}{6} V_i + \frac{2}{3} V_{i+1} + \frac{\alpha \Delta z}{3}\right) \end{bmatrix} \qquad (43)$$

$$D = \frac{\varepsilon_z}{\Delta z}, \qquad (44)$$

The summation given in Equation 27 gives the rules for construction the matrices for all finite elements; the matrices [P] and [S] become tridiagonal matrices. The final set of equations is a generalization of Equation 40.

Time-Dependent Solution

The final set of equations derived above can be expressed by:

$$[\tilde{P}] \left\{\frac{d\phi}{dt}\right\} + [\tilde{S}] \left\{\phi\right\} = \left\{\tilde{R}\right\} \qquad (45)$$

where

$[\tilde{P}]$ matrix = a symmetric tridiagonal

$[\tilde{S}]$ matrix = an unsymmetric tridiagonal

$\left\{R\right\}$ = a load vector.

This final system of equations is approximated by a Crank-Nicholson scheme (Varga 1965):

$$[\tilde{P}] \frac{\{\phi\}^{n+1} - \{\phi\}^{n}}{\Delta t} = - \frac{1}{2} [\tilde{S}] \left(\{\phi\}^{n+1} + \{\phi\}^{n}\right) + \frac{1}{2} \left(\{R\}^{n+1} + \{R\}^{n}\right) \qquad (46)$$

Solving the for n+1 value of , this expression can be rearranged to obtain:

$$[\bar{P}] \{\phi\}^{n+1} = [\bar{S}] \{\phi\}^{n} + \{\bar{R}\} \qquad (47)$$

where the new coefficient matrices are:

$$[\bar{P}] = [\tilde{P}] + \left(\frac{\Delta t}{2}\right) [\tilde{S}] \qquad (48)$$

$$[\bar{S}] = [\tilde{P}] - \left(\frac{\Delta t}{2}\right) [\tilde{S}] \qquad (49)$$

$$\{\bar{R}\} = \Delta t\ \{\tilde{R}\} = \frac{\Delta t}{2}\left(\{R\}^{n+1} + \{R\}^{n}\right) \tag{50}$$

This type of approximation is second order correct, unconditionally stable and easily solved by most available tridiagonal solution schemes.

A computer program has been written in the FORTRAN preprocessor language FLECS to implement the model (Onishi and Wise 1979). However, a standard FORTRAN IV version of SERATRA is also available.

3.5 LISTS OF INPUT DATA AND SIMULATION OUTPUT

SERATRA, consisting of the three submodels, is applicable to nontidal rivers and impoundments. One of the advantages of SERATRA is that it can be applied to water bodies over large longitudinal distances and shallow depths by using a large aspect ratio of a computational cell. Input data requirements for SERATRA are:

- Common Data Requirements for all the Submodels:
  - Channel geometry
  - Discharges and flow depths of the rivers during the simulation period
  - Discharges of tributaries, overland runoff and other point/nonpoint sources
  - Vertical dispersion coefficient
- Additional Requirements for Sediment Transport Submodel
  - Sediment size fractions
  - Sediment density and fall velocities of sediments (sand, silt, and clay)
  - Critical shear stresses for erosion and deposition of cohesive sediment (silt and clay)
  - Erodibility coefficient of cohesive sediment

  Initial Conditions
    - Sediment concentration for each sediment size fraction
    - Bottom sediment size fraction

  Boundary Conditions
    - Sediment concentration at the upstream end of the study reach

- Contributions of sediments from overland, tributaries and other point and nonpoint sources.

- Additional Requirements for Dissolved and Particulate Contaminant Transport Submodels:
  - Distribution coefficients and transfer rates of contaminant with sediment in each sediment size fraction (i.e., sand, silt, and clay). If values of distribution coefficients are not available, it is necessary to know clay mineral and organic sediment content to estimate these values.
  - Degradation, volatilization and decay rates of contaminants

  Initial Conditions
    - Dissolved contaminant concentration
    - Particulate contaminant concentration for each sediment size fraction (i.e., those attached to sand, silt, and clay)

  Boundary Conditions
    - Dissolved and particulate contaminant concentrations for each sediment size fraction at the upstream end of the study reach
    - Contributions of dissolved and particulate contaminant concentrations from tributaries, overland, and other point/nonpoint sources.

With the input data described above, SERATRA simulates the following:

1. Sediment simulation for any given time
   - longitudinal and vertical distributions of total sediment (sum of suspended and bed load) concentration for each sediment size fraction
   - longitudinal and vertical distributions of sediment size fractions in the river bed
   - change in bed elevation (elevation changes due to sediment deposition and/or scour)
2. Contaminant simulation for any given time
   - longitudinal and vertical distributions of dissolved contaminant concentration
   - longitudinal and vertical distributions of contaminant concentration adsorbed by sediment for each sediment size fraction

- longitudinal and vertical distributions of contaminant concentrations in the bottom sediment within the bed for each sediment size fraction.

4.0 MODEL TESTING

This chapter describes the testing program which has led to this application of SERATRA to the Cattaraugus and Buttermilk Creeks in New York. Sensitivity analysis results are also discussed here. SERATRA was developed as a site assessment tool for contaminants in surface waters. To build its credibility as a reliable transport model, a rigorous four point testing program was established:

1. analytical solution confirmation
2. mass balance check
3. steady flow field verification
4. unsteady flow field verification.

SERATRA is now in the final phase of model verification.

4.1 ANALYTICAL SOLUTION

First, the model was tested under conditions where analytical solutions were known. These tests examined how accurately the code algorithm portrays the vertical sediment and contaminant distributions. This was accomplished by applying the code to well-posed convection-diffusion boundary value problems having analytical solutions. One of the cases dealt with the following unsteady one-dimensional convection-diffusion equation:

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial y} = \varepsilon_y \frac{\partial^2 C}{\partial y^2}$$

with an initial condition of

$$C(y,o) = \exp\left(\frac{Uy}{2\varepsilon_y}\right) \sin\left(\frac{\pi y}{\ell}\right)$$

and boundary conditions of

$$C(o,t) = 0 \text{ and } C(\ell,t) = 0.$$

Parameter values employed in the test cases were length (ℓ) = 1, velocity (U) = -2, and vertical dispersivity (ε_y) = 1. The computed results and the analytical solution compared favorably (Figure 4.1). Such agreement verified that the finite-element computational scheme of the SERATRA code accurately solves the convection-diffusion equation.

4.2 MASS BALANCE

Fundamental to any successful application model is the ability to conserve mass. Errors in mass balance can be due to the model formulation or the truncation error of the computer. Hence, after examining the model against analytical solutions as discussed in Section 4.1, the mass balance of SERATRA

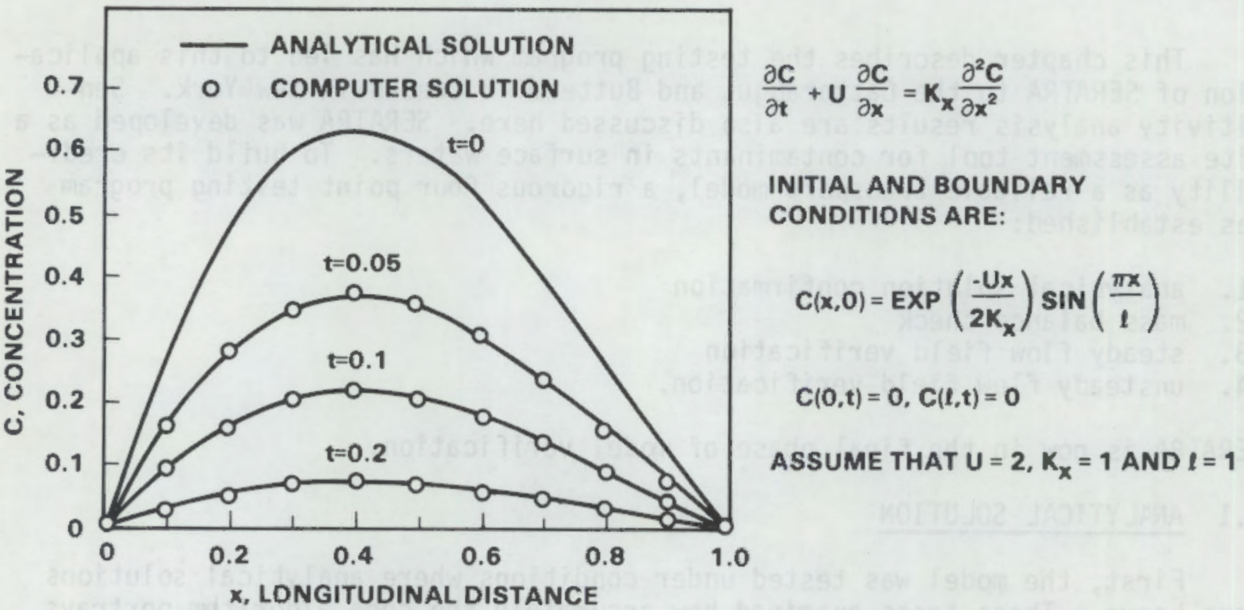


FIGURE 4.1. Comparison of SERATRA Results with the Analytical Solution to the Unsteady Convection-Diffusion Equation

was tested for 18 runs. These numerical experiments were designed to isolate the various physical and chemical processes in SERATRA for mass balance behavior. Table 4.1 summarizes the processes evaluated in this part of the testing program.

The machine accuracy of the computer used to apply SERATRA is seven significant figures. Each segment in this simulation displays mass conservation with an accuracy of at least five significant figures for each of the tested processes.

4.3 SENSITIVITY ANALYSES

As indicated in Chapter 3, only model parameters and coefficients which can be adjusted to fit to measured sediment and radionuclide data are vertical dispersion coefficient, and three parameters for cohesive sediment erosion and deposition (critical shear stresses for erosion and deposition and erodibility coefficient). Sensitivity analyses revealed that dispersion coefficient was rather important not only to the vertical sediment and contaminant distributions but also to the overall stability of the modeling. Three parameters for cohesive sediment erosion and deposition strongly affect the fine sediment distributions in water column and river bed, thus radionuclide transport, deposition and erosion. For example, sediment concentrations almost linearly increase with the erodibility coefficient once the bed shear stress is above the critical shear stress of erosion. Unfortunately, these parameters are

TABLE 4.1. SERATRA Mass Balance Testing Program

	Test																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Scour/Deposition of Sediment							–	–	–	–	–	–						
Radionuclide Adsorption/ Desorption in Stream		–		–	–	–		–		–	–	–						
Radionuclide Adsorption/ Desorption in Bed			–	–	–	–			–	–	–	–						
Tributary Boundary Conditions					–						–							
Bed Initial Radionuclide Condition						–												
Radionuclide Decay													–					
Biological Decay														–				
Degradation Due to Photolysis															–			
Degradation Due to Hydrolysis																–		
Degradation Due to Oxidation																	–	
Degradation Due to Volatilization																		–

some of the least known parameters due to the lack of general understanding of cohesive sediment erosion and deposition. Further field and laboratory studies on the mechanisms of fine sediment transport, deposition and erosion should be conducted to improve the current understanding of the fine sediment transport characteristics to reduce the uncertainty on the fine sediment, thus also radionuclide transport modeling.

Other model parameters and coefficients should be determined by theoretical, experimental and field studies prior to model calibration rather than to adjust these values as a part of the model calibration to fit predicted distributions to measured data.

The study also reveals that the distribution coefficient is a very important parameter and almost linearly affects the particulate radionuclide concentrations, as shown in a series of cases discussed in the next chapter. Profound effects of flow and sediment diameters on the migration of radionuclides are also revealed as indicated in Chapter 5.

4.4 PREVIOUS FIELD TESTING UNDER STEADY FLOW CONDITIONS

The goal of the field testing program was to demonstrate the effectiveness of the model under a wide range of field conditions.

The Columbia River in Washington between Priest Rapids (River Kilometer 640) and McNary Dams (River Kilometer 470) was modeled under previous studies for the transport of sediments, radioactive ^{65}Zn (Onishi and Wise 1979), and a heavy metal (Onishi et al. 1982). The Columbia is a large river (~1700 m^3/s) which contains both free flowing and backwater regions. Flow conditons were assumed to be steady. A comparison of the SERATRA predicted results with measured ^{65}Zn concentrations appears in Figure 4.2. Correlation is excellent.

The next site chosen for another previous study was the Clinch River in Tennessee (Onishi et al. 1980). The Clinch is of intermediate proportions (~120 m^3/s) also exhibiting steady flow conditions. In this case, the modeled reach was 37.2 km of backwater from the river mouth to Melton Hill Dam (river kilometer 37.2). Results from this modeling of ^{90}Sr are in excellent agreement with measured concentrations (Figure 4.3).

4.5 PREVIOUS FIELD TESTING UNDER UNSTEADY FLOW CONDITIONS

The success of SERATRA in larger rivers under steady flow condiions paved the way for the first field application with unsteady boundary conditions. Generally, the time scale for events on a large stream are much longer than those on a small stream. Thus, without going to longer simulations, the best way to test the dynamics of the code is to apply it to smaller streams. The baseflow of Wolf Creek in Iowa is ~7 m^3/s. High runoff events on this stream can raise the flow to 20 m^3/s for short periods of time which was the

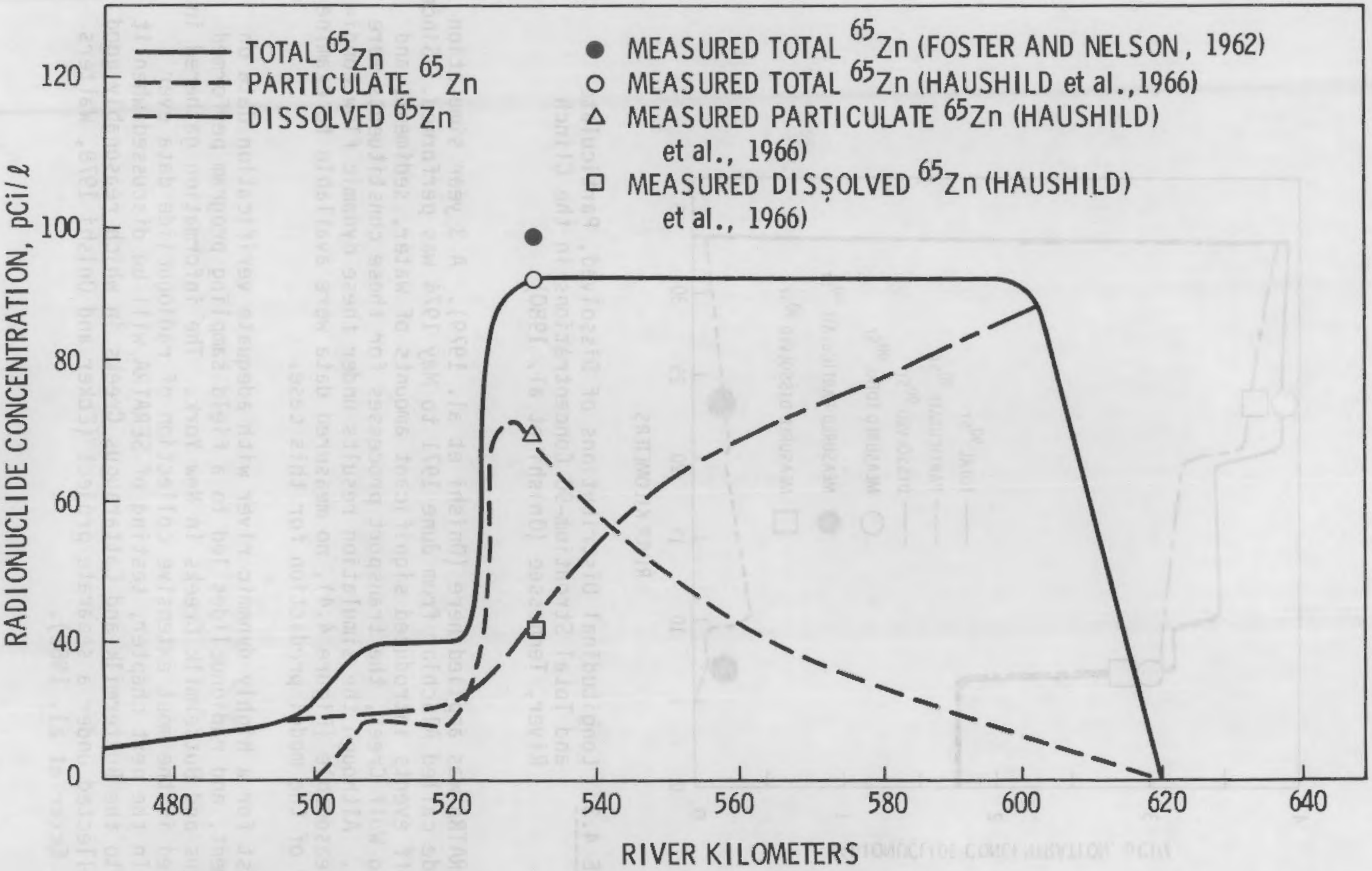


FIGURE 4.2. Comparison of Predicted Results with Measured Zinc-65 Concentrations in the Columbia River, Washington (Onishi et al. 1979)

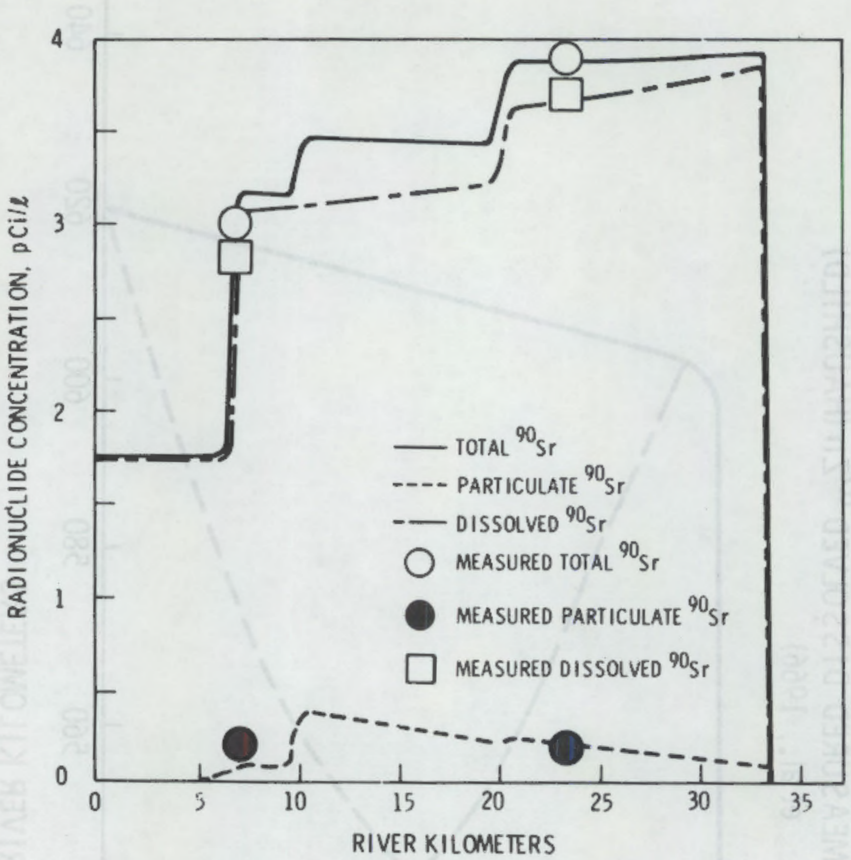


FIGURE 4.3. Longitudinal Distributions of Dissolved, Particulate and Total Strontium-90 Concentrations in the Clinch River, Tennessee (Onishi et al. 1980)

case when SERATRA was applied here (Onishi et al. 1979). A 3 year simulation of a pesticide called Alachlor from June 1971 to May 1974 was performed. Since several runoff events introduced significant amounts of water, sediment, and alachlor into Wolf Creek, the transport processes for these constituents were very dynamic. Although the simulation results under these dynamic flow conditions seem reasonable (Figure 4.4), no measured data were available to examine the accuracy of the model prediction for this case.

The quest for a highly dynamic river with adequate verification data on water, sediment, and radionuclides led to a field sampling program performed on Cattaraugus and Buttermilk Creeks in New York. The information gathered in this watershed is the most extensive collection of radionuclide data ever assembled. In the next chapter, testing of SERATRA will be discussed when it was applied to the Buttermilk and Cattaraugus Creeks in which reasonably good data were collected under a separate project (Ecker and Onishi 1978, Walters et al. 1982, Ecker et al. 1982).

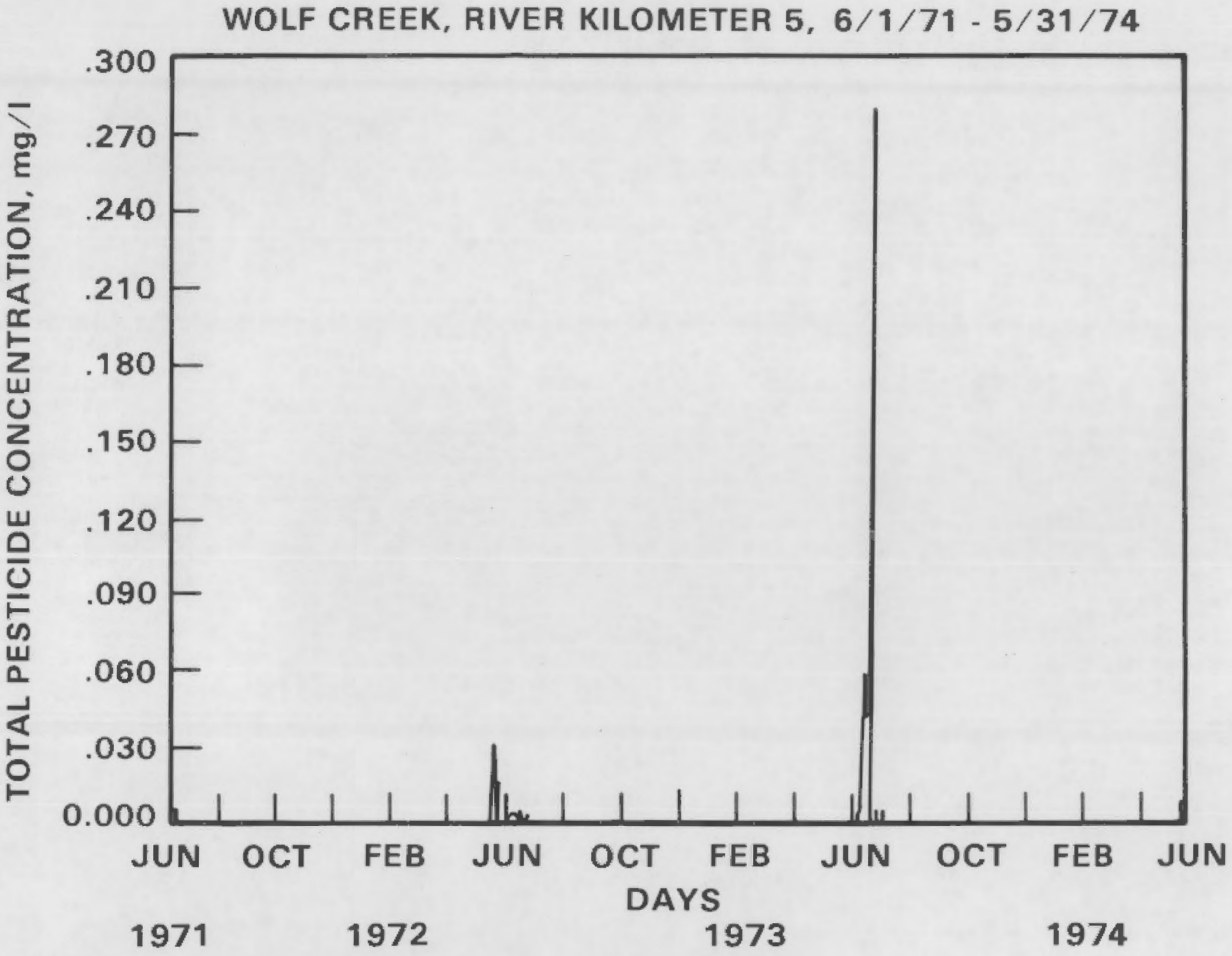

WOLF CREEK, RIVER KILOMETER 5, 6/1/71 - 5/31/74

FIGURE 4.4. Time Variation of Total Alachlor Concentration at Wolf Creek River Kilometer 5 During the 3-Year Simulation Period (Onishi et al. 1979)

5.0 MODELING APPLICATION

In this chapter, SERATRA, a transient, two-dimensional (laterally-averaged), sediment and radionuclide transport model, is applied to the Cattaraugus/Buttermilk Creeks in New York. Data from an extensive field sampling and analysis program provided the information necessary for the execution of this computer model. Water, sediment, and radionuclides were analyzed for various properties including temperature, concentration and activity levels.

Hydrologic modeling of rainfall, runoff, and instream hydrodynamics were performed to generate data necessary for SERATRA. These data were calibrated against measured streamflow in Cattaraugus Creek. A calibration of the cohesive sediment transport parameters was also done.

Ten simulations were performed on three flow events. The modeled radionuclides were ^{137}Cs, ^{90}Sr, ^{239,240}Pu and ^{3}H.

5.1 SITE DESCRIPTION

The Western New York Nuclear Service Center, shown in Figure 5.1, is located about 30 miles south of Buffalo, New York. The Center consists of a 3345-acre site in the north central portion of Cattaraugus County. The Center is situated along an elongated rolling plain with glaciated bedrock hills along the eastern, western and southern boundaries, and Buttermilk Valley along the northern boundary. All surface drainage of the Center discharges into Buttermilk Creek. At the northwest end of the property, Buttermilk Creek joins Cattaraugus Creek which flows in a westerly direction into Lake Erie, 39 miles away. Cattaraugus Creek flows in a general westerly direction through Zoar Valley, Gowanda, and Cattaraugus Indian Reservation and empties into Lake Erie, 27 miles southwest of Buffalo. It is 20 stream miles from the confluence of Buttermilk and Cattaraugus Creeks to Gowanda and another 19 miles to the mouth of Cattaraugus Creek at Lake Erie. Franks Creek (Erdmans Brook), a tributary of Buttermilk Creek, serves as a receptor for runoff from the Center's Burial site.

Three water courses, Franks Creek, Buttermilk Creek and Cattaraugus Creek, are the principal water courses of interest in the study of radionuclide transport in surface waters from the Western New York Nuclear Service Center. The following is a brief description of each of these water courses.

Franks Creek, commonly referred to as Erdmans Brook, includes the drainage area for both the low- and high-level nuclear burial sites. The creek flows into Buttermilk Creek about 0.5 miles downstream of the burial sites. The stream flow in the creek is intermittent, varying between 0 and 100 cubic feet per second (cfs). The creek is very narrow, varying in width from 2 to 10 ft. The creek is comprised of chutes and pools, and flows in some places through swampy areas. Stream gradients are moderately steep, and the creek shows active down-cutting through previously undisturbed glacial

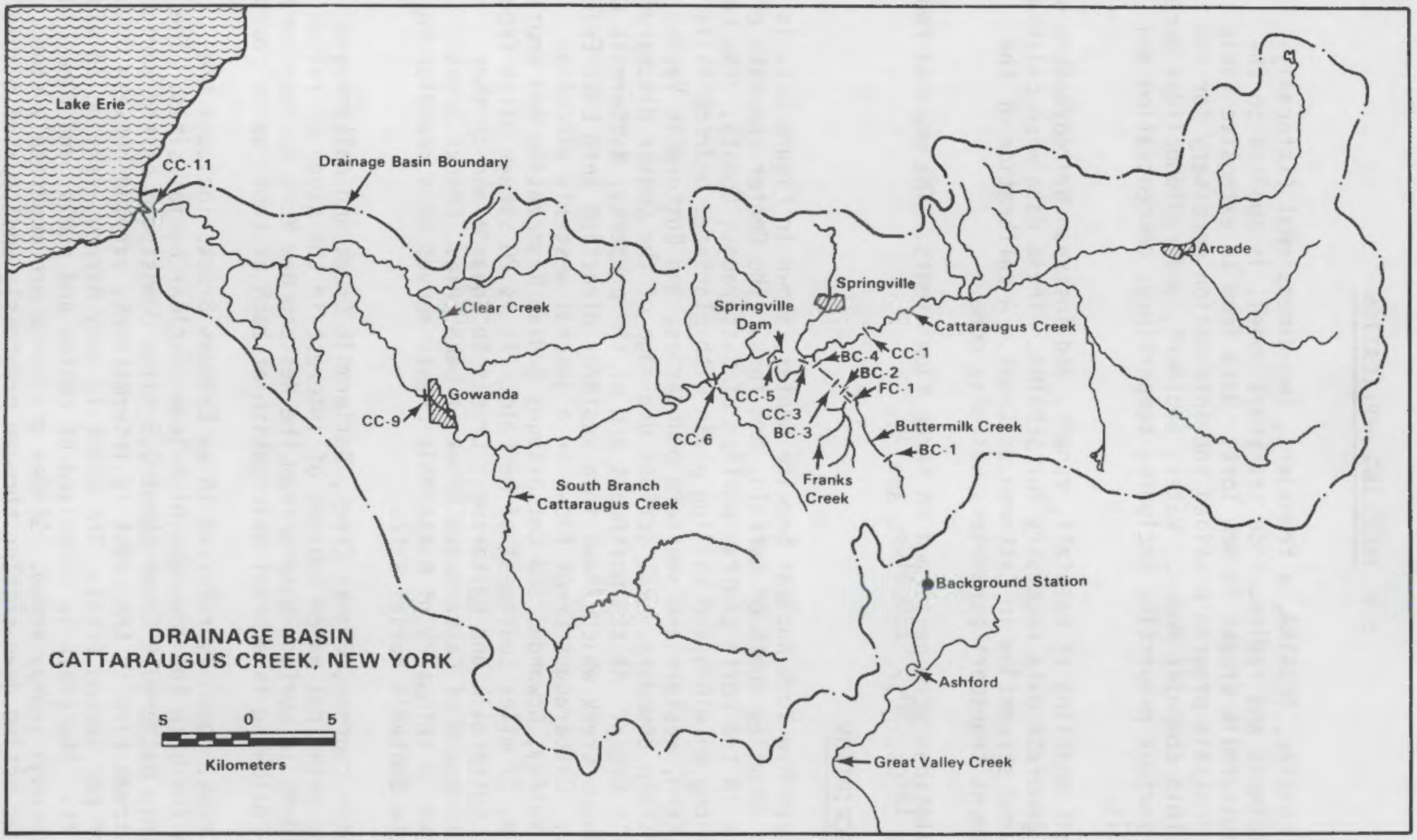


FIGURE 5.1. Map of Cattaraugus, Buttermilk and Franks Creeks

till which is comprised of a very stiff clayey material. This clayey material appears to be fairly resistant to erosion. The creek flows through a narrow and steep, V-shaped valley.

Buttermilk Creek has a drainage area of approximately 29.4 mi^2. For the period of record from October 1961 to September 1968, the average discharge of Buttermilk Creek was 46.5 cfs. The extreme maximum and minimum discharges during the period of record were 3,910 cfs on 28 September 1967 and 2.1 cfs on 10 October 1963, respectively. Buttermilk Creek flows into Cattaraugus Creek about 2.25 miles downstream of the confluence with Franks Creek. The creek width under normal conditions varies from about 20 ft at the upper end to about 75 ft near the confluence with Cattaraugus Creek. The channel bed is comprised of sand, gravel and cobbles with minor amounts of silt and clay size material. Water frequently overflows the channel banks leaving deposits of fine clayey silt along the flood plain. The flood plain varies from 300 to 500 ft wide with sparse to moderate vegetation.

A reservoir upstream of the Buttermilk Creek study reach collects runoff from a small watershed and periodically releases overflow into Buttermilk Creek. Discharge from the reservoir is regulated by a siphon spillway that maintains reservoir levels below a certain elevation. Once the siphon is primed, large quantities of water are discharged in a short period of time, producing extremely fast rising hydrographs in Buttermilk Creek during periods of relatively low flow.

Cattaraugus Creek has an estimated drainage area of 555 mi^2 at Lake Erie, 432 mi^2 at Gowanda and 218 mi^2 at the confluence with Buttermilk Creek. Based on the United States Geological Survey (USGS) flow data records for Cattaraugus Creek at Gowanda, New York, the average discharge for the period of record, 1940-1976, is 731 cfs. The extreme maximum and minimum daily discharges during the period of record were 34,600 cfs on 7 March 1956, and 6 cfs, respectively, on 21 August 1941.

Peak discharges generally occur on Cattaraugus Creek in October and November, prior to the onset of winter snowfall and again in February and March as a result of snowmelt. Low discharges generally occur during the summer months of July through September when rainfall is less and again during the winter months of December and January when persistent freezing conditions exist. Figure 5.2 is a summary of the 1975 and 1976 water year monthly discharge records of Cattaraugus Creek at Gowanda, New York. Cattaraugus Creek, as well as Buttermilk Creek, can be categorized as "flashy" due to their very rapid changes in discharge. Figure 5.3 is an excerpt from the 1976 water year discharge records showing the September daily discharges of Cattaraugus Creek at Gowanda. Discharges can be seen to vary by >5000 cfs in a period of one day.

Cattaraugus Creek is generally free flowing except for a small impoundment (Springville Dam) near the Village of Springville. Water flow in the creek is confined to a fairly well-defined channel under normal discharge conditions and cuts through a series of bedrock gorges which are connected by shallow valley deposits of sand, silt and gravel. Bed deposits in the gorges appear to be

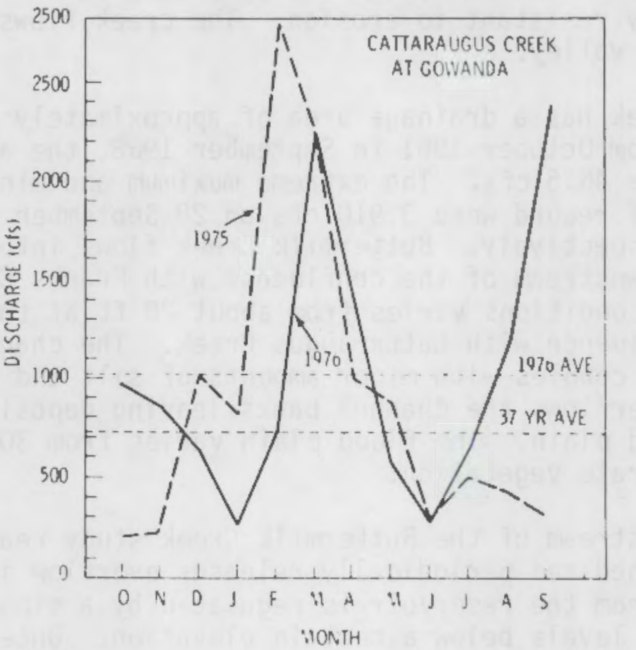


FIGURE 5.2. 1975-76 Monthly Discharges of Cattaraugus Creek at Gowanda

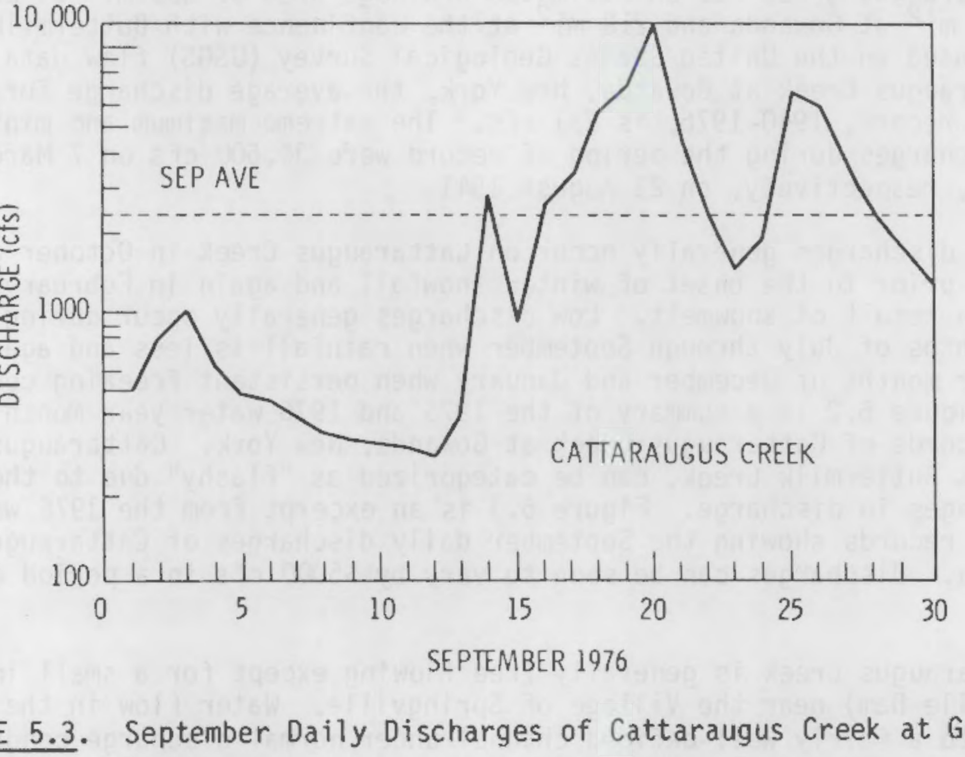


FIGURE 5.3. September Daily Discharges of Cattaraugus Creek at Gowanda

slight and have well defined cross-section profiles. Little bank interaction appears to occur during average- or low-flow conditions.

Springville Dam (Creek Mile 36.5), located about 2.5 miles downstream of the confluence with Buttermilk Creek, is a weir type dam and is 20 ft high. The pool behind the dam is only a few acres in size, is narrow and is surrounded by nearly vertical walls of a deep gorge.

In this study, 41.5 miles of stream length on Buttermilk and Cattaraugus Creeks were modeled. The modeling began on Buttermilk Creek, 2.5 miles above the confluence with Cattaraugus Creek, and continued on Cattaraugus Creek for 39.0 miles to Lake Erie. The only tributary to Buttermilk Creek included in the model was Franks Creek.

Cattaraugus Creek has ten tributaries of varying magnitude, some of which are ephemeral, in addition to numerous transient lateral inflow contributions. The major tributaries on this stretch of Cattaraugus Creek are Spring Brook above Springville Dam, and Spooner, Connoisarauley, South Branch Cattaraugus, and Clear Creeks below the dam. Other than the 0.5 mile long reservoir behind Springville Dam, Cattaraugus Creek is free-flowing. The only permanent stream gaging station on the study reach is operated by the U.S.G.S. at Gowanda Bridge on Cattaraugus Creek 20 creek miles downstream from the Buttermilk Creek confluence.

5.2 SAMPLING PROGRAM

The Cattaraugus/Buttermilk Creeks sampling program consisted of field surveys of channel geometry and the monitoring of water, sediment, and radionuclides during three time periods: November 30-December 5, 1977; September 20-24, 1978; and April 26-29, 1979. These monitoring periods are referred to as Phase 1, Phase 2, and Phase 3, respectively. Detailed accounts of these monitoring programs can be found in related publications (Ecker and Onishi 1979, Walters et al. 1982, Ecker et al. 1982).

The modeled streams include 2.5 miles of Buttermilk Creek and 39.0 miles of Cattaraugus Creek immediately downstream of the Buttermilk confluence. Although the total modeled streamlength is 41.5 miles, six of the eight data verification stations (Table 5.1) are located in the first 8.8 miles of simulated streamlength.

The data collection effort on the three phases of monitoring are similarly unbalanced. More samples were taken during Phase 3 than in Phases 1 and 2 combined. This is because only in Phase 3 were time-varying data for water, sediment, and radionuclides collected.

Therefore, the problem which is best defined is the Phase 3 simulation of the 8.8 miles of streamlength along Buttermilk and Cattaraugus Creeks. This stretch of channel begins just above the Franks Creeks confluence on Buttermilk Creek, continues as Buttermilk Creek enters Cattaraugus Creek and ends at Frye Bridge, 3.8 miles below Springville Dam (Figure 5.1). In this study, the Phase 3 data will be the most heavily relied upon and the Franks Creek to Frye Bridge area will be under closer scrutiny than the downstream areas.

TABLE 5.1. Sampling Station Location

SERATRA Segment	Sampling Station	River Mile	Description	Phase 1	Phase 2	Phase 3
1	BC-2	BCM 2.05	1200 ft downstream of Franks Creek Confluence	X		
3	BC-3	BCM 1.34	Bond Road Bridge	X	X	X
6	BC-4	BCM 0.21	Thomas Corners Bridge	X	X	X
8	CC-3	CCM 38.4	Felton Bridge	X	X	X
14	CC-5	CCM 36.5	Springville Dam	X	X	X
21	CC-6	CCM 32.7	Frye Bridge			X
28	CC-9	CCM 16.4	Gowanda Bridge	X	X	X
34	CC-11	CCM 1.5	Mouth of Cattaraugus Creek	X	X	X

The modeling strategy was to use the Phase 3 data for calibration, attempting to match, as well as possible, the model results to the information from the data stations in the first 8.8 miles of the simulation reach. Once the input data for SERATRA were prepared, the cohesive sediment parameters and the vertical dispersion coefficient remained to be calibrated. Using the Phase 3 flow event, these parameters were calibrated and then applied without recalibration to the Phase 1 and Phase 2 simulations. All other input parameters were specified from the data collection program.

Channel Geometry

Surveys of the channel cross-sectional geometry were performed during the Phase 1 field investigation and supplemented by additional surveys in the fall of 1980. More than 50 cross-sections were logged, primarily upstream of Frye Bridge. Long stretches of unsurveyed channel exist between Frye Bridge and Lake Erie due to access problems. U.S. Geological Survey Topographic Maps aided in the synthesis of these missing cross-sections.

Sediment Sampling

Grab samples of sediment, both in the channel bed and suspended in the water column, were the source of sediment data input to SERATRA. Samples were taken at each of the collection stations but not in the tributaries. The bulk concentration of the suspended sample was determined before both bed and suspended sediment samples were mechanically separated into sand (>74 µm), silt (74 µm ~ 4.0 µm), and clay (<4.0 µm) fractions.

Radionuclide Sampling

Radionuclides can exist in both aqueous and particulate forms. On the microscopic level there is a constant exchange of radionuclides between solution and particle surfaces. In either form, radionuclide measurement requires sophisticated laboratory analysis.

After fractioning and weighing the collected bed and suspended sediment samples from Cattaraugus and Buttermilk Creeks, the samples were sent to the University of Washington for laboratory testing. Thirty radionuclides and their respective activity levels were measured for in this testing. Dissolved radionuclides were collected on reactive resin beds as field-sampled water was pumped through the beds. These beds were then sent to the University of Washington and tested in a manner similar to the sediment samples.

In addition to the activity levels detected in the water and sediment, the University of Washington provided distribution coefficients for five radionuclides: ^{137}Cs, ^{85}Sr, ^{237}Pu, ^{106}Ru, and ^{241}Am (Schell et al. 1979).

5.3 HYDROLOGIC MODELING

As part of its input data set, SERATRA requires depths and discharges at each timestep for every computational segment. The hydrodynamic modeling of Cattaraugus and Buttermilk Creeks which provided these data was performed with two models, DWOPER and MUSK. Boundary conditions for these models were based on measured and synthesized flows.

DWOPER, a one-dimensional dynamic wave model developed by the National Weather Service Hydrologic Research Laboratory (Fread 1978), was intended to be the sole model of instream hydrodynamics in this study. However, the application of DWOPER to Buttermilk Creek resulted in depths and velocities which were unreasonable despite the apparently satisfactory resolution of discharges (Figure 5.4a,b,c). Highly dynamic flow on steep, shallow streams seems to cause the model to underestimate the flow depth (Figure 5.5). This results in a prediction of supercritical flow in areas where it was not observed. Generally, problems of this nature can be alleviated by increasing the Manning roughness coefficient and if necessary, averaging cross-sections so that a smoother transition between computational nodes occurs. Although these techniques produce palatable results, they also have the effect of obscuring the description of the physical phenomena. Since errors in the hydrodynmics are passed on and magnified in the subsequent sediment and radionuclide modeling, they must be kept to a minimum. Cattaraugus Creek was modeled satisfactorily by DWOPER and there was no reason to abandon the model due to difficulties in a relatively short stretch of Buttermilk Creek. The depth calculation problems in Buttermilk Creek were avoided by applying MUSK, a one-dimensional diffusion wave model developed at Colorado State University (Ponce 1980), to this section of the hydrodynamic simulation (Figure 5.6a,b,c).

Model Descriptions

DWOPER

DWOPER was developed for application to large dendritic river systems such as the Mississippi-Ohio. However, the model is generally applicable to rivers having irregular geometry, variable roughness parameters, and lateral inflows. In addition, it has certain features to be discussed below which provide the necessary flexibility for its application to the extreme hydraulic conditions found in the Cattaraugus-Buttermilk Creek system.

As described by Fread (1978), DWOPER uses a finite difference solution to the one-dimensional unsteady flow equations consisting of conservation of mass and momentum equations, i.e.,

$$\frac{\partial Q}{\partial x} + \frac{\partial (A+A_o)}{\partial t} - q = 0 \tag{51}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_f + S_e\right) - qv_x + W_f B = 0 \tag{52}$$

in which Q is discharge, A is cross-sectional area, A_o is off-channel cross-sectional area wherein velocity is considered negligible, q is lateral inflow or outflow, x is distance along the channel, t is time, g is gravitational acceleration, v_x is the velocity of lateral inflow in the x-direction, W_f is the wind term, B is the channel top width and S_f is the friction slope defined as:

$$S_f = \frac{n^2|Q|Q}{2.2\, A^2 R^{4/3}} \tag{53}$$

in which n is the Manning roughness coefficient and R is the hydraulic radius. The term S_e is defined as:

$$S_e = \frac{K_e \partial (Q/A)^2}{2g\, \partial x} \tag{54}$$

in which K_e is the expansion-contraction coefficient.

Equations (51) and (52) are solved using the weighted four-point finite difference scheme originally developed by Preissmann (1961). In the weighted four-point scheme, the continuous x-t region in which solutions of h and Q are sought is represented by a rectangular net of discrete points. The scheme allows the use of equal or unequal intervals of Δx and Δt along the x and t axes, respectively. Each point is identified by a subscript (i) which designates the x position and a superscript (j) for time position. The time derivatives are approximated by:

$$\frac{\partial K}{\partial t} \simeq \left(K_i^{j+1} + K_{i+1}^{j+1} - K_i^{j} - K_{i+1}^{j}\right)/2\Delta t \tag{55}$$

in which K represents any variable. The spatial derivatives are approximated by a finite difference quotient positioned between two adjacent time lines according to weighting factors t and 1-θ, i.e.,

$$\frac{\partial K}{\partial x} \simeq \theta \left(K_{i+1}^{j+1} - K_{i}^{j+1}\right) / \Delta x + (1-\theta) \left(K_{i+1}^{j} - K_{i}^{j}\right) / \Delta x \tag{56}$$

and variables other than derivatives are approximated in a similar manner, i.e.,

$$K \simeq \theta \left(K_{i}^{j+1} + K_{i+1}^{j+1}\right) / 2 + (1-\theta) \left(K_{i}^{j} + K_{i+1}^{j}\right) / 2 \tag{57}$$

Generally, the ability of a model such as DWOPER to reproduce actual flow events depends on the amount and quality of data available for the stream system under study. These data include: 1) channel geometry, 2) hydraulics, 3) estimate of channel roughnes, and 4) initial conditions.

Channel geometry is represented in the model by surface widths as a function of stage at computational points corresponding to actual cross section locations. From the surface widths, wetted area and conveyance are also determined as functions of stage.

Hydraulic data refers to boundary conditions and observed stages and/or discharges. Both upstream an downstream hydrographs are needed on each stream for the operation and calibration of DWOPER. For this study, the upstream boundaries included the inflow hydrographs for each stream as previously discussed. Channel roughness in the model is represented by a single lumped parameter, Manning's "n", which accounts for all the processes that contribute to the loss of energy or momentum, excluding expansion and contraction losses [see Equation (54)]. Initial values for Manning's "n" for the two study streams were computed indirectly from Manning's equation based on velocity measurements at the upstream boundaries. Initial conditions were computed for each computation point using standard step backwater. The use of the computed "n" values resulted in super-critical flow conditions at several locations. This was corrected by increasing the "n" values, within reasonable limits, until the flow became subcritical.

The use of a variable Δx and the ability to change Δt and the weighting factor θ are important in the application of DWOPER to Cattaraugus Creek because of the flexibility they provide, when judiciously selected, in controlling the model's numerical stability and convergence. In implicit schemes, such as that used by DWOPER, the finite difference approximations of Equations (51) and (52) converge to the true solutions of the partial differential equations as Δx and Δt approach zero (Abbot and Ionescu 1967, Leendertse 1967). In this sense, convergence is the measure of the error in the numerical scheme due to improper discretization. Stability refers to the ability of a numerical scheme to limit error growth due to round-off. The only necessary condition for stability of implicit schemes is that the weighting factor θ be greater than 0.5. Therefore, for a give value of θ, a decrease in the values of Δx and Δt increases the accuracy of the model. On the other hand, as θ approaches 1.0, the model becomes stable and less convergent, increasing numerical distortion.

Certain channel and hydrograph characteristics can also have an effect on the level of numerical distortion present in the model. Fread (1973) demonstrated that numerical distortion increases with increasing channel length, roughness factor and channel slope or with decreasing initial depth of flow. Also, as the time to peak of the upstream boundary hydrograph decreases, the numerical distortion increases. From this it can be seen that the usual problems encountered in building and running mathematical models are magnified considerably in the face of conditions similar to those in the Cattaraugus Creek system.

MUSK

MUSK is a simplified flood routing model of the diffusion wave class. In general, it can be applied in steep channels where no downstream controls exist. Unlike DWOPER, MUSK is designed for use on a single primary stream with lateral inflow introduced along the streamlength. Irregular geometries and spatially varying roughness coefficients are normal model input data for MUSK.

The MUSK formulation is based on a manipulated form of the one-dimensional unsteady flow equations. In place of the conservation of momentum equation [Equation (52)], a single-valued resistance equation, i.e., Manning, is substituted. This is known as the kinematic wave approximation. Using this approximation, the one-dimensional convection equation can be derived from the mass conservaton equation.

$$\frac{1}{c}\frac{\partial Q}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (58)$$

where c = celerity
Q = discharge

A finite difference representation of this equation with weighting in the time dimension yields the following equation

$$\frac{1}{c\Delta t}\left\{\theta\left(Q_i^{j+1} - Q_i^j\right) + (1-\theta)\left(Q_{i+1}^{j+1} - Q_{i+1}^j\right)\right\} + \frac{1}{2\Delta x}\left\{\left(Q_{i+1}^{j+1} - Q_i^{j+1}\right) + \left(Q_{i+1}^j - Q_i^j\right)\right\} = 0 \qquad (59)$$

An explicit solution scheme is used in MUSK to solve for Q across the x-t domain.

The convection equation is inherently nondiffusive, meaning that a flood wave shape is routed downstream without attenuation. This is precisely the behavior of a kinematic wave, the assumption used in the MUSK formulation. However, an analysis of the higher order error terms of the finite difference analogs discloses that numerical deviations in the flood wave will occur. The actual deviation is a function of Δx, Δt, c, and θ. It can be shown that if the diffusion wave approximation is used in place of the conservation of momentum equation, i.e., inertia terms are neglected, the one-dimensional convection-diffusion equation can be derived from the unsteady flow equation set

$$\frac{1}{c}\frac{\partial Q}{\partial t} + \frac{\partial Q}{\partial x} = \frac{Qo}{2bS_o c}\frac{\partial^2 Q}{\partial x^2} \qquad (60)$$

By matching the truncation error of the convection equation finite difference scheme to the physical diffusion found in the convection-diffusion equation, the weighting value θ can be calculated to produce a physically-based diffusion. Thus, although the MUSK formulation is based on a unique stage-discharge relationship, the flood wave attenuation computed by MUSK does not reflect a single-valued rating curve. The behavior described by MUSK is similar to the less simplified parabolic partial differential equation which describes the diffusion wave. Since this is the case, flow depths are calculated by using continuity rather than the resistance equation.

Nonuniform Δx and a constant Δt are user supplied in MUSK while the weighting factor, θ, is computed by the model. Because MUSK solves an initial value problem rather than a boundary value problem, a "marching" solution which propagates downstream is used. This precludes any backwater effects from being resolved by the model.

The data requirements by MUSK are very similar to those of DWOPER. The largest difference occurs in the hydraulic data. MUSK needs discharge hydrographs only at the upstream and lateral inflow boundary conditions. Because it solves an initial value problem, internal and downstream boundary conditions are not necessary. MUSK also uses the Manning roughness coefficient in its formulation; however, in this case energy losses from channel expansion and contraction are lumped into this parameter. The Manning resistance coefficient in MUSK is location dependent.

MUSK has been shown to be unconditionally stable and convergent for the types of problems where it is applicable.

MODEL APPLICATIONS

The MUSK simulation used 13 nodes to represent the 2.5 miles of Buttermilk Creek at the beginning of the study reach (Figure 5.7). The smallest distance between nodes was 0.20 miles while the longest interval was 0.26 miles. The upstream boundary condition was the hydrograph calculated at the beginning of the simulation reach. Lateral inflow from Franks Creek was brought in as a hydrograph at the second node.

The DWOPER simulation of Cattaraugus Creek was divided into two separate simulations: 12 nodes (4.8 miles) above Springville Dam and 21 nodes below. The upstream boundary condition hydrograph for the upper Cattaraugus Creek simulation was located 2.3 miles above the Buttermilk Creek confluence and based on data collected at Bigelow Bridge. The downstream boundary condition was a single-valued rating curve at Springville Dam (Figure 5.7). The longest interval between nodes on the upper simulation was 0.63 miles while the shortest interval was 0.15 miles. Major tributaries on this simulation reach were Spring Brook and Buttermilk Creek. The discharge hydrograph calculated by MUSK at the end of the Buttermilk Creek was used by DWOPER as the lateral inflow boundary condition to Cattaraugus Creek.

The DWOPER simulation below the dam use a calculated hydrograph as the upstream boundary condition and observed stage hydrographs at Lake Erie as the downstream boundary condition (Figure 5.8). The longest interval between nodes on the lower Cattaraugus Creek simulation was 3.6 miles while the shortest interval was 0.25 miles. Below Springville Dam, four major tribuaries enter Cattaraugus Creek: Spooner, Connoisarauley, South Branch Cattaraugus, and Clear Creeks. These tributaries are treated as lateral inflow boundary conditions requiring discharge hydrographs.

In this study, Snyder's method of hydrograph synthesis was used in conjunction with rainfall information and the SCS (Soil Conservation Service) curve number method for runoff calculation (Viessman et al. 1977). Where boundary conditions were not sufficiently monitored in the field, synthetic unit hydrographs based upon watershed characteristics were computed for individual sub-basins. Rainfall data from NOAA were used to reconstruct precipitation events and determine magnitudes for the individual hydrographs. Runoff reaching the boundary condition site was calculated using the SCS curve number method and superposed upon the estimated baseflows.

Hydrodynamic Modeling Results

In the context of the three phases of sampling, the Phase 3 hydrodynamic were moderate in discharge and unsteadiness. Phase 3 was selected for the first modeling effort because boundary conditions and calibration data were available from the field investigation. During Phase 3, all upstream boundary conditions and most major tributaries were gaged for discharge. Hydrograph synthesis was required only at South Branch Cattaraugus Creek which is downstream of the area of primary interest. Calibration of Manning resistance cofficients for the Phase 3 hydrodynamic modeling was available at Frye Bridge (Creek Mile 32.7) and Gowanda Bridge (Creek Mile 16.4). Results of the Phase 3 hydrodynamic modeling are compared with measured values at Gowanda in Figure 5.9. The Phase 3 hydrodynamic modeling began at 8:00 a.m. April 27, 1979 and ended at 8:00 a.m. April 29, 1979. Of the three phases, the Phase 3 hydrodynamics were moderate, as a 48 hr flood wave with a peak discharge of 920 cfs traveled downstream. The modeled discharges are in excellent agreement with the Gowanda stream data.

Phase 2 discharges were the lowest and least dynamic of the three phases. Synthetic inflows were generated for South Branch Cattaraugus, Connoisarauley and Clear Creeks in addition to the Cattaraugus Creek upstream boundary condition at Bigelow Bridge. Measured baseflows were used in Franks and Buttermilk Creek while a 0.4 cfs/sq. mi. runoff distribution was used to determine other lateral inflows. The average basin rainfall during the Phase 2 simulation period was 2.28 in. of which 0.14 in. were calculated to become runoff. For the most part, Manning resistance coefficients calibrated in the Phase 3 hydrodynamic simulation were used in the Phase 2 simulation although coefficients in the steeper sections of lower Cattaraugus Creek were increased in some cases. Figure 5.10 is a comparison of computed and measured discharges at Gowanda.

Phase 2 radionuclide sampling began at 8:00 a.m. September 20, 1978 and ended at 12:00 noon September 24, 1978. Since the radionuclide sampling began on the falling limb of a flood hydrograph, it was necessary to begin the hydrodynamic modeling 74 hr earlier to simulate the entire flood wave. Only the last 30 hr of the flood wave are included in the radionuclide modeling as the stream returned to baseflow for the concluding 70 hr of simulation. The computed flood wave is a few hours out of phase with the measured wave; however, the representation of the hydrodynamics during the period of radionuclide simulation is good.

Phase 1 hydrodynamics were the most unsteady and had the highest discharges of the three phases of data collection. Flow measurements in this phase were not sufficient to provide the necessary boundary conditions for the hydrodynamic modeling. Thus, all boundary conditions were computed. Hydrograph synthesis was performed at the Cattaraugus and Buttermilk Creeks upstream boundary condition sites in addition to four major tributaries: Spring Brook, Spooner, South Branch Cattaraugus, and Clear Creeks. The remaining lateral inflows were determined on a basin square mile basis. Unfortunately, the U.S.G.S. streamgaging station at Gowanda was not operating during the Phase 1 simulation period and accurate calibration information was unavailable. The uncalibrated model resuts at Gowanda appear in Figure 5.11.

The Phase 1 hydrodynamic modeling began at 1:00 a.m. November 29, 1977 in Buttermilk Creek and at 3:00 a.m. November 30, 1977 in Cattaraugus Creek. The additional modeling period in Buttermilk Creek was needed to resolve a complete flood wave. The Cattaraugus Creek simulation ended at 3:00 a.m. December 5, 1977. The baseflow in Buttermilk Creek was used to fill out the aditional simulation time required by the Cattaraugus Creek modeling. The modeling results reveal two distinct flood waves occurring during the simulation period with peak discharges exceeding 3000 cfs.

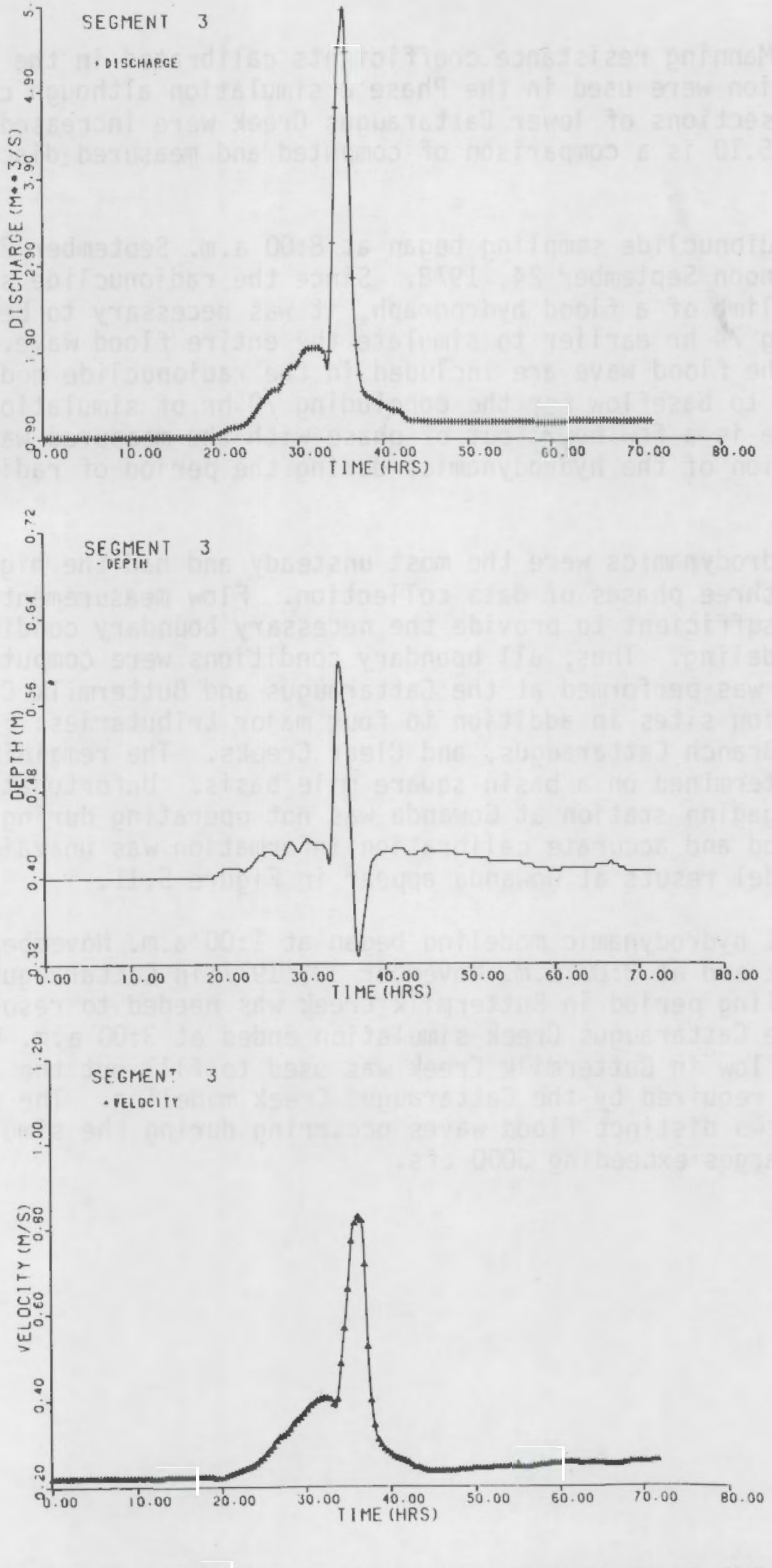


FIGURE 5.4. DWOPER Modeling at Buttermilk Creek Mile 1.6: a) Discharge, b) Depth, and c) Velocity

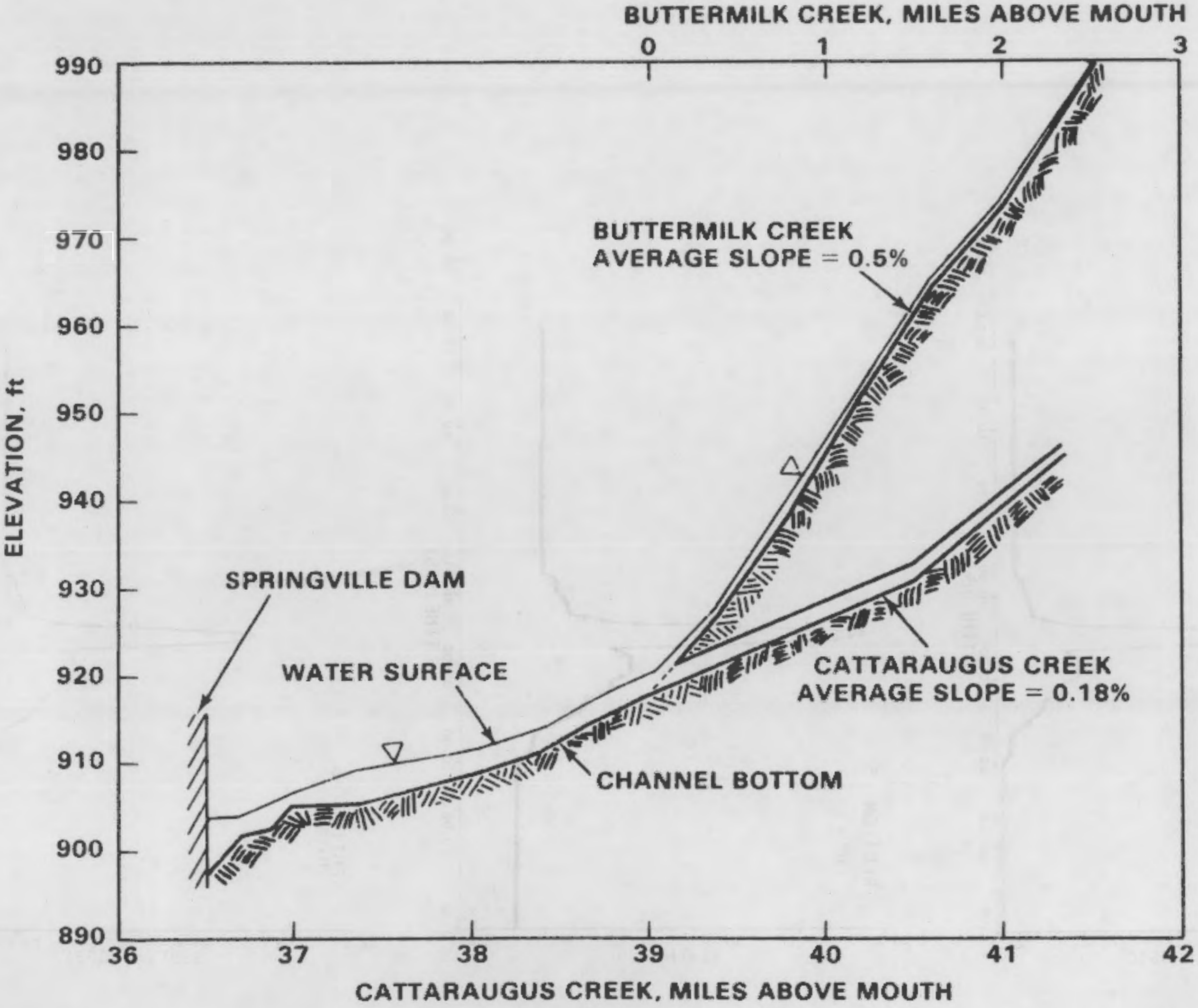


FIGURE 5.5. Channel Bottom and Water Surface Profiles of Cattaraugus-Buttermilk Creeks

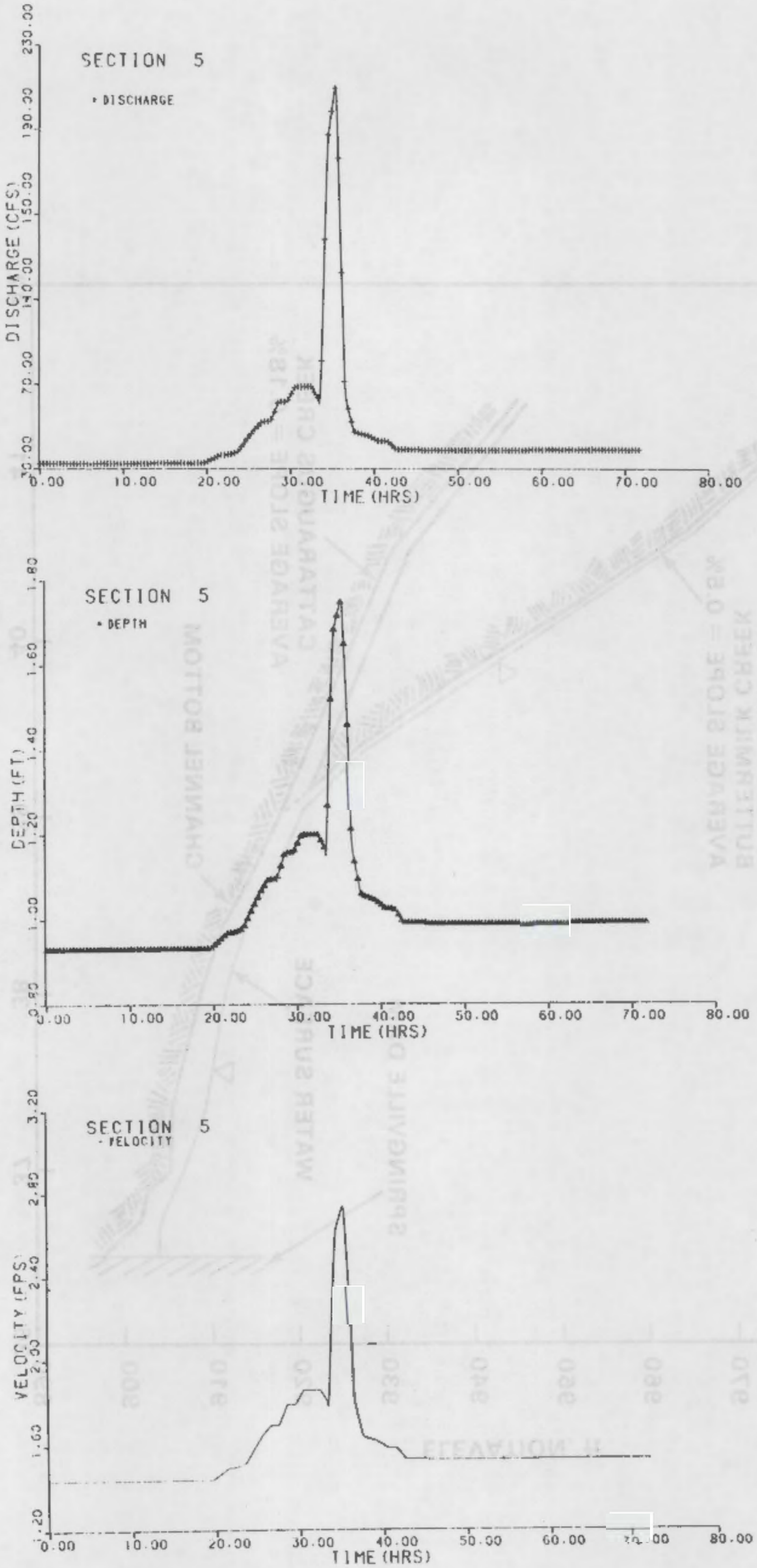


FIGURE 5.6. MUSK Modeling at Buttermilk Creek Mile 1.6: a) Discharge, b) Depth, and c) Velocity

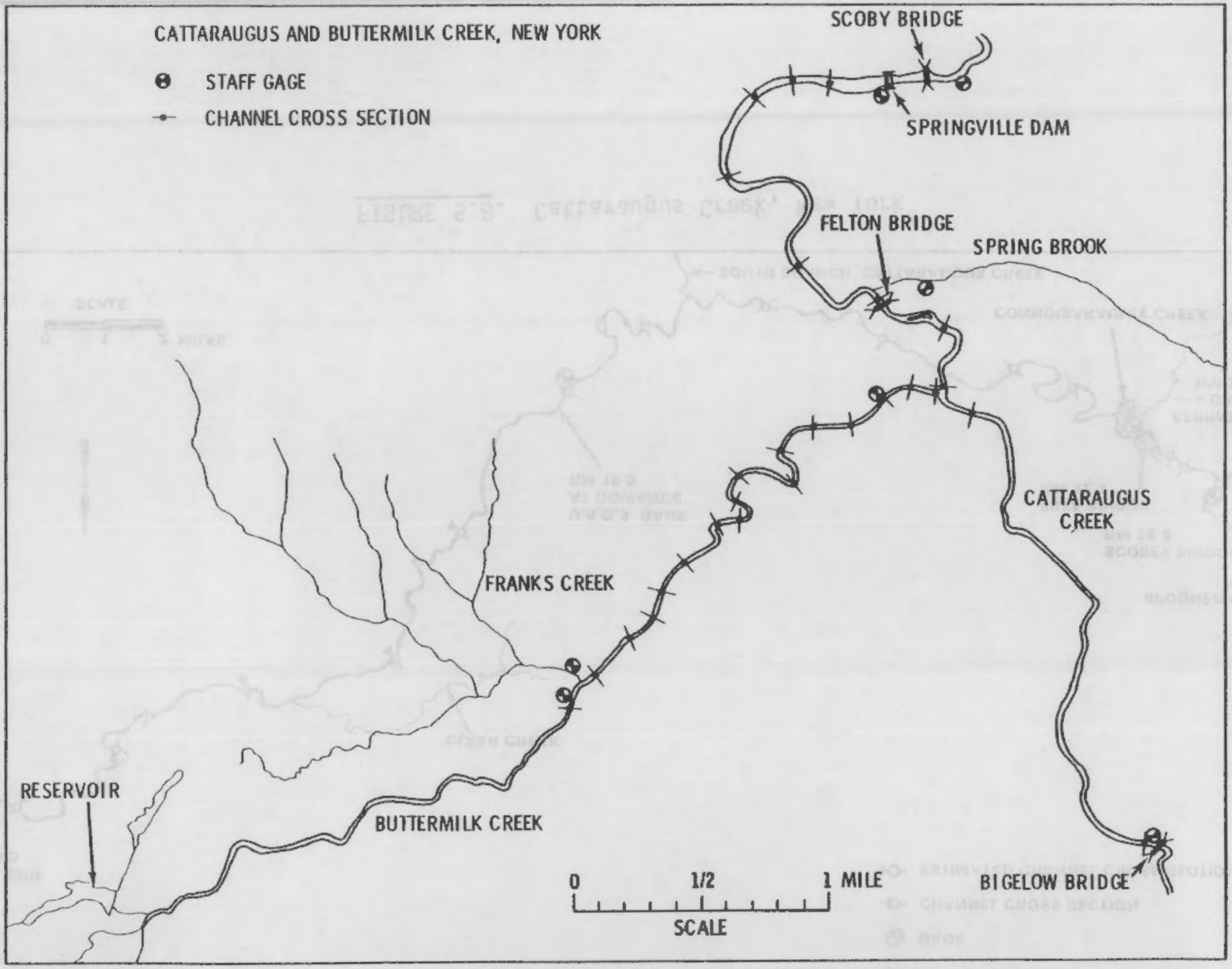


FIGURE 5.7. Map of Cattaraugus-Buttermilk Creeks System, New York

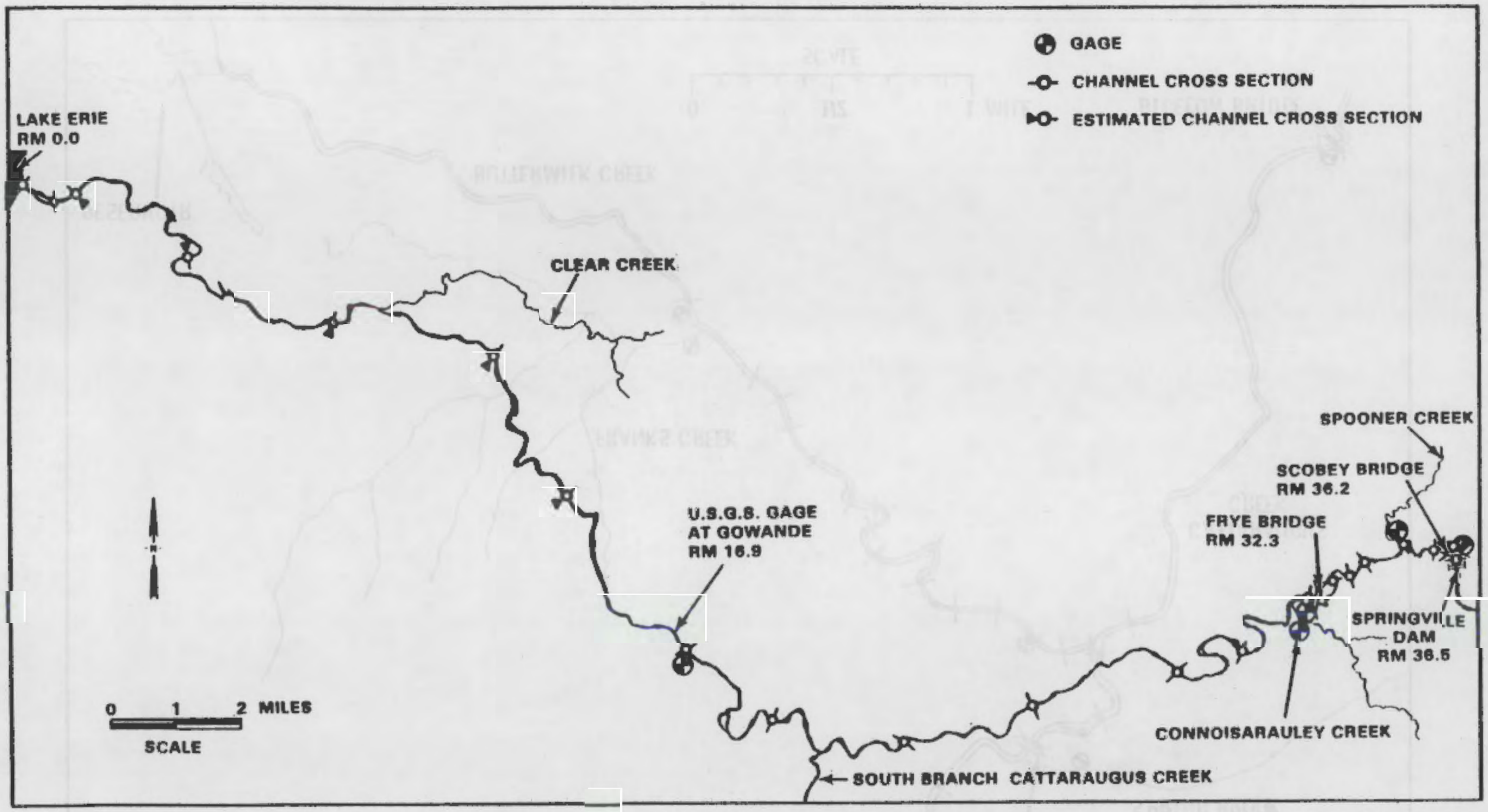


FIGURE 5.8. Cattaraugus Creek, New York

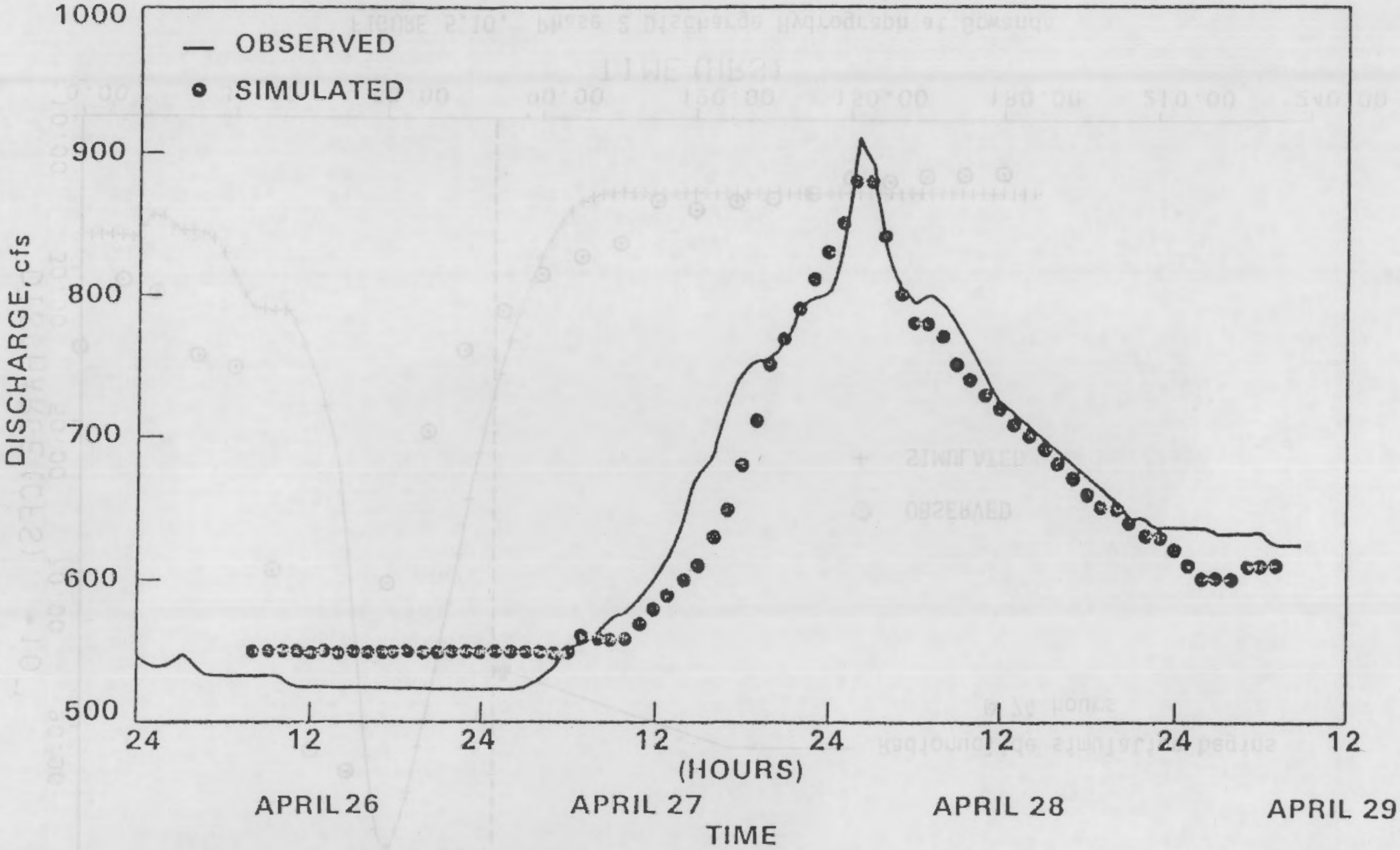


FIGURE 5.9. Phase 3 Discharge Hydrograph at Gowanda

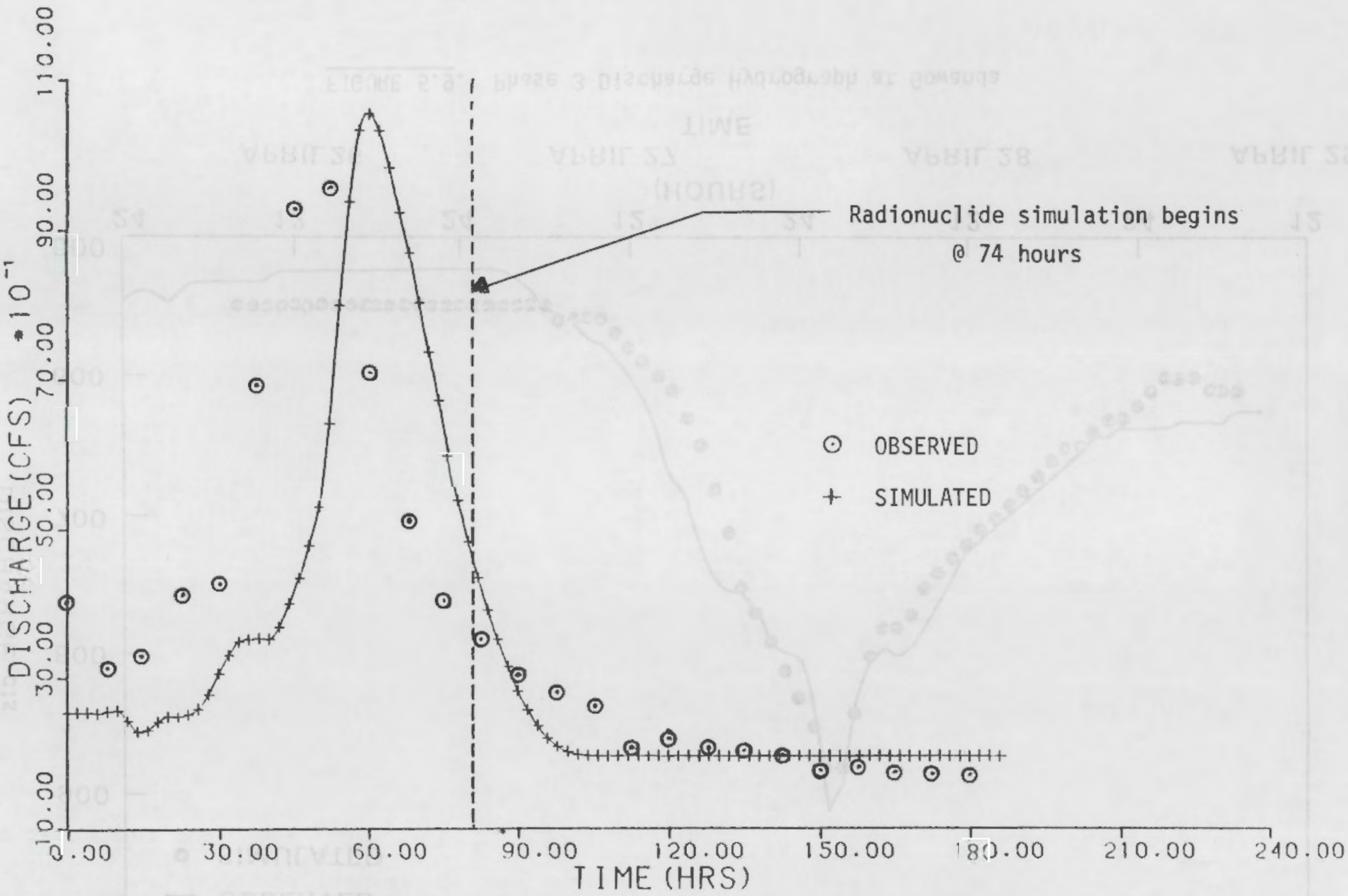


FIGURE 5.10. Phase 2 Discharge Hydrograph at Gowanda

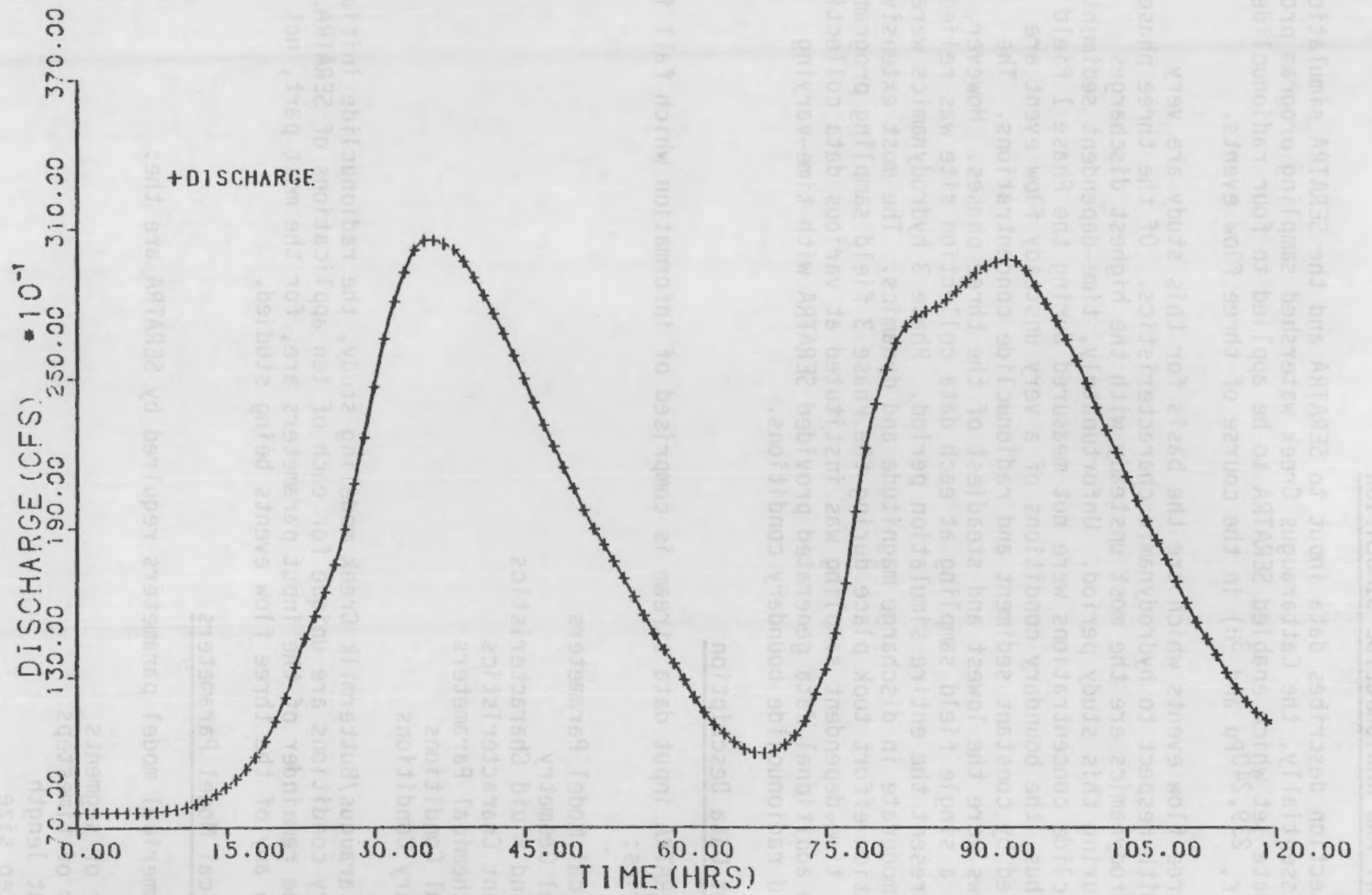


FIGURE 5.11. Phase 1 Discharge Hydrograph at Gowanda

5.4 SEDIMENT AND RADIONUCLIDE SIMULATION

This section describes data input to SERATRA and the SERATRA simulation results. Essentially, the Cattaraugus Creek watershed sampling program provided the data set which enabled SERATRA to be applied to four radionuclides (^{137}Cs, ^{90}Sr, ^{239,240}Pu and ^{3}H) in the course of three flow events.

The three flow events which are the basis for this study are very different with respect to hydrodynamic characteristics. Of the three phases, Phase 1 hydrodynamics are the most unsteady with the highest discharges occurring during this study period. Unfortunately, time-dependent sediment and radionuclide concentrations were not measured during the Phase 1 field program. Thus, the boundary conditions of a very unsteady flow event are characterized by constant sediment and radionuclide concentrations. The Phase 2 flows were the lowest and steadiest of the three phases. However, as in Phase 1, a single field sampling at each data collection site was relied upon to represent the entire simulation period. Phase 3 hydrodynamics were relatively moderate in discharge magnitude and dynamics. The most extensive data collection effort took place during the Phase 3 field sampling program. In Phase 3, time-dependent sampling was instituted at various data collection sites. The additional data generated provided SERATRA with time-varying sediment and radionuclide boundary conditions.

5.4.1 Input Data Description

The SERATRA input data stream is comprised of information which fall into six categories:

1. Numerical Model Parameters
2. Channel Geometry
3. Flow and Fluid Characteristics
4. Sediment Characteristics
5. Radiochemical Parameters
6. Initial Conditions
7. Boundary Conditions

In the Cattaraugus/Buttermilk Creek modeling study, the radionuclide initial and boundary conditions are unique for each of ten applications of SERATRA. However, the remainder of the input parameters are, for the most part, not specific to any of the three flow events being studied.

Numerical Model Parameters

The numerical model parameters required by SERATRA are the:

1. number of segments
2. number of timesteps
3. segment length
4. timestep size

5. water column standard element thickness
6. standard channel bed layer thickness
7. number of initial layers in the channel bed.

Basically, the segments and timesteps used in the hydrodynamic modeling of Cattaraugus and Buttermilk Creeks were preserved in the sediment-radionuclide transport simulations. Although segment lengths vary along the study raeach, the same channel representation is used for each of the three flow events. Channel bed parameters, i.e., the number of initial bed layers and the bed layer thickness were assigned to be initially constant in this study, regardless of location or flow event.

Channel Geometry

At each computational segment, SERATRA requires:

1. segment elevation, and
2. depth-surface area data pairs.

The modeling effort divided the 41.5 mile simulation reach into 34 computational segments. Some of the cross-sections used in the modeling effort were modified/averaged from the original surveys. This is because of model requirements and the existence of more field-surveyed cross-sections than model cross-sections. SERATRA represents channel geometry as depth-width data pairs, i.e., at a given elevation a certain width is associated. This precludes the accurate description of complex or braided channels. For such geometry, an optimized representation of the channel must be developed. Where field information is plentiful, the geometry for a particular cross-section might be the result of averaging two or more field-surveyed cross-sections. In this study, each cross-section at a given location is uniquely characterized but unchanged for all three phases. The channel geometry is taken from the hydrodynamic modeling study performed prior to the execution of the SERATRA code.

Flow and Fluid Characteristic

1. the number of water columns based on the flow depth obtained by hydrodynamic models

2. flow discharges obtained by hydrodynamic models

3. water temperature.

Sediment Characteristics

The sediment characteristics input to SERATRA are:

1. particle diameter
2. particle density
3. settling velocity
4. critical shear stress for deposition of cohesive sediment
5. critical shear stress for resuspension of cohesive sediment

6. erodability of cohesive sediment, and
7. vertical diffusion coefficient.

In the present application of SERATRA, three particle sizes representing the sand, silt and clay sediment fractions are routed. The selection of the specific size range for each of the three classifications was based on the field measurements in Cattaraugus and Buttermilk Creeks.

The sand fraction can be routed by either the Tofaletti or Colby sediment transport method. The Tofaletti method was used in this study. Silt and clay are treated as cohesive soils whose erosion and deposition rates were estimated by Partheniades (1962) and Krone's Formulas (1962). In the Buttermilk and Cattaraugus Creeks field sampling program, it was not possible to determine the three cohesive sediment parameters (resuspension critical shear stress, deposition critical shear stress, and erodability) required by the SERATRA input stream for the silt and clay size fractions. Therefore, a set of calibration runs were performed prior to the application of the model. The Phase 3 event was chosen for the calibration runs because of the extensive data that was available. To avoid "curve-fitting" the simulation results to the field values, the cohesive sediment transport parameters calibrated with the Phase 3 data were used without recalibration in the Phase 1 and Phase 2 simulations. This is possible because these parameters are theoretically event-independent. The sediment transport parameters are summarized in Table 5.2.

TABLE 5.2. Sediment Characteristics

	Sand	Silt	Clay
Diameter, m	3.0×10^{-4}	1.72×10^{-5}	2.0×10^{-6}
Density, kg/m^3	2650.0	2650.0	2650.0
Porosity	0.5	0.5	0.5
Vertical Diffusion Coefficient, m^2/s	0.03	0.03	0.03
Erodability kg/m^2/s	n.a.	1.87×10^{-5}	1.87×10^{-5}
Critical Scour Shear Stress kg/m^2	n.a.	0.9	2.0
Critical Deposition Shear Stress kg/m^2	n.a.	0.05	0.01

n.a. = not applicable

A reasonable radionuclide modeling requires boundary conditions, distribution coefficients, and verification data to be adequately defined. Of the 30 radionuclides which were detected in the field samples, only four radionuclides generated sufficient information for a reasonable modeling study: ^{137}Cs, ^{90}Sr, ^{239,240}Pu, and ^{3}H. Except for the Phase 1 simulation where only ^{137}Cs and ^{3}H were modeled, these four radionuclides were simulated in the Phase 2 and Phase 3 events. Fortunately, these four radionuclides display a wide range of behavior with which SERATRA can be tested. Half lives vary from 12 to 7000 yr while distribution coefficients, i.e., K_ds, range over two orders of magnitude.

SERATRA is unique in its treatment of the adsorption/desorption phenomenon. Not only does the model simulate the time-dependent exchange of radionuclide between the dissolved and sorbed forms, but the adsorption and desorption processes are treated as distinctly different mechanisms requiring separate K_d values. The adsorption K_d values used in this study are from laboratory measurements of samples taken from the Cattaraugus and Buttermilk Creeks. However, the desorption K_ds were not measured in the field.

Radiochemical Parameters

The radiochemical parameters used in this modeling study are the:

1. adsorption distribution coeficient
2. desorption distribution coeficient
3. adsorption transfer rate
4. desorption transfer rate, and
5. radionuclide decay rate.

The adsorption/desorption parameters were determined through laboratory radionuclide analyses of bulk water-sediment samples in Cattaraugus Creek. Where data were insufficient, desorption parameters were calculated using adsorption/desorption ratios from other studies (Schell et al. 1980). Specific distribution coefficients for each sediment size fraction were created by apportioning the bulk values such that a weighted average of the distribution coefficients would equal the laboratory value. Radionuclide decay rates were based on published physical data. The radiochemical parameters used in this study were unique to the radionuclide being modeled but were kept independent of the flow event being simulated.

Distribution coefficients for adsorption and desorption measured at other freshwater sites (Table 5.3) were used to estimate the desorption K_ds in this study. For each radionuclide modeled by SERATRA, an average ratio of desorption K_d was determined from data published in previous studies. This ratio was then applied to the adsorption distribution coefficient measured in Cattaraugus Creek to create the necessary model input (Schell et al. 1980).

TABLE 5.3. Adsorption and Desorption Distribution Coefficients (m^3/kg)

	^{137}Cs		^{85}Sr		^{237}Pu	
	Adsorption	Desorption	Adsorption	Desorption	Adsorption	Desorption
Lake Michigan	0.509	5.57	0.0822	1.41	141	479
Lake Washington	n.a.	n.a.	n.a.	n.a.	120	300
Clinch River	1.36	n.a.	0.124	0.46	47.1	154
Hudson River	0.401	3.65	0.0737	0.49	9.3	360
Cattaraugus Creek	0.600	n.a.	0.0623	n.a.	20.9	n.a.

n.a. = not available.

The adsorption-desorption process is also a function of sediment size with finer sediment exhibiting a stronger affinity for dissolved radionuclides. SERATRA accounts for this variation by allowing each sediment size fraction to be treated with a separate K_d value. Since the distribution coefficients measured by the University of Washington were not differentiated by sediment size, an approximate partitioning was employed. It was assumed that a 1:5:10 ratio for sand, silt, and clay distribution coefficients was appropriate. The actual value of each K_d value was computed such that a weighted average based on sediment fractions yielded the bulk value measured in the laboratory, i.e.,

$$(K_d)_{sand} \quad (\%\ sand) + (K_d)_{silt} \quad (\%\ silt) + (K_d)_{clay} \quad (\%\ clay)$$

$$= (K_d)_{measured}$$

where

$$(K_d)_{silt} = 5 \cdot (K_d)_{sand}$$

$$(K_d)_{clay} = 10 \cdot (K_d)_{sand}.$$

Radionuclide input data provided to SERATRA are shown in Table 5.4.

TABLE 5.4. Radionuclide Data Input to SERATRA

		Adsorption		
	$\lambda_s{-1}$	Kd Sand m^3/kg	Kd Silt m^3/kg	Kd Clay m^3/kg
^{137}Cs	7.27×10^{-10}	0.1	0.5	1.0
^{90}Sr	7.82×10^{-10}	0.01	0.05	0.10
$^{239,240}Pu$	3.34×10^{-12}	3.5	17.0	35.0
^{3}H	1.79×10^{-9}	0.0	0.0	0.0

		Desorption		
	$\lambda_s{-1}$	Kd Sand m^3/kg	Kd Silt m^3/kg	Kd Clay m^3/kg
^{137}Cs	7.27×10^{-10}	1.0	5.0	10.0
^{90}Sr	7.82×10^{-10}	0.1	0.5	1.0
$^{239,240}Pu$	3.34×10^{-12}	35.	170.	350.
^{3}H	1.79×10^{-9}	0.0	0.0	0.0

Initial Conditions

SERATRA requires the following initial conditions to be specified at each segment:

1. bed sediment size fractions
2. bed radionuclide activity
3. suspended sediment size fractions and concentrations
4. suspended radionuclide activity, and
5. dissolved radionuclide activity.

Except for the dissolved radionuclide activity, the initial conditions are defined for each of the three sediment size fractions being modeled. The initial bed conditions for sediment and radionuclide are based on the field sampled values while the water column initial conditions are specified to match boundary conditions at the beginning of the SERATRA simulation.

Boundary Conditions

The boundary conditions in SERATRA represent time-varying loadings external to the study reach and include:

1. suspended sediments concentrations
2. particulate radionuclides, and
3. dissolved radionuclides.

Other than the dissolved radionuclides, boundary conditions are specified for each sediment size fraction. Two types of boundary conditions are possible in SERATRA: upstream and lateral inflow. The time-varying boundary conditions in this modeling study were generated by fitting a curve through field-sampled values which were taken over a period of time. If time varying data was sparse, an average value was used.

5.4.2 Sediment Transport Simulation Results

In general, the sediment transport modeling describes a silt-dominated suspended sediment load washing through the creek system. The three flow events modeled are accompanied by relatively high suspended sediment concentrations due in part to the erosion of the channel bed in the study reach. Very little of the fine-grained sediments (silt and clay) are deposited on the channel bottom as the flow carries these particles into Lake Erie. On the other hand, sand displays a net deposition as it passes through the Cattaraugus Creek system. The deposited sediments occur almost exclusively in the Lake Erie and Springville Dam backwaters. Except for these backwater areas, the general tendency is for bed scouring. This scouring of the smaller bed sediment particles leaves a protective surface layer of larger particles which prevents further erosion of the finer sediment. This phenomenon is called bed armoring and was predicted to occur especially during the Phase 1 flow event. The comparison of computed and measured sediment concentrations are shown in this section as well as in Appendix A.

Phase 3

From a modeling standpoint, the Phase 3 simulation by SERATRA was well-defined. Time-dependent sampling of water, sediment, and radionuclides at the boundary conditions and verification sites provided a data set which required minimal data generation. Calibration was necessary only for the cohesive sediment transport submodel. All other parameters, including those used in the radionuclide transport submodel were fully specified, thus, no calibration was performed in these cases.

Throughout the simulation silt is a dominant size fraction in the water column accounting for about 85% of the total suspended sediments. Clay accounted for the bulk of the remaining 15% as sand occurred in relatively small concentrations.

The Phase 3 sediment and radionuclide simulation period begins at 8:00 a.m. April 26, 1979 and ends at 8:00 a.m. on April 29, 1979. A summary of the observed and predicted Phase 3 sediment concentrations is found in Table 5.5.

Results from the Phase 3 sediment transport modeling showed a sediment cloud propagating downstream with the 40 hour flood wave. The 'spike' of high discharge in Buttermilk Creek was not reflected in the predicted suspended sediment concentrations, in fact there was a slight decrease in clay concentrations as the spike passed through Buttermilk Creek (Figure 5.12). Although

TABLE 5.5. Phase 3 Observed and Computed Sediment Concentrations

Phase 3 Sediment Comparison (mg/ℓ) (Calibration Run)

Location	Observed	Computed
BC-3		
Sand	4.46	1.2
Silt	89.01	42.5
Clay	17.82	8.9
BC-4/1		
Sand	0.22	0.3
Silt	15.81	13.1
Clay	4.56	2.0
BC-4/2		
Sand	1.03	1.5
Silt	90.10	62.3
Clay	23.07	7.2
BC-4/3		
Sand	0.26	0.4
Silt	18.27	11.1
Clay	5.27	2.7
CC-3		
Sand	1.06	0.4
Silt	16.31	11.8
Clay	3.74	2.1
CC-5/1		
Sand	0.35	0.3
Silt	19.99	12.0
Clay	4.96	2.9
CC-5/2		
Sand	1.98	0.5
Silt	52.54	34.0
Clay	9.47	6.3
CC-5/3		
Sand	2.18	0.5
Silt	22.68	30.3
Clay	2.84	5.8
CC-6/1		
Sand	0.18	0.5
Silt	15.76	36.9
Clay	4.66	3.3

TABLE 5.5. (contd)

Phase 3 Sediment Comparison (mg/ℓ) (contd)

Location	Observed	Computed
CC-6/2		
Sand	2.84	0.5
Silt	39.36	53.4
Clay	5.00	5.3
CC-6/3		
Sand	2.42	0.6
Silt	27.88	46.2
Clay	5.91	6.9
CC-9		
Sand	2.25	0.5
Silt	15.12	65.7
Clay	2.92	4.3
CC-11		
Sand	5.33	0.1
Silt	19.22	85.7
Clay	2.65	5.6

the total mass of suspended sediment increased as the spike passed through, dilution by the sudden increase of water volume offset any increases in sediment concentration.

The results of the Phase 3 sediment calibration efforts with SERATRA are in general agreement with measured data. At BC-3, computed silt concentrations are the highest of the three sediment constituents, with clay and sand concentrations considerably below the silt levels. Unlike the sudden high discharges found in Phase 1, a sediment wave gradually changing over 40 hours of simulation characterizes the plots of sediment concentrations. A comparison with the field sampled concentrations at hour 27.5, show predicted concentrations to be 50% lower.

Three field samplings were taken at BC-4 at 3.4, and 36, and 64.5 hr. The gross phenomenon indicated by the field data is a sediment concentration peak occurring near the time of the 37-hour sample. Computed concentrations are in agreement with this trend and compare favorably with the field values (Figure 5.12), especially at the 3.5 and 64.5 hr marks. The predicted sediment concentrations, except for sand, are below the sampled concentrations. As the sediment from Buttermilk Creek enters Cattaraugus Creek, suspended sediment concentrations are reduced by a factor of two (Figure 5.13). A more diffuse sediment wave of a 55 hr duration occurs in this section of Cattaraugus

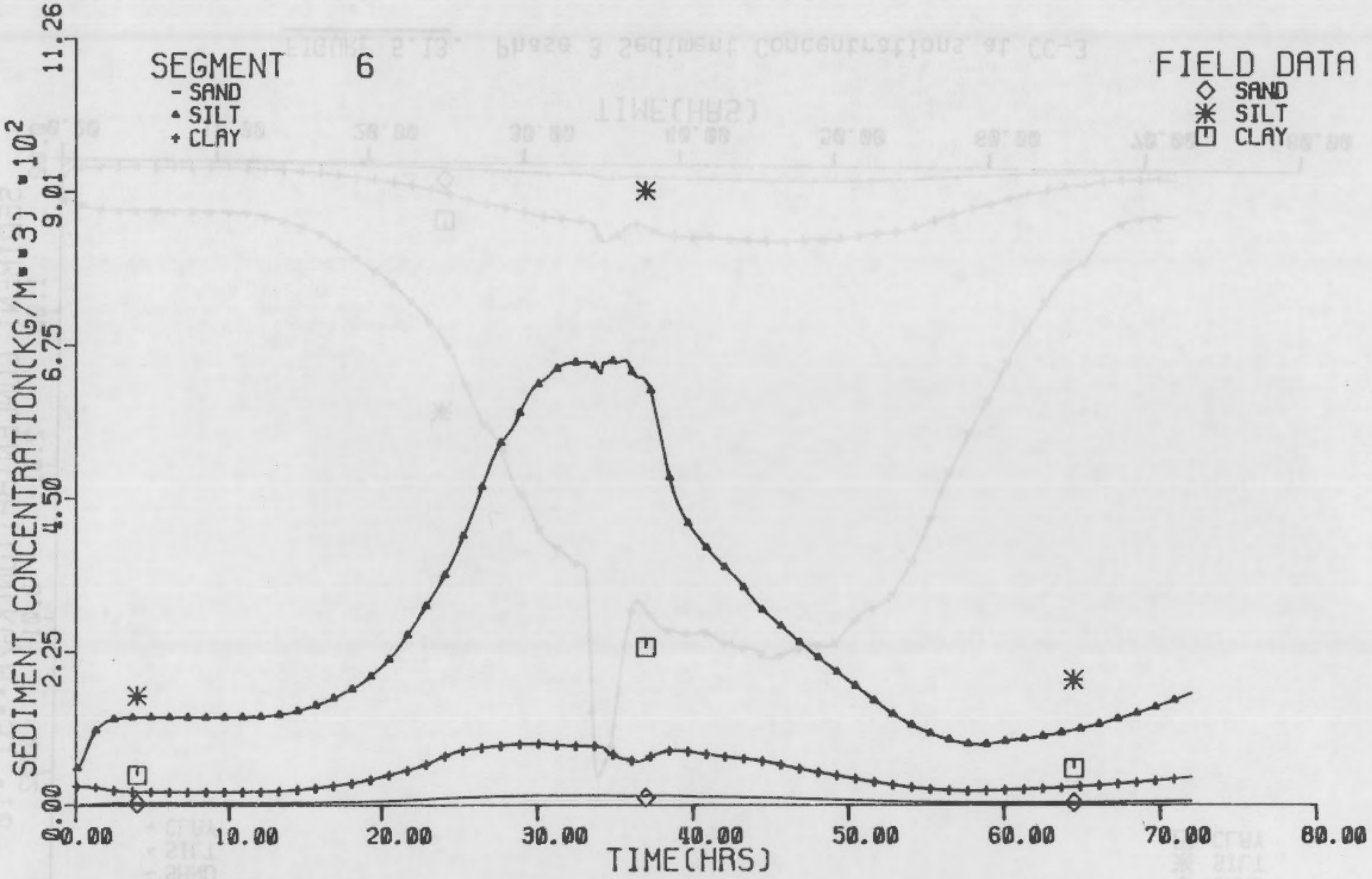


FIGURE 5.12. Phase 3 Sediment Concentrations at BC-4

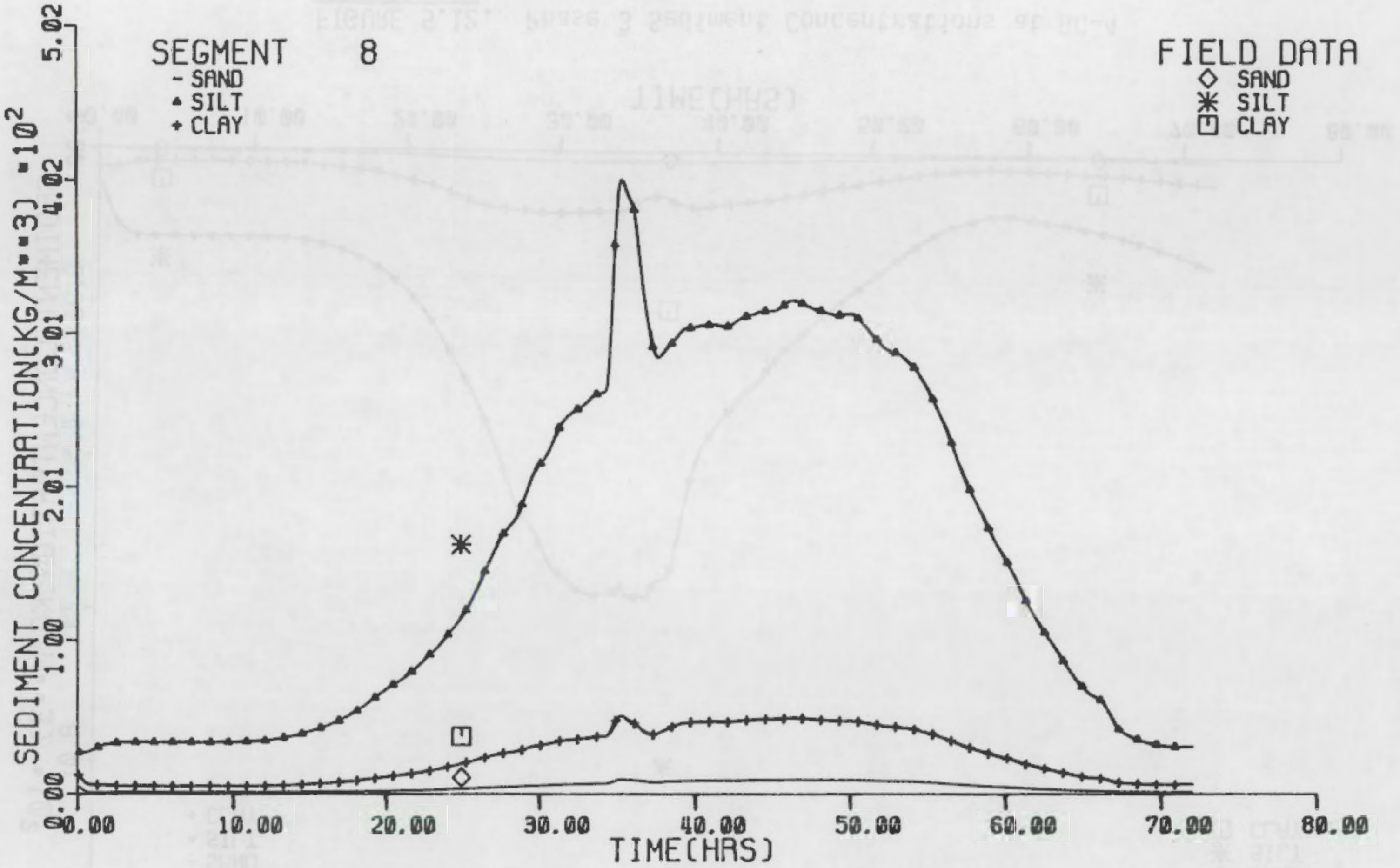


FIGURE 5.13. Phase 3 Sediment Concentrations at CC-3

Creek than in Buttermilk Creek. In this case however, the effect of the Buttermilk Creek discharge is visible. This is due to the sudden increase of sediment mass entering Cattaraugus Creek with the discharge spike.

At CC-3 (Figure 5.13), downstream of the Buttermilk confluence, the predicted sediment wave is broader at the base than that seen on Buttermilk Creek. The "spike" of the Phase 3 hydrodynamics is visible on the sediment wave at CC-3 because the concentrations in Buttermilk Creek are higher than those found in Cattaraugus Creek. Predicted concentrations closely approximate the measured values at 25 hr and are consistently lower.

The field data at CC-5 are samplings at 9, 33, and 59 hr. These data indicate a sediment peak around the 33-hr mark of the event. The modeled peak occurs at 37 hr (Figure 5.14). At 9 and 33 hr, predicted concentrations are consistently 35% below the field concentrations. At 59 hr, predicted silt and clay concentrations are higher than the measured values while the predicted sand is lower than the field concentration.

Downstream of Springville Dam, the wave of predicted sediment becomes more diffuse, taking up the entire simulation period. Although peak sediment concentrations follow the trend of the flood wave, the transported sediment displays the effects of bed scouring and subsequent armoring. Elevated levels of silt concentrations in the first 20 hr of the simulation are the result of bed material suspended by scour. After 50 hr of simulation, the drop in the silt concentration is attributable to the armoring of the silt in the bed by the heavier sand fraction. Clay and sand suspended fractions are not strongly affected by the scouring mechanism and remain in low concentrations with less dynamic effects.

At CC-6 (Figure 5.15) and subsequent segments, the computed silt fraction of the suspended sediment is increasing due to scour. The trend exhibited by the three field samples is in general preserved quite well by the simulation. Clay and sand concentrations computed by SERATRA are within 0.002 kg/m^3 of the measured concentrations. Predicted silt concentrations are consistently about 0.015 kg/m^3 higher than the field silt values.

Data Stations CC-9 and CC-11 have very similar results. The sharp wave outline has dissipated, leaving a gentle increase in concentration at hour-50 of the simulation. While the sand and clay concentrations predicted by SERATRA match quite well with sampled data, the silt concentration is about four times higher than the field value. The elevated silt concentrations produced by the model is a result of silt scoured off the channel bottom.

Figure 5.16 is the predicted longitudinal distribution of the total suspended sediment concentration at the end of the 72 hour simulation period. The first four data points represent the modeled concentrations at sites BC-3, BC-4, CC-3, and CC-5. The temporal concentration distributions at these locations indicate these concentrations are at levels near those which existed prior to the flood event. The steady increase in concentration from CC-3 through CC-11 is the spatial description of the falling limb of the sediment wave.

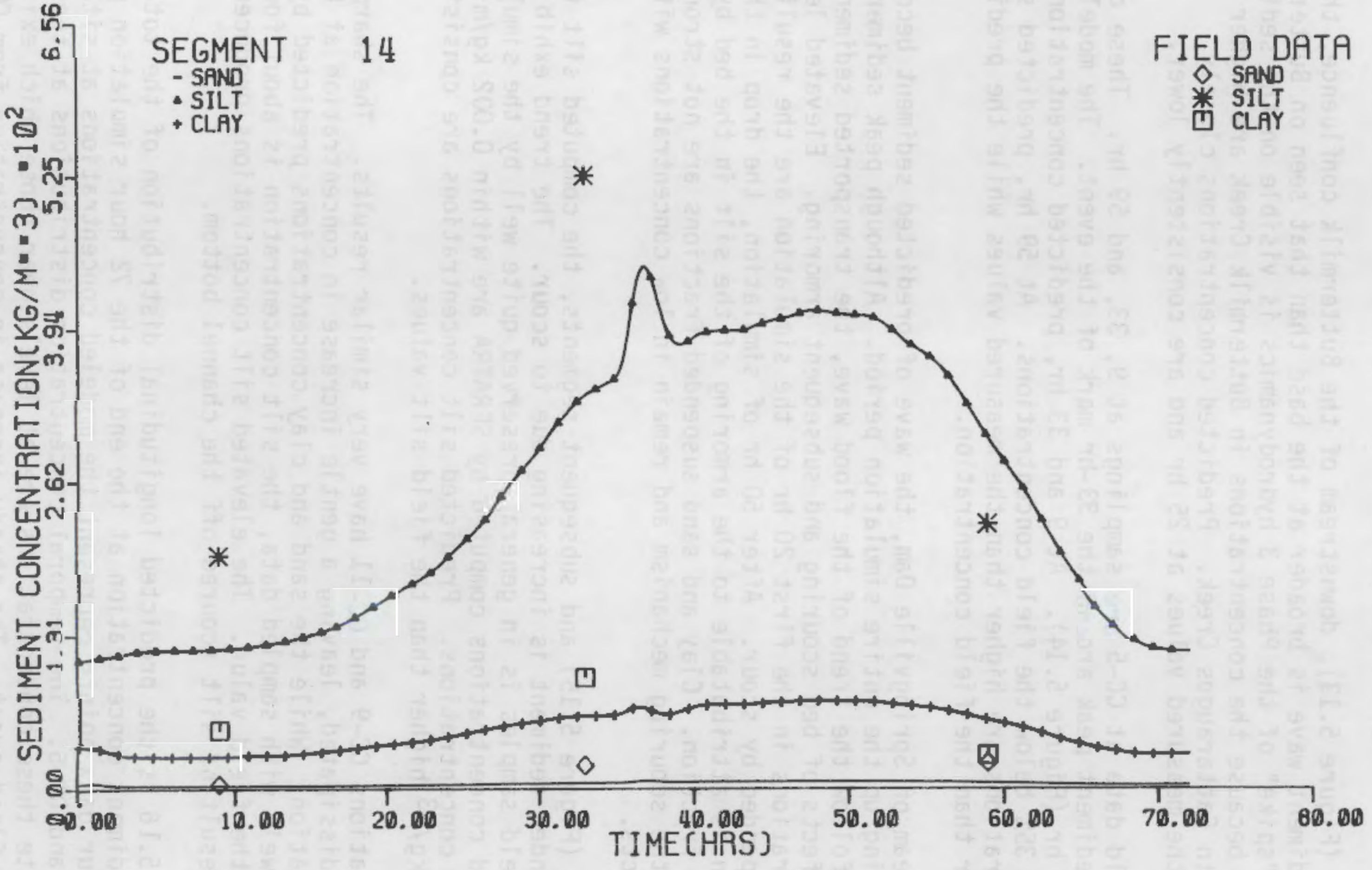


FIGURE 5.14. Phase 3 Sediment Concentrations at CC-5

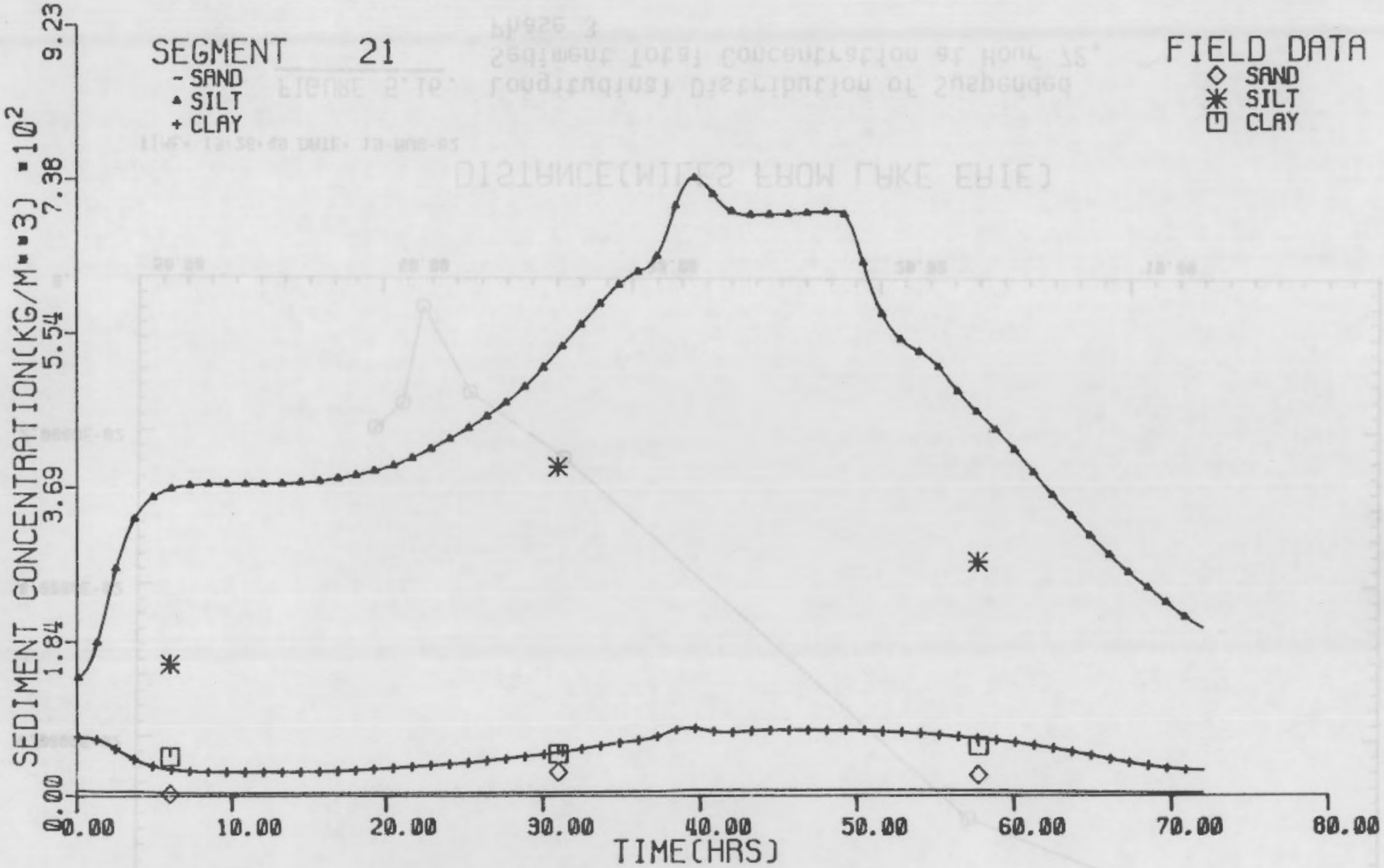


FIGURE 5.15. Phase 3 Sediment Concentrations at CC-6

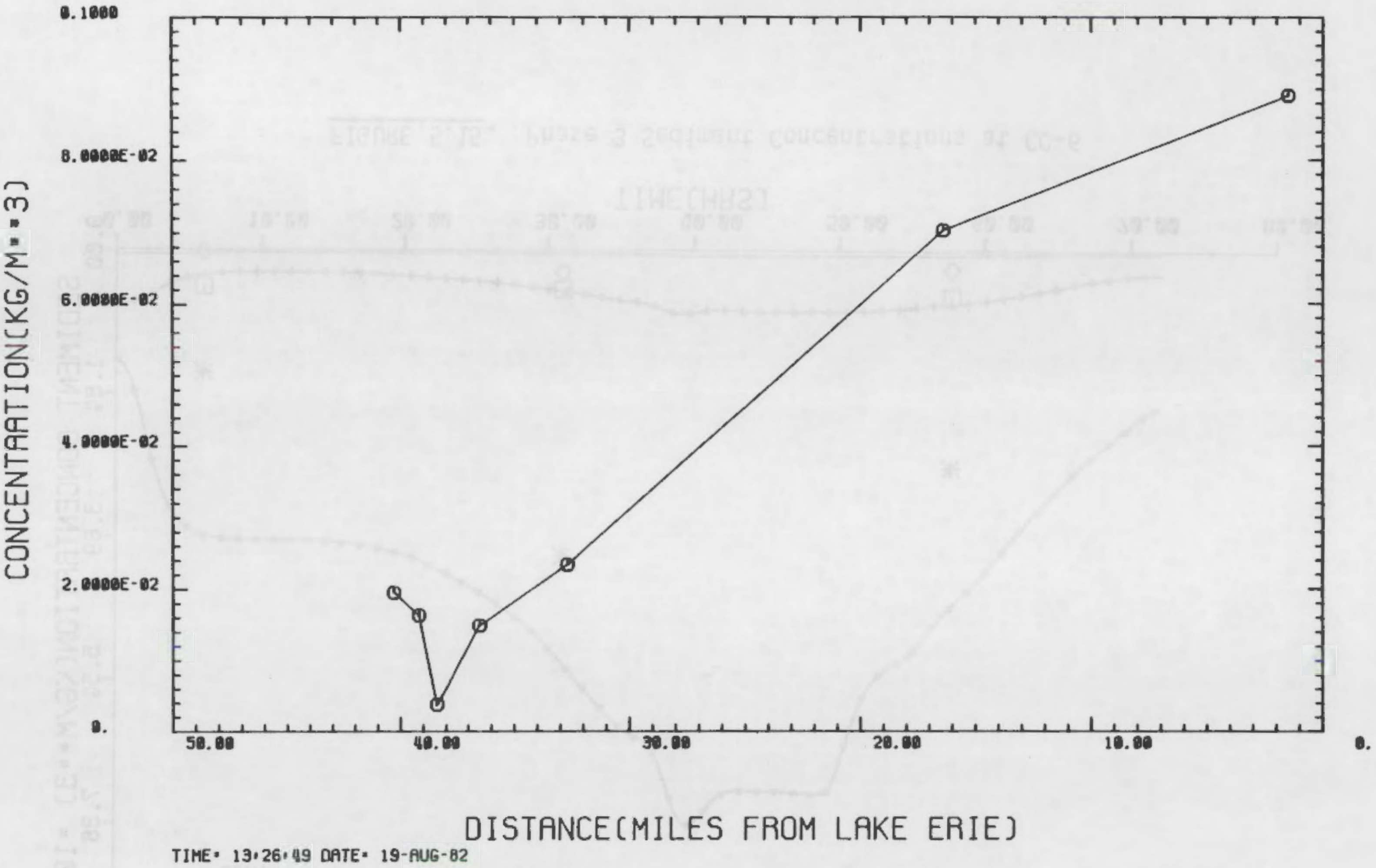


FIGURE 5.16. Longitudinal Distribution of Suspended Sediment Total Concentration at Hour 72, Phase 3

In Phase 3, deposition was predicted to occur only at Springville Dam (segment 14) and at the mouth of Cattaraugus Creek at Lake Erie (segment 34). These are the two backwater areas on this creek system. Scour was predicted in almost all the other modeled segments. Figure 5.17 is a bar graph of the predicted deposition and scour occurring as a function of distance. The areas of the bars reflects the total mass of sediment scoured or deposited. Large depositions of sand at the Springville Dam and Lake Erie backwaters offset the sand scoured in the other segments. In Phase 3 the net sand deposited amounted to 3400 kg. As Figure 5.17 indicates, the largest volumes of scoured bed material occurred below Springville Dam. Ninety-eight percent of the scoured material was silt amounting to 410,000 kg while scoured clay amounted to 7500 kg. The most intensive erosion took place just below Springville Dam.

A summary of the observed and predicted suspended sediment concentrations is found in Table 5.5. Additional plots of sediment concentration at the data collection stations are in Appendix A. Comparison of these values revealed that SERATRA reproduced reasonably well a dynamic pattern of sediment transport and that most predictions were within 50% of the measured data. Considering the complexity of the stream system and the accuracy of the field data, SERATRA was judged reasonably capable of simulating a dynamic sediment transport process.

Phase 2

Other than the calibration of the cohesive sediment parameters in Phase 3, no other calibration was performed in this study. In Phase 2 and Phase 1, only a single sample was taken at each data station along the study reach. Thus, no time-dependent sediment or radionuclide information was available. The assumption of constant influence concentrations throughout the flow event was made with the full knowledge that some inaccuracy might result.

The Phase 2 sediment and radionuclide simulation period began at 8:00 a.m. on September 20, 1978 and ended at 12:00 non on September 24, 1978. A summary of the observed and predicted suspended sediment concentrations is found in Table 5.6.

The modeled flow event begins on the falling limb of a flood wave after which a steady discharge occurs. The effect of the flood wave is significant downstream of the dam. Upstream of the dam, suspended sediment concentrations are virtually constant with silt comprising about 75% of the suspended material while clay accounts for the bulk of the remaining 25%.

TABLE 5.6. Phase 2 Observed and Computed Sediment Concentrations

Phase 2 Sediment Comparison (mg/ℓ)		
Location	Observed	Computed
BC-4		
Sand	0.42	1.1
Silt	45.65	45.7
Clay	13.55	14.7
CC-3		
Sand	0.105/0.15/0.21	0.6
Silt	7.15/8.37/15.90	19.3
Clay	2.42/2.40/2.19	5.4
CC-5		
Sand	0.01/0.01/0.01	0.1
Silt	20.61/15.10/11.45	18.1
Clay	2.48/2.14/1.17	5.2
CC-9		
Sand	0.57	0.1
Silt	20.16	10.5
lay	6.86	3.0
CC-11		
Sand	0.02	0.0
Silt	3.49	20.4
Clay	0.83	2.5

At BC-4 (Figure 5.18), the steady Buttermilk Creek discharge is reflected in unchanging sediment concentrations. Silt is the largest constituent with clay and sand sediment accounting for one-fourth of the total suspended sediment. In comparison with field samples, the predicted concentrations are in excellent agreement.

As sediment enters Cattaraugus Creek from Buttermilk Creek, sediment concentrations are reduced by a factor of three. In Cattaraugus Creek Station CC-3, the predicted concentrations are in general 100% higher than the measured values. At CC-5, good correlation for sand and silt fractions with field data is seen in Figure 5.19. Through CC-5, the concentrations computed by SERATRA were steady. Downstream of Springville Dam, the high discharges from the flood wave are accompanied by high sediment concentrations. The increased suspended sediment load is due to the scour of the channel bed primarily below the dam.

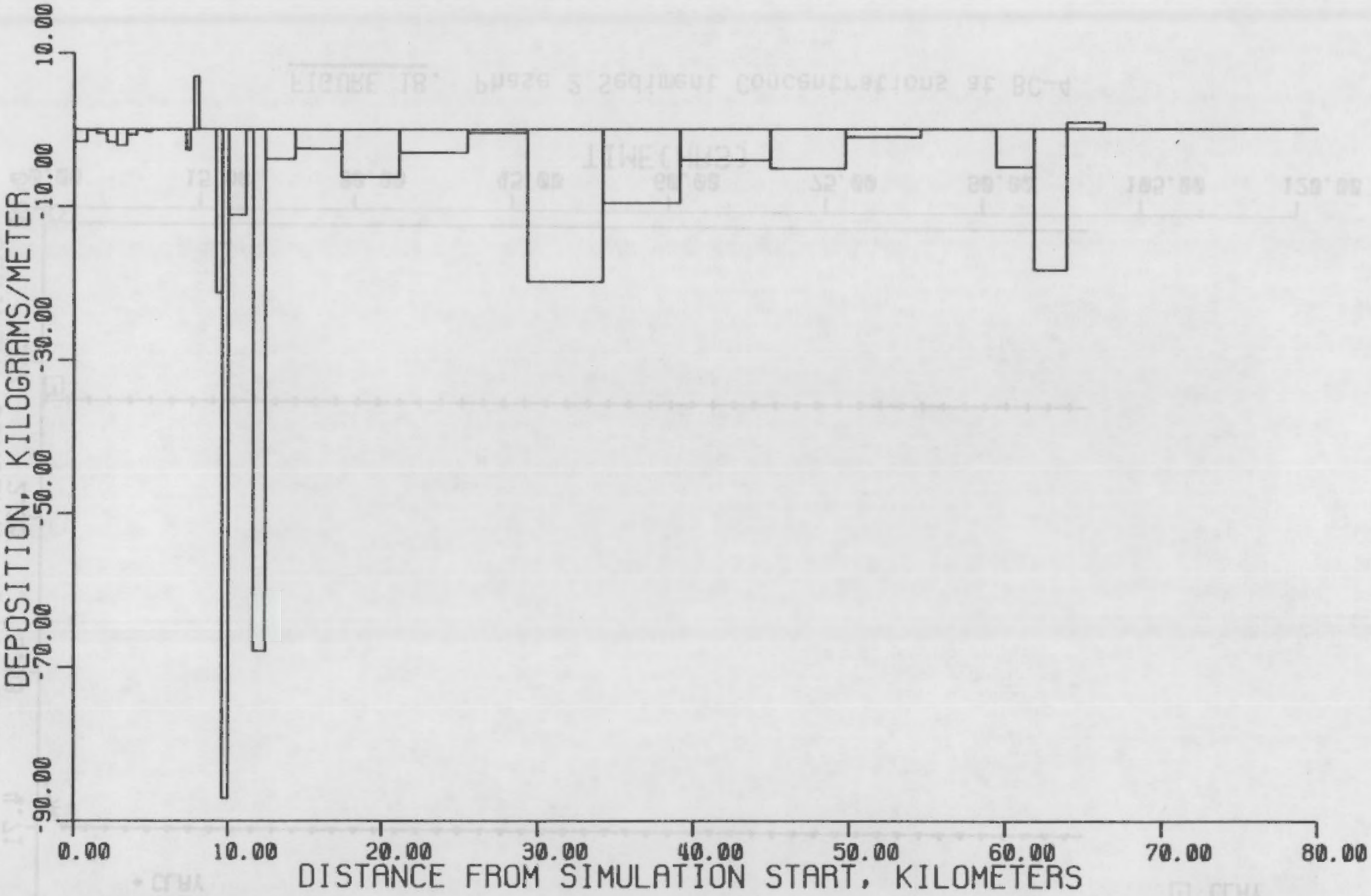


FIGURE 5.17. Predicted Sediment Deposition and Erosion, Phase 3

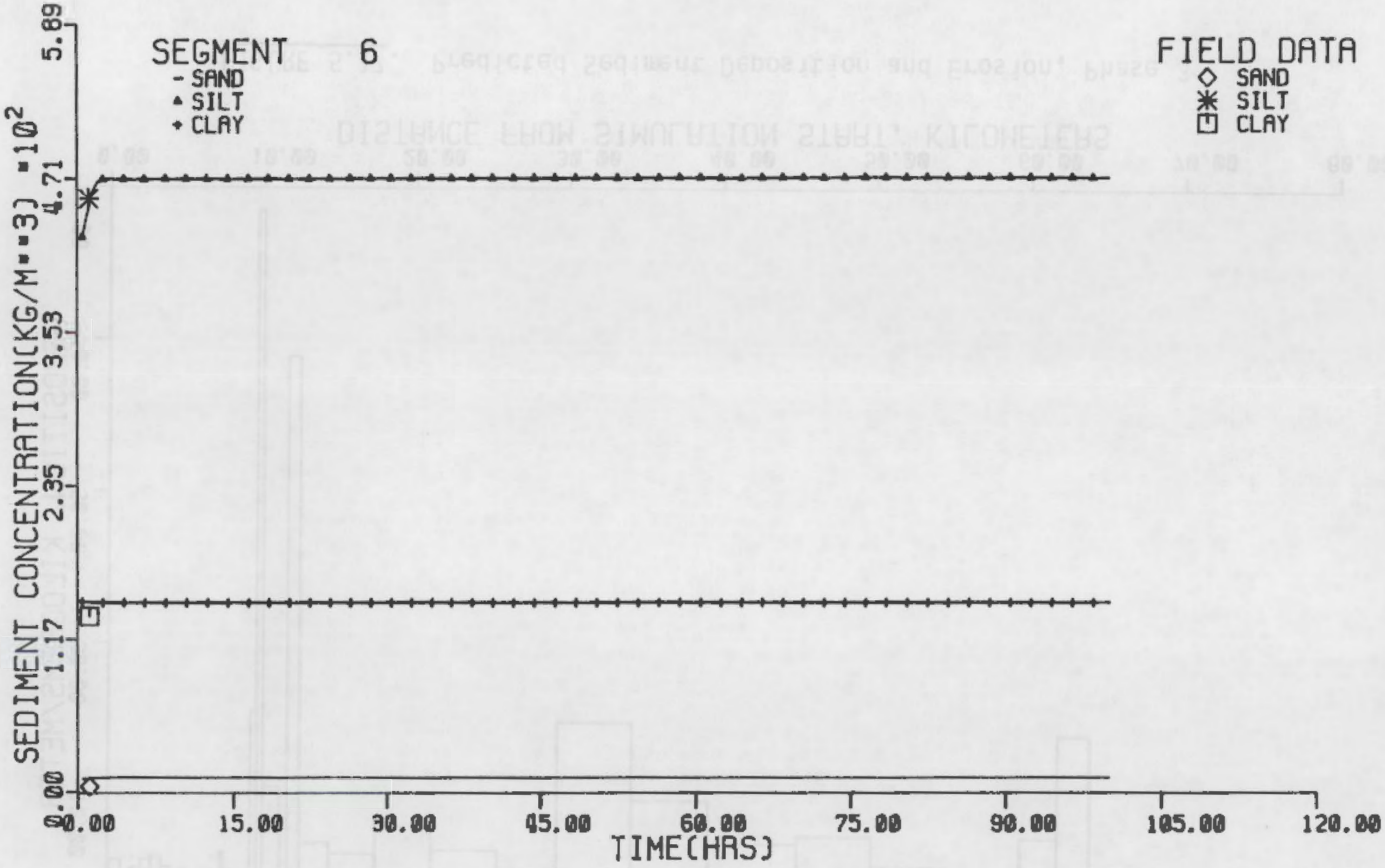


FIGURE 18. Phase 2 Sediment Concentrations at BC-4

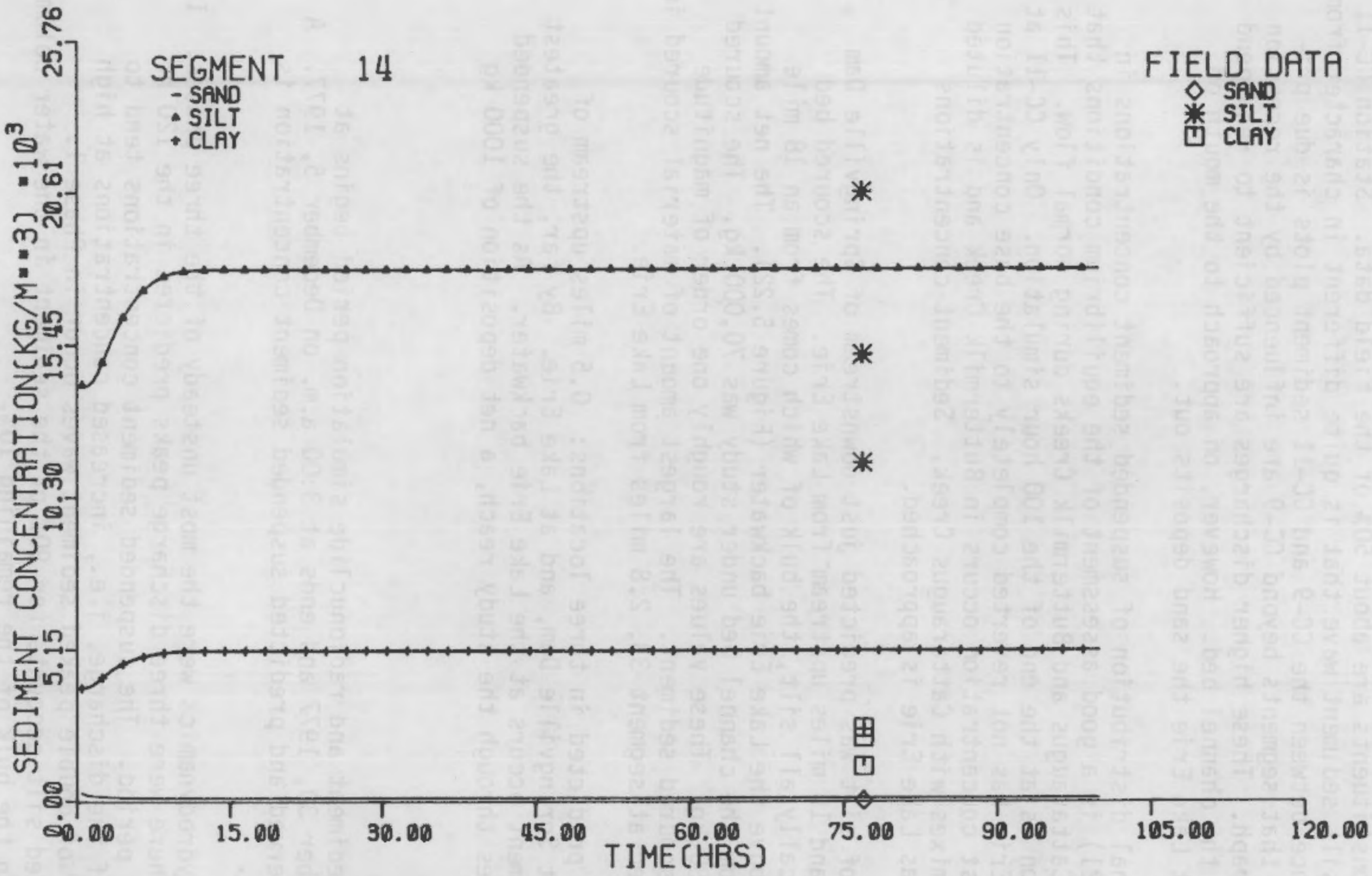


FIGURE 5.19. Phase 2 Sediment Concentrations at CC-5

Figure 5.20 is the plot of sediment concentrations at CC-9. Obviously, the dynamics displayed in CC-9 are due to scouring and eventual armoring of the stream bed downstream of Springville Dam. In this case, predicted concentrations for all constituents are about 50% of the field data. Station CC-11 has a very smooth silt sediment wave that is quite different in character from CC-9. The difference between the CC-9 and CC-11 sediment plots is due primarily to the fact that segments beyond CC-9 are influenced by the recession limb of the hydrograph. These higher discharges are sufficient to resuspend sand and silt from the channel bed. However, on approach to the mouth of Cattaragus Creek at Lake Erie the sand deposits out.

The longitudinal distribution of suspended sediment concentrations in Phase 2 (Figure 5.21) is a good assessment of the equilibrium conditions that one might find on Cattaraugus and Buttermilk Creeks during normal flow. This spatial distribution is at the end of the 100 hour simulation. Only CC-11 at the mouth of Lake Erie has not reverted completely to the base concentration levels. The highest concentration occurs in Buttermilk Creek and is diluted 2.5 times when it mixes with Cattaraugus Creek. Sediment concentrations decrease slightly as Lake Erie is approached.

Bed armoring of silt was predicted just downstream of Springville Dam (Creek Mile 35.5) and 15 miles upstream from Lake Erie. The scoured bed material is practically all silt, the bulk of which comes from an 18 mile stretch of creek above the Lake Erie backwater (Figure 5.22). The net amount of silt scoured from the channel bed under study was 70,000 kg. The scoured clay amounted to 280 kg. These values are roughly one order of magnitude below the Phase 3 scoured sediment. The largest amount of material scoured in one segment occurred at segment 33, 2.8 miles from Lake Erie.

Deposition is predicted in three locations: 0.5 miles upstream of Springville Dam, at Springville Dam, and at Lake Erie. By far, the greatest deposition of sediment occurs at the Lake Erie backwater. As the suspended sand fraction passes through the study reach, a net deposition of 1000 kg occur.

Phase 1

The Phase 1 sediment and radionuclide simulation period begins at 3:00 a.m. on November 30, 1977 and ends at 3:00 a.m. on December 5, 1977. A summary of the observed and predicted suspended sediment concentration is found in Table 5.7.

The Phase 1 hydrodynamics were the most unsteady of the three phases. In Buttermilk Creek there were three discharge peaks predicted in the 120 hr SERATRA simulation period. The suspended sediment concentrations tend to follow the trend of the discharge, i.e., increased concentrations at high flows. Two trains of double peaked sediment waves occur in Phase 1. Buttermilk suspended silt accounts for 90% of the sediment in the water column while clay makes up the bulk of the remaining 10%.

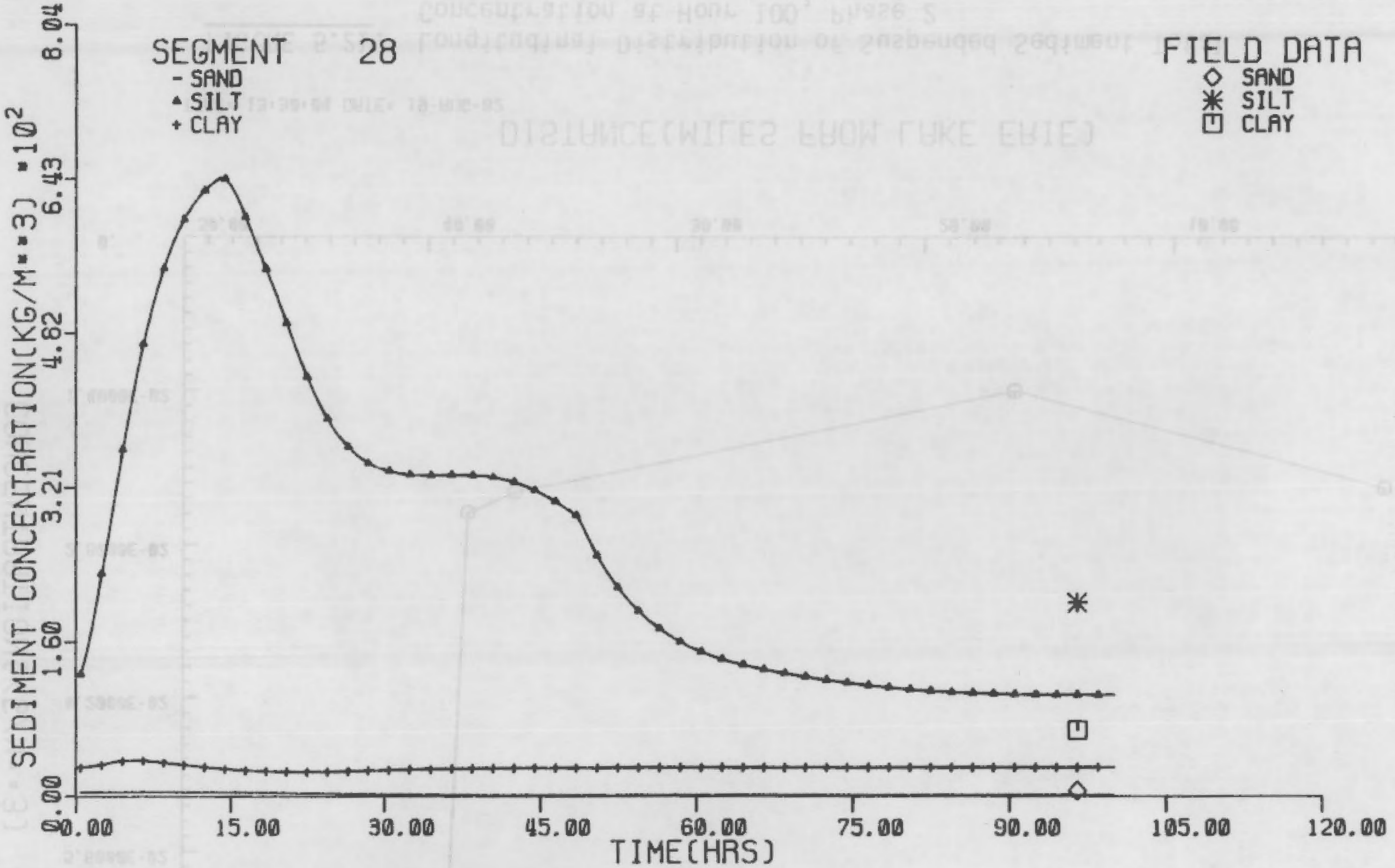


FIGURE 5.20. Phase 2 Sediment Concentrations at CC-9

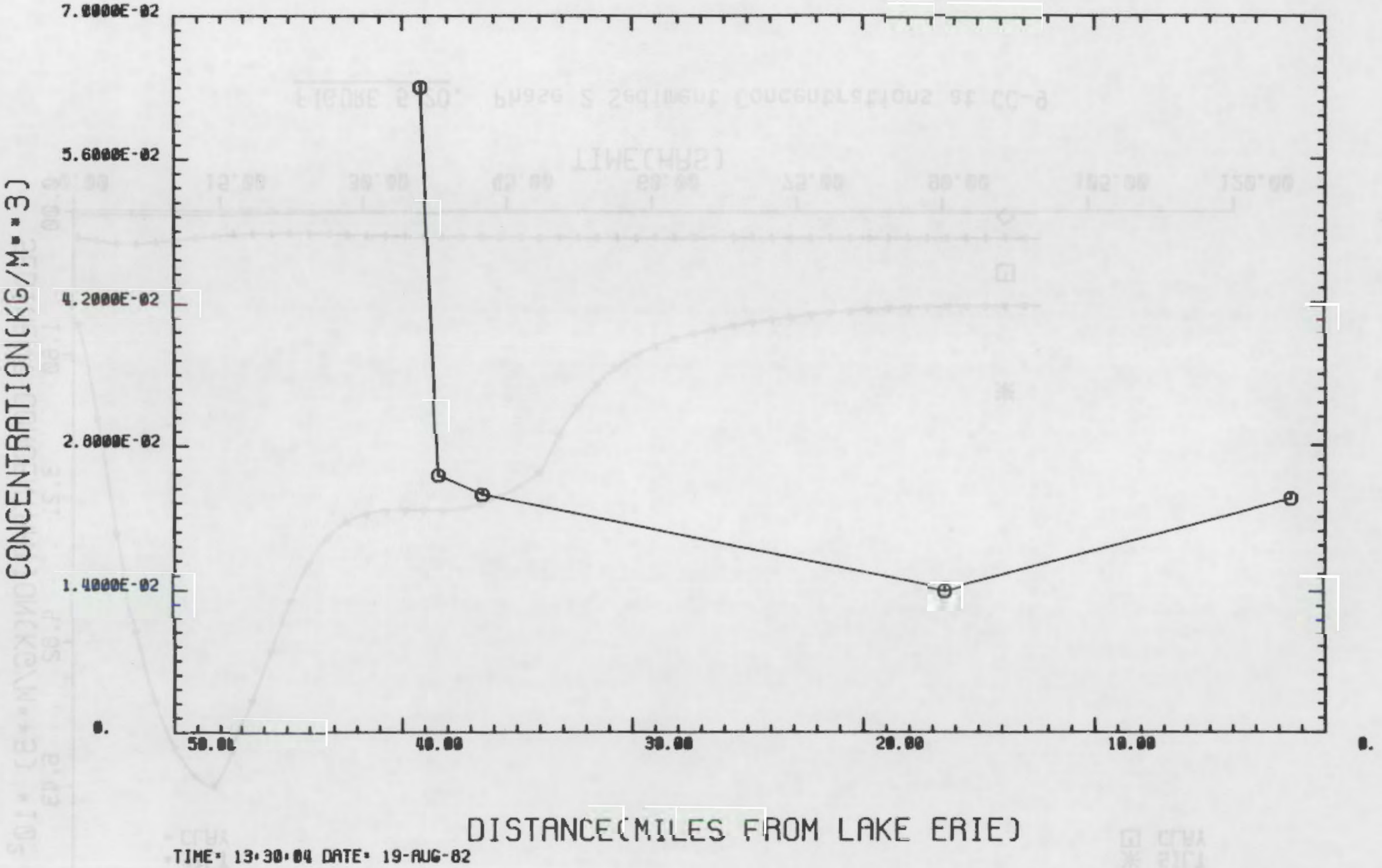


FIGURE 5.21. Longitudinal Distribution of Suspended Sediment Total Concentration at Hour 100, Phase 2

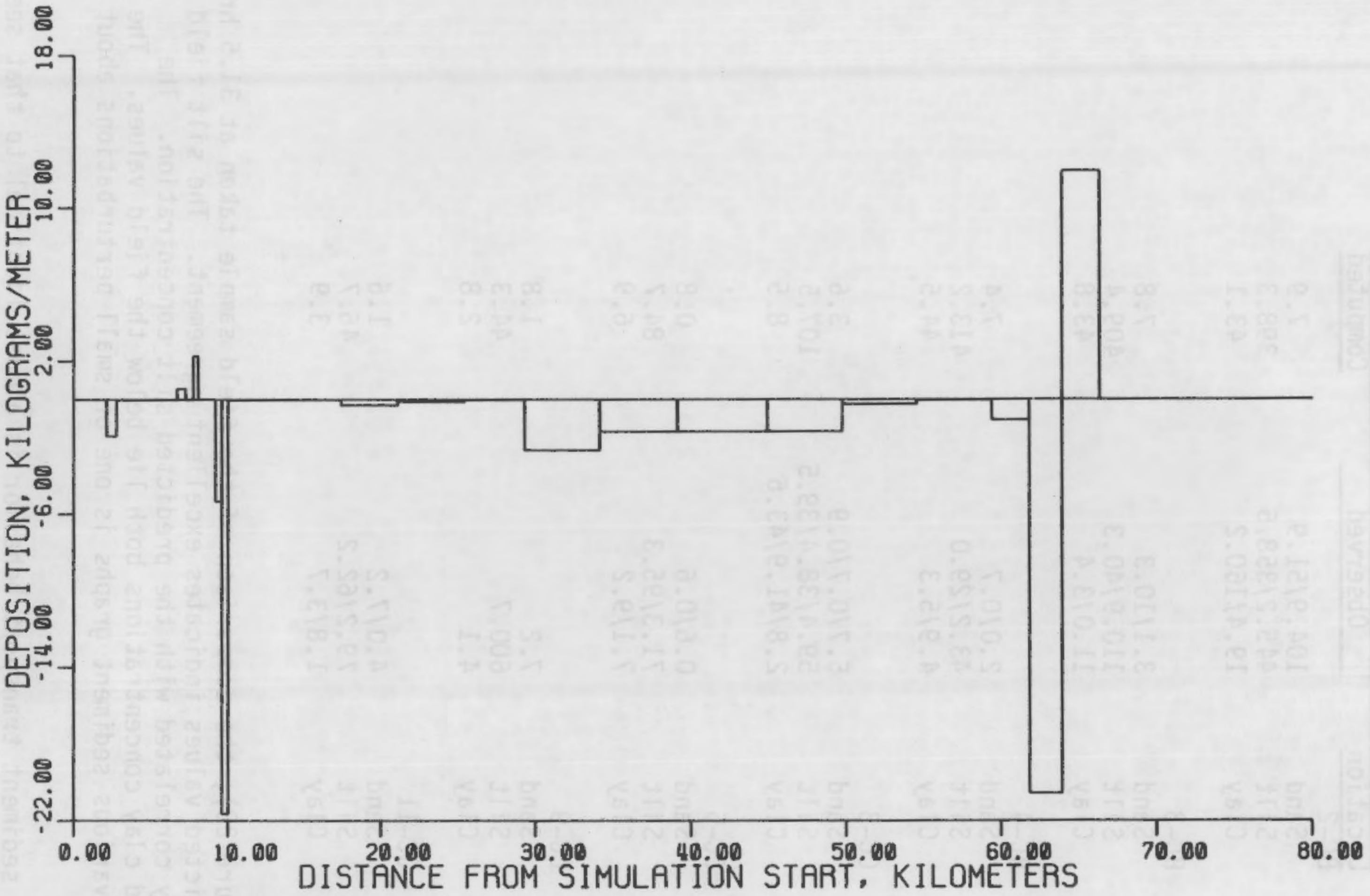


FIGURE 5.22. Predicted Sediment Deposition and Erosion, Phase 2

TABLE 5.7. Phase 1 Observed and Computed Sediment Concentrations

Phase 1 Sediment Comparison (mg/ℓ)		
Location	Observed	Computed
BC-2		
Sand	104.9/51.9	7.9
Silt	445.2/358.5	398.3
Clay	19.4/160.2	43.1
BC-3		
Sand	3.1/10.3	7.8
Silt	110.9/40.3	409.4
Clay	11.0/3.4	43.8
BC-4		
Sand	2.0/0.7	7.4
Silt	43.2/29.0	413.2
Clay	4.9/5.3	44.5
CC-3		
Sand	5.7/0.7/0.9	3.6
Silt	59.4/38.4/39.5	107.5
Clay	2.8/41.9/43.6	8.5
CC-5		
Sand	0.6/0.6	0.8
Silt	71.3/95.3	84.7
Clay	7.1/9.2	6.9
CC-9		
Sand	7.2	1.8
Silt	600.7	44.3
Clay	4.1	2.8
CC-11		
Sand	4.0/7.2	1.6
Silt	79.2/62.2	46.7
Clay	1.8/3.7	3.9

At BC-2 (Figure 23), the comparison of the field sample taken at 31.5 hr with SERATRA predicted values indicates excellent agreement. The silt field value is perfectly correlated with the predicted silt concentration. The predicted sand and clay concentrations both lie below the field values. The character of the various sediment graphs is one of small perturbations about a base value.

At BC-3, the sediment transport behavior is almost identical to that seen at Station BC-2. However, in this case only the predicted sand value is close

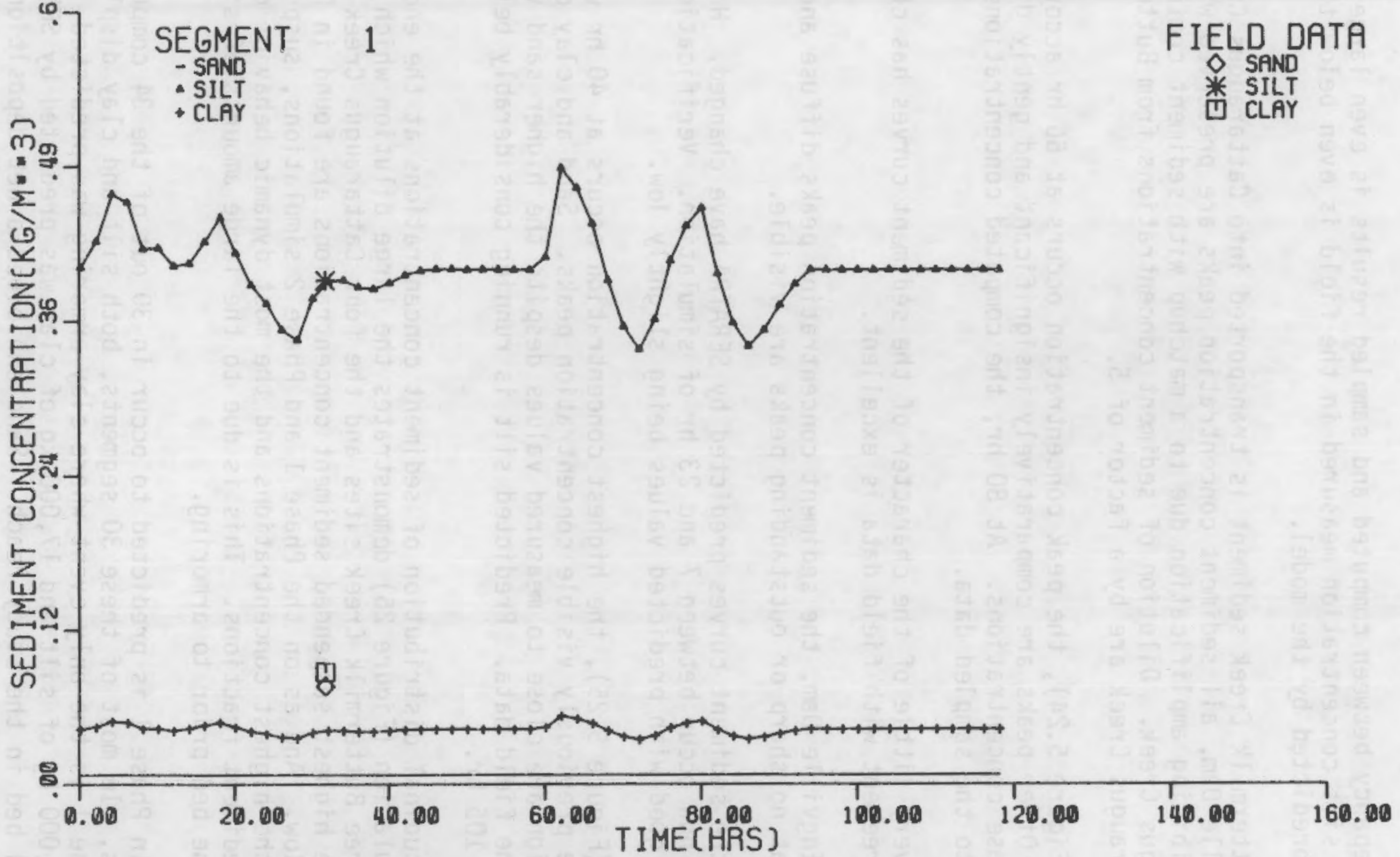


FIGURE 5.23. Phase 1 Sediment Concentrations at BC-2

to the field sand concentration as the field-sampled concentrations exhibit a large deviation from the BC-2 values. Computed silt and clay are four to five times larger than the measured counterparts.

The discrepancy between computed and sampled results is even larger at BC-4 where the silt concentration measured in the field is even below the clay concentration predicted by the model.

As the Buttermilk Creek sediment is transported into Cattaraugus Creek above Springville Dam, all sediment concentration peaks are preserved with the 65 hr peak exhibiting amplification due to a matchup with sediment coming from Upper Cattaraugus Creek. Dilution of sediment concentrations from Buttermilk Creek to Cattaraugus Creek are by a factor of 5.

At CC-3 (Figure 5.24), the peak concentration occurs at 66 hr according to the model. Other peaks are comparatively insignificant and gently dispersing into the base concentrations. At 80 hr, the computed concentrations match quite closely to the sampled data.

At CC-5, very little of the character of the sediment curves has changed from CC-3. Agreement with field data is excellent.

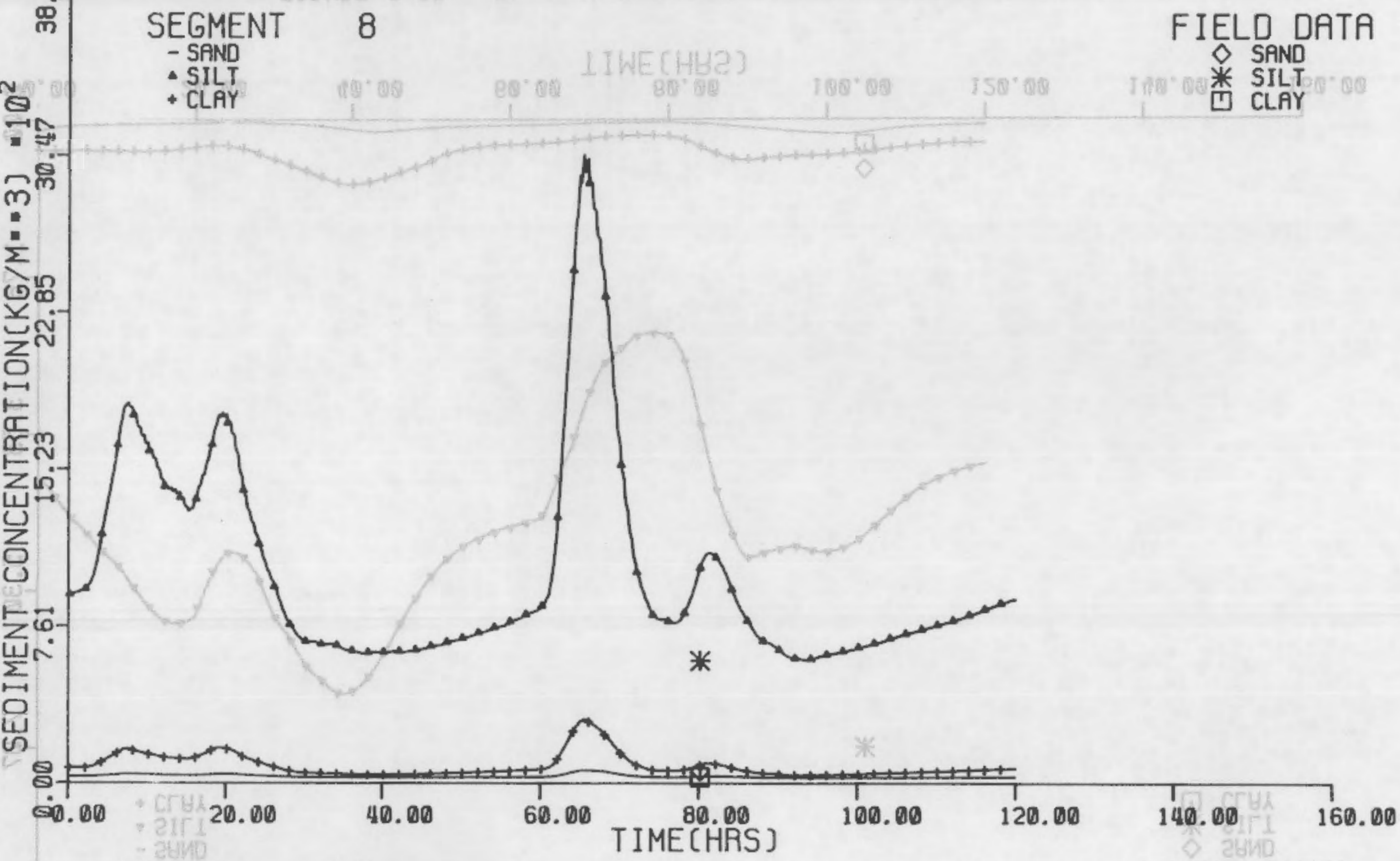
Below Springville Dam, the sediment concentration peaks diffuse and join together so that no sharp or outstanding peaks are visible.

At CC-9, the sediment curves predicted by SERATRA have changed. Highest concentrations now occur between 7 and 23 hr of simulation. Verification at 108 hr is very good with predicted values being slightly low.

At CC-11 (Figure 5.25), the highest concentration occurs at 40 hr with no evidence of the previously visible concentration peaks. Sand and clay computed by the simulation are close to measured values despite the higher sand values indicated in the field data. Predicted silt is running considerably below the field value at 105 hr.

The longitudinal distribution of sediment concentrations at the end of the 120 hr simulation (Figure 26) demonstrates the large dilution which occurs between the three Buttermilk Creek sites and the four Cattaraugus Creek sites. In general, the highest suspended sediment concentrations are found in Phase 1 even at base flow. And as on the Phase 1 and Phase 2 simulations, suspended silt displays the highest concentrations and the most dynamic behavior of the three routed sediment fractions. This is due to the large amounts of silt removed from the bed prior to armoring.

Armoring in Phase 1 is predicted to occur in 30 out of the 34 computational segments. In most of these 30 segments, both silt and clay display armoring. Phase 1 is the only event where clay armoring was predicted. A net erosion of 200,000 kg of silt and 17,000 kg of clay was predicted by SERATRA for the channel bed in the study reach. Sand exhibited a net deposition of 19,000 kg. The deposition of sand occurred strictly in the backwaters of Springville Dam and Lake Erie. Figure 5.27 is a bar graph of scour and



<u>FIGURE 24</u>. Phase 1 Sediment Concentrations at CC-3

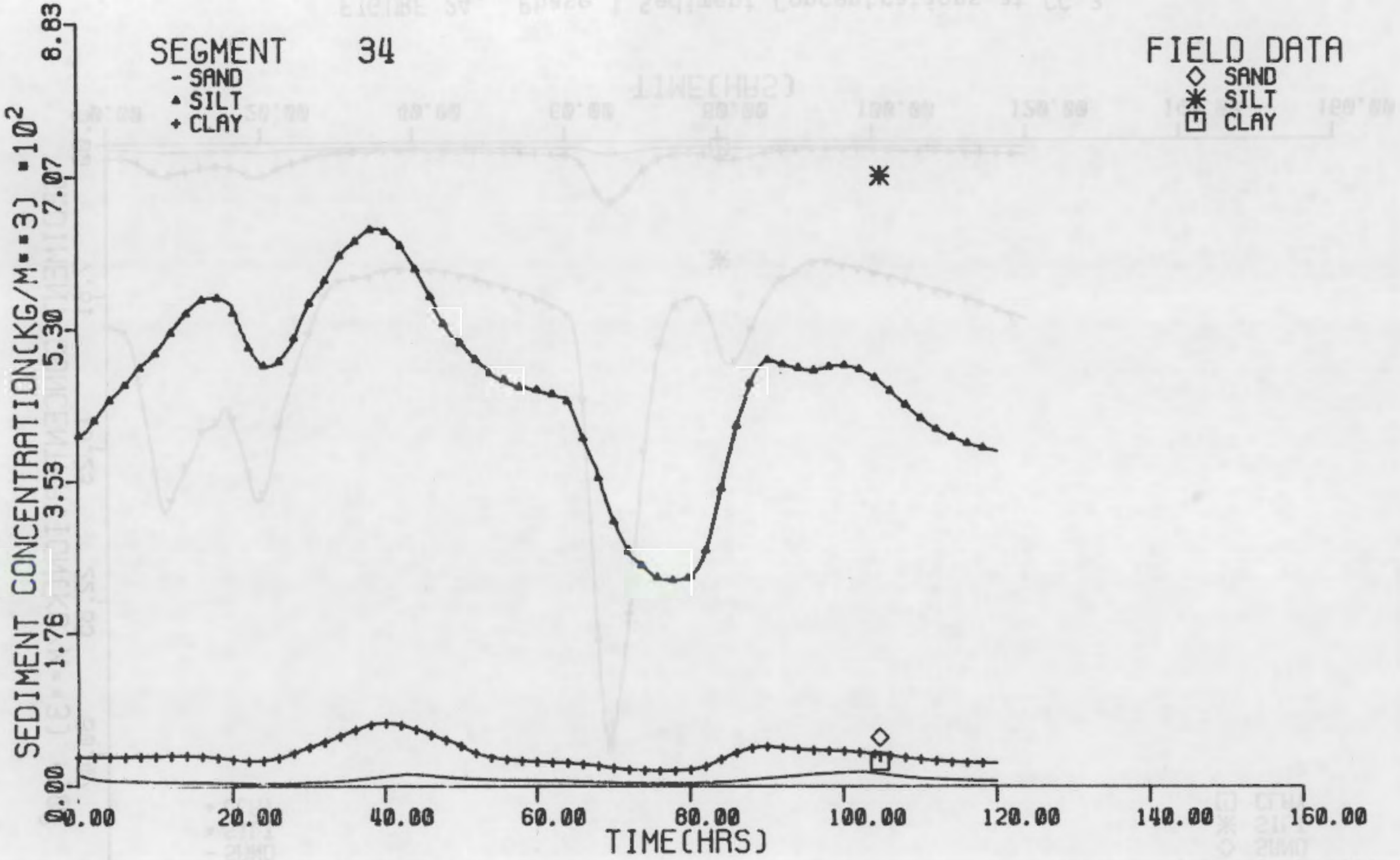


FIGURE 5.25. Phase 1 Sediment Concentrations at CC-11

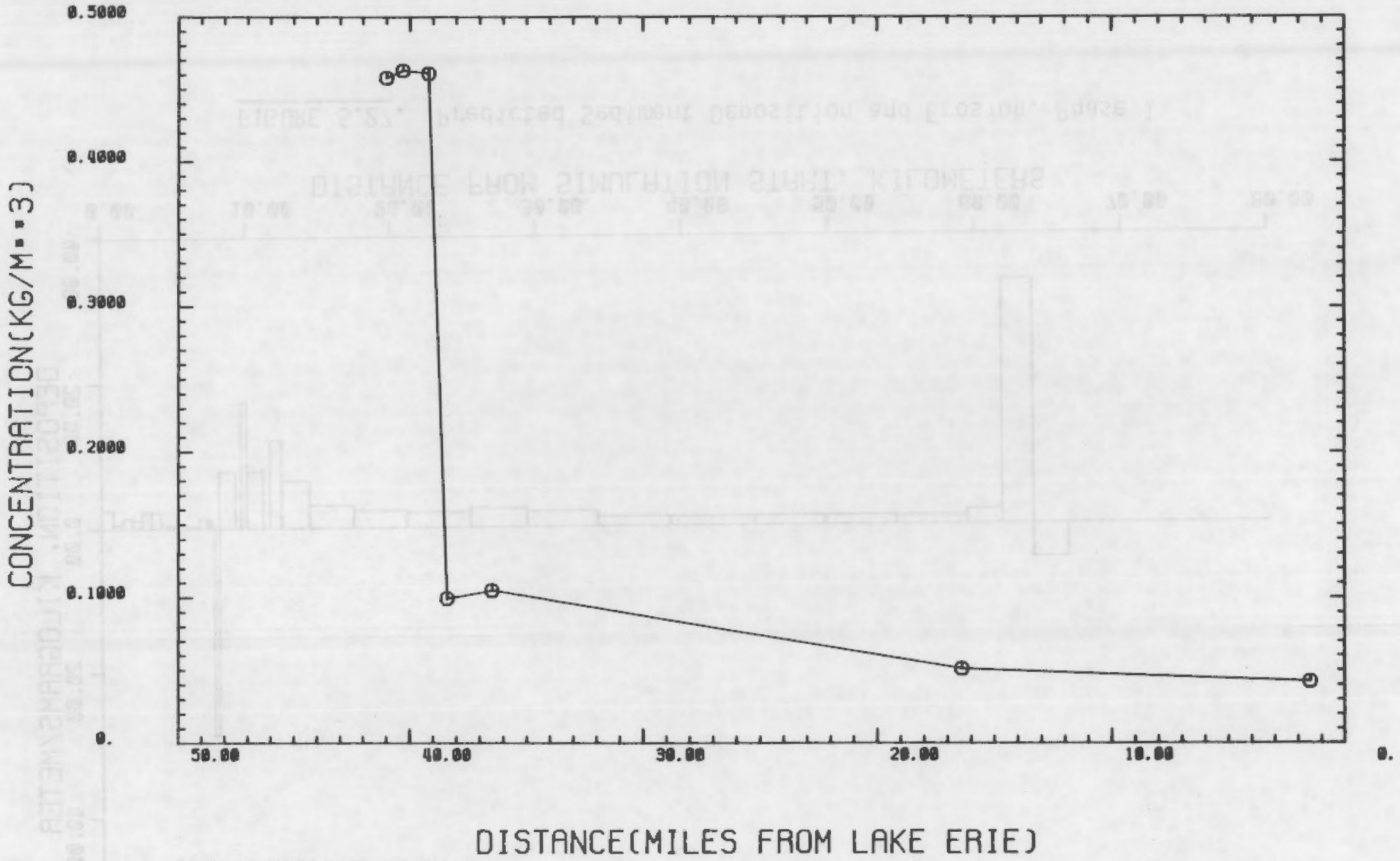


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FIGURE 5.26. Longitudinal Distribution of Suspended Sediment Total Concentration at Hour 120, Phase 1

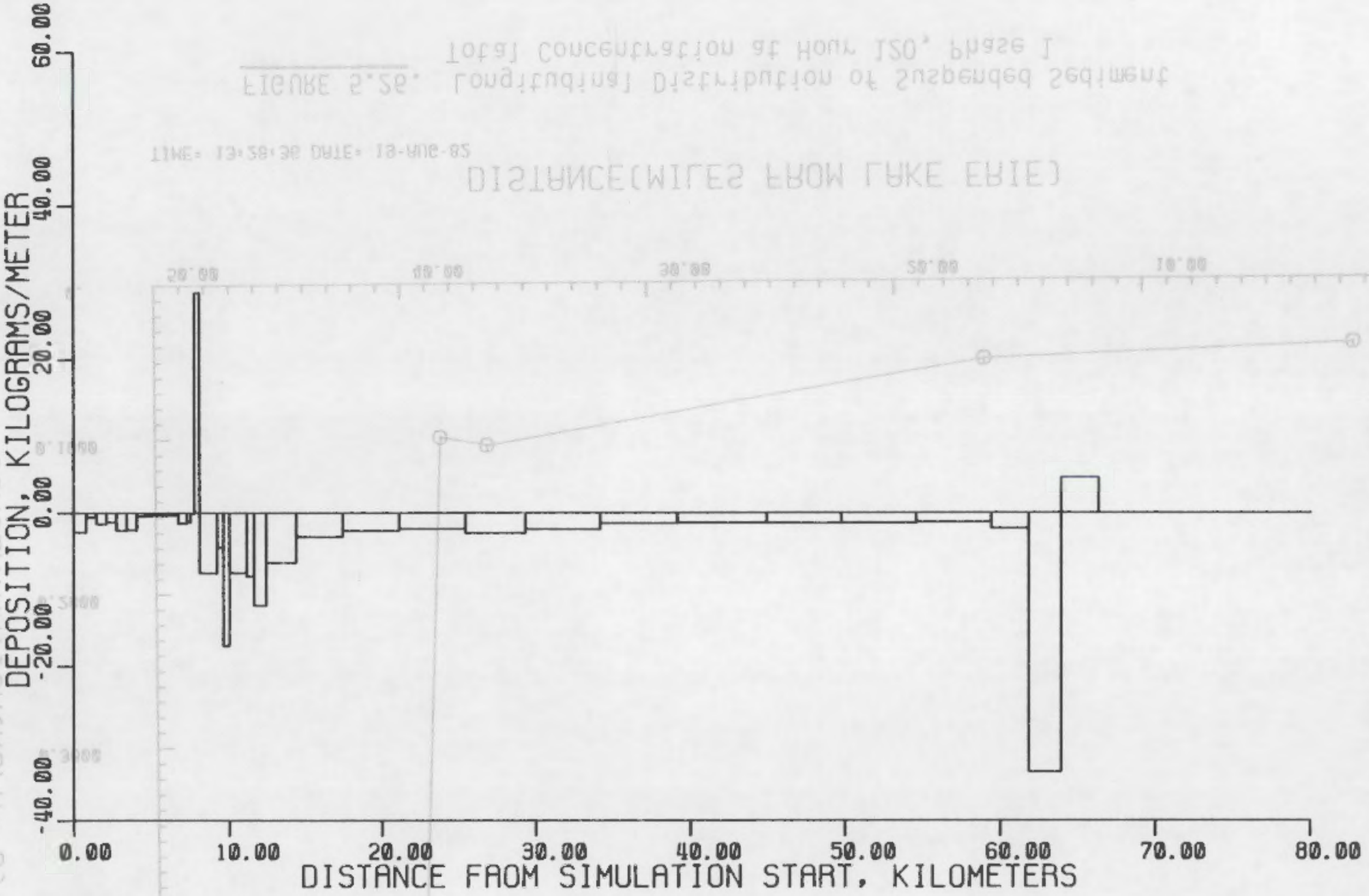

FIGURE 5.27. Predicted Sediment Deposition and Erosion, Phase 1

deposition predicted in each segment during Phase 1. Deposition occurs only in the two backwater areas while scour occurs everywhere else. The most intensive deposition occurs at Springville Dam (Segment 14) whereas the most intensive bed scour is found above the Lake Erie backwater, where slope and depth are quite large. However, the segments immediately below Springville Dam collectively exhibit the area where bed scouring is most active.

5.4.3 Radionuclide Transport Simulation Results

Ten applications of the SERATRA code were performed in the course of this modeling study. Four radionuclides, ^{137}Cs, ^{90}Sr, $^{239,240}Pu$ and ^{3}H were modeled using the Phase 2 and Phase 3 flow events while ^{137}Cs and ^{3}H were modeled with the Phase 1 data.

Although 30 radionuclides were tested for in the laboratory, only these four radionuclides had sufficient information to properly pose the problem for a modeling study. The radionuclides available for modeling were limited largely by the number of distribution coefficients (K_ds) measured in Cattaraugus Creek. Of the five radionuclides with measured K_d values, ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$ had adequate data at boundary conditions and verification points. Tritium, which does not sorb to sediment, was sampled separately and thus had the necessary information for a modeling effort. Phase 1 was modeled with ^{137}Cs and ^{3}H because ^{90}Sr and $^{239,240}Pu$ did not have data suitable for modeling.

The purpose of simulating the transport and fate of four radionuclides during three flow events was to test SERATRA under a wide range of hydraulic and radiochemical conditions. Two radionuclides, ^{137}Cs and ^{3}H, were tested under highly dynamic, moderate, and near-steady flows to demonstrate the effect of varying the field conditions while keeping the radionuclide parameters constant. The use of four radionuclides allows the radiochemical effects to be tested, i.e., varying the radionuclide parameters while field conditions are kept constant. This latter analysis pertains to the Phase 2 and Phase 3 SERATRA simulations where all four radionuclides were modeled. The characteristics of the modeled radionuclides are very diverse. $^{239,240}Pu$ has a half-life of 6,600 years and a measured adsorption K_d of 21 m^3/kg. ^{3}H, on the other hand, has a half-life of 12 years and no measurable distribution coefficient. The other two radionuclides fall between these extremes.

Radionuclides levels in Franks Creek are the highest in the area with dissolved and sorbed forms exhibiting activity many times greater than that found upstream of the study reach. As Franks Creek enters Buttermilk Creek, activity is reduced by dilution and by the mixing of the relatively 'clean' Buttermilk Creek sediments with the contaminated Franks Creek sediments. Subsequent reductions in radionuclide levels occur as Buttermilk Creek joins Cattaraugus Creek and wherever lateral inflow (such as a tributary) is found. The general trend is for lower activity levels to be found at greater distances from Franks Creek.

For the most part, Springville Dam contains the downstream transport of coarse sediment. This limits the activity levels in the downstream channel beds to values lower than those upstream of Springville Dam.

In general, bed activity levels do not change much unless large amounts of sediment with radionuclide concentrations very different from the bed are deposited. Since significant deposition occurs only at the Springville Dam and Lake Erie backwater areas (near the mouth of Cattaraugus Creek), sorbed levels in the bed in most areas during the simulation periods are largely unchanged even under the most unsteady flow conditions.

Of the four modeled radionuclides, ^{239,240}Pu consistently has the lowest dissolved and particulate activity levels. Highest dissolved concentrations are found with ^{3}H while, the highest sorbed activities are found with ^{137}Cs.

Partitioning among the three sediment size fractions usually reflects the K_d values associated with each size fraction, i.e., highest sorbed levels with the clay sediment and lowest with the sand fraction. However, in some instances sand with organic matter or silt exhibit the highest concentrations due to upstream boundary conditions which have such partitioning. For the relatively short reach modeled, these radionuclides do not have enough time to equilibrate. Thus, these uncommon distributions will persist.

The SERATRA radionuclide results presented here are from the same simulations which produced the previously discussed sediment transport results. Thus, the beginning and ending times for the three phases of simulation are the same as those reported earlier and can be directly compared. As in the sediment transport results, time is referenced from the beginning of the SERATRA simulations.

The comparison of computed and measured radionuclides will be shown in this section as well as in Appendix A.

Phase 3

The general description of the radionuclide concentrations in Phase 3 is a dilution and dispersion of initially dynamic activity levels. The spike of high discharge which occurs on Buttermilk Creek at 35 hours has the effect of causing low radionuclide concentrations in Buttermilk Creek due to dilution and high concentrations in Cattaraugus Creek because of the suddenly large fraction of contaminated water entering from Buttermilk Creek. The dilution of the lateral inflow and the dispersion caused by the vertical velocity shear smooths the upstream changes in radionuclide levels to gentle curves as the radionuclides are transported downstream.

^{137}Cs

The total sorbed concentration of ^{137}Cs was always higher than the dissolved concentration in this simulation. This was merely a reflection of the boundary conditions at Buttermilk and Franks Creeks. Considering the suspended sediment concentrations in this phase and the distribution coefficients used for ^{137}Cs, the system was not in equilibrium, with desorption from particulate to dissolved forms occurring. For the short reach of creek being simulated, the system did not have sufficient time to equilibrate to the sampled K_d value.

The partitioning of ^{137}Cs among the three modeled sediment size fractions was usually highest for clay and lowest for sand. This was to be expected as the finer sediments normally have more capacity to adsorb radionuclides than the coarser sediments.

In Buttermilk Creek, ^{137}Cs sorbed to the suspended sediment (pCi/kg) has two peaks during the 72 hr simulation, spaced 50 hr apart. The peaks occurred before and after the suspended sediment concentration peak. This was due to the relatively uncontaminated sediment in the wave which originated upstream of the Franks Creek confluence. As greater amounts of the 'clean' sediment mixed with the influent activity from Franks Creek, a strong dilution occurred. Dissolved ^{137}Cs entered Buttermilk Creek as a wave of higher concentration in the first 30 hr of simulation. Sorbed concentrations per unit volume of water (pCi/m^3) tend to increase with the suspended sediment concentration.

Predicted sorbed activities associated with the three types of sediment at BC-3 are very close to the field data values as shown in Appendix A. The predicted clay activity is slightly higher and the sand and silt activities are slightly lower than the sampled values.

Although clay has the highest sorbed activity (activity per unit weight of sediment), the relatively low concentrations of clay sediment prevent the radionuclides associated with clay from being greater than the amount of radionuclides sorbed to silt. "Dips" in the concentration at the 35-hour mark coincide with the passing of the spike of water. The predicted dissolved concentration is below the BC-3 concentration data.

In Segment 6, BC-4, predicted sorbed activities are 2 to 3 times higher than those found in the field (Appendix A). The three field samplings appears to be very consistent while the predicted results are somewhat unsteady. Only the field data taken at 37 hours matches closely with the predicted values. The two dissolved radionuclide field data points agree well with the predicted concentrations.

In Cattaraugus Creek above Springville Dam both sorbed and dissolved ^{137}Cs have been diluted by a factor of three from the Buttermilk Creek levels. At CC-3, Segment 8, predicted and measured data are highly correlated in both sorbed activity and concentration. This is borne out by Figures 5.28 and 5.29. Interestingly, the plot of silt concentration in Figure 5.29 bears a resemblance to the Buttermilk hydrograph. This would seem to imply that the activity in Buttermilk Creek has a very strong imprint on the subsequent results in Cattaraugus Creek despite the relatively small discharge found in Buttermilk Creek.

At Springville Dam, the field values for sorbed activity are fairly consistent with the predicted concentrations at the 9- and 59-hour data points. At 33 hours predicted silt and clay sorbed activities are 800 pCi/kg higher

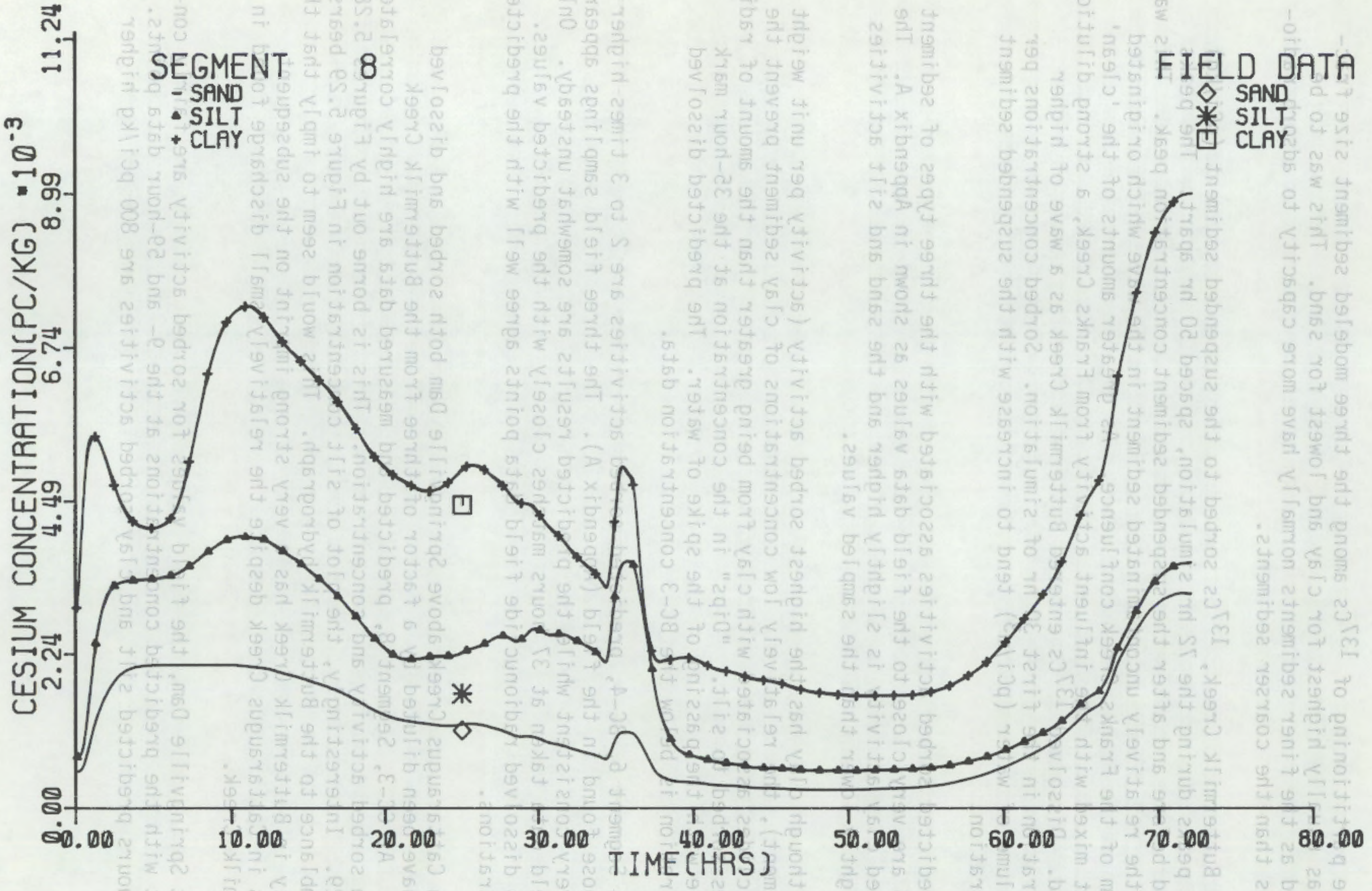

FIGURE 5.28. Phase 3 Particulate Radionuclide Concentrations: ^{137}Cs at CC-3

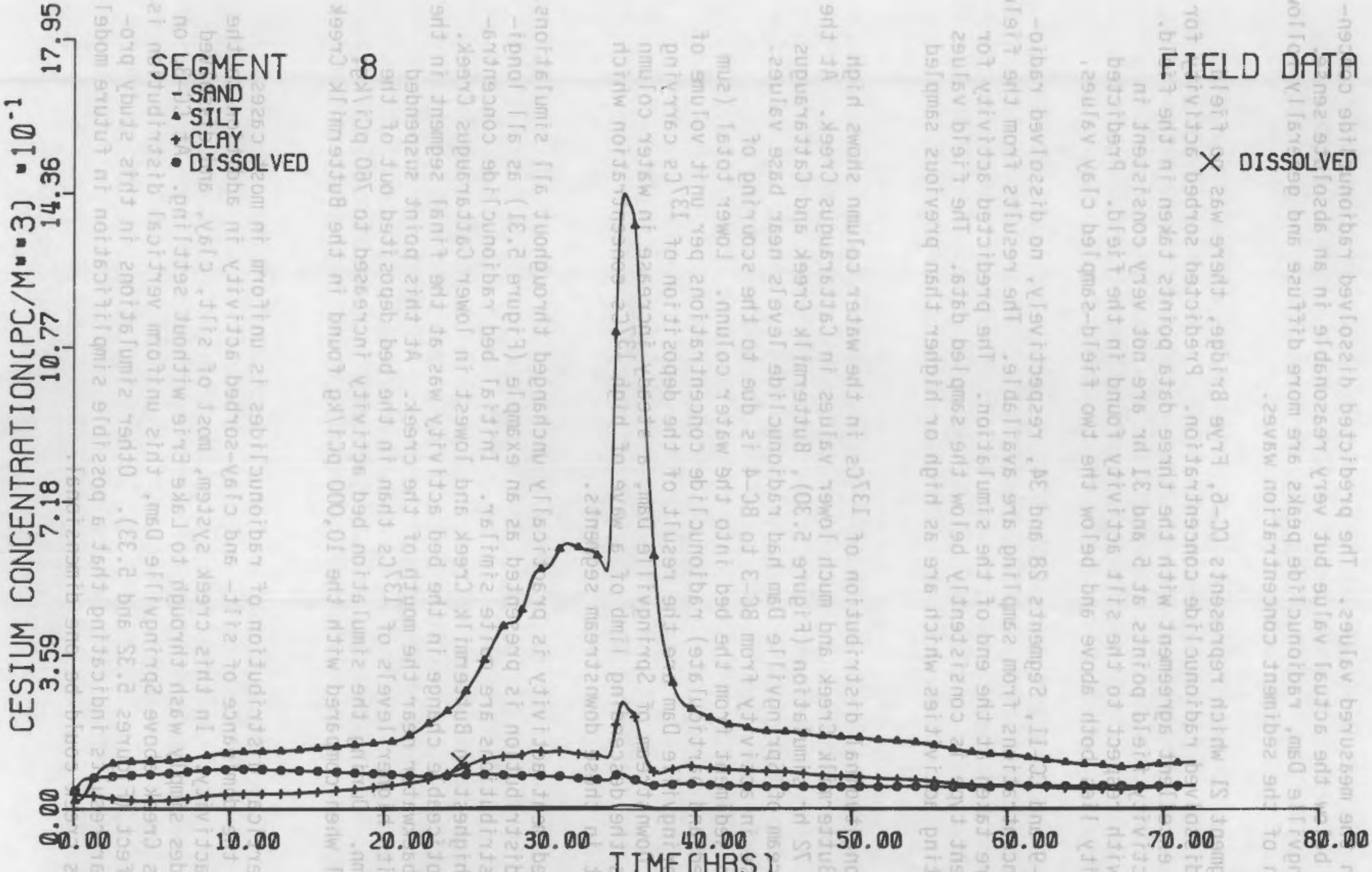

FIGURE 5.29. Phase 3 Particulate and Dissolved Radionuclide Concentrations: ^{137}Cs at CC-3

higher than the measured values. The predicted dissolved radionuclide concentration is below the actual value but very reasonable in an absolute sense. Below Springville Dam, radionuclide peaks are more diffuse and generally follow the pattern of the sediment concentration waves.

At Segment 21 which represents CC-6, Frye Bridge, there was no field value for dissolved radionuclide concentration. Predicted sorbed activity for silt is in excellent agreement with the three data points taken in the field. The clay activity field points at 5 and 31 hr are not very consistent in magnitude with respect to the silt activity found in the field. Predicted clay activity lies both above and below the two field-sampled clay values.

At CC-9 and CC-11, Segments 28 and 34, respectively, no dissolved radionuclide concentrations from sampling are available. The results from the field sampling are taken at the end of the simulation. The predicted activity for each sediment type is consistently below the sampled data. The field values are indicating activities which are as high or higher than previous sampled data.

The longitudinal distribution of ^{137}Cs in the water column shows high values in Buttermilk Creek and much lower values in Cattaraugus Creek. At the end of the 72 hr simulation (Figure 5.30), Buttermilk Creek and Cattaraugus Creek upstream of Springville Dam had radionuclide levels near base values. The increase in activity from BC-3 to BC-4 is due to the scouring of ^{137}Cs-laden sediment from the bed into the water colunn. Lower total (sum of dissolved and particulate) radionuclide concentrations per unit volume of water at Springville Dam are the result of the deposition of ^{137}Cs carrying sediment. Downstream of Springville Dam, a steady increase in water column activity is the descending limb of a wave of high ^{137}Cs concentration which was present in these downstream segments.

Bed sediment activity is practically unchanged throughout all simulations. The ^{137}Cs distribution is presented as an example (Figure 5.31) as all longitudinal distributions are quite similar. Initial bed radionuclide concentrations are highest in Buttermilk Creek and lowest in lower Cattaraugus Creek. The only noticeable change in the bed activity was at the final segment in the Lake Erie backwater near the mouth of the creek. At this point suspended sediment with higher levels of ^{137}Cs than in the bed deposited out of the water column. During the simulation bed activity increased to 760 pCi/kg; quite small when compared with the 10,000 pCi/kg found in the Buttermilk Creek bed.

The vertical distribution of radionuclides is uniform in most cases because of the dominance of silt- and clay-sorbed activity in addition to the dissolved activity. In this creek system, most of silt, clay, and dissolved radionuclides simply wash through to Lake Erie without settling. At CC-3, on Cattaraugus Creek above Springville Dam, this uniform vertical distribution is almost perfect (Figures 5.32 and 5.33). Other simulations in this study produce similar results indicating that a possible simplification in future modeling of this creek could be one dimensional.

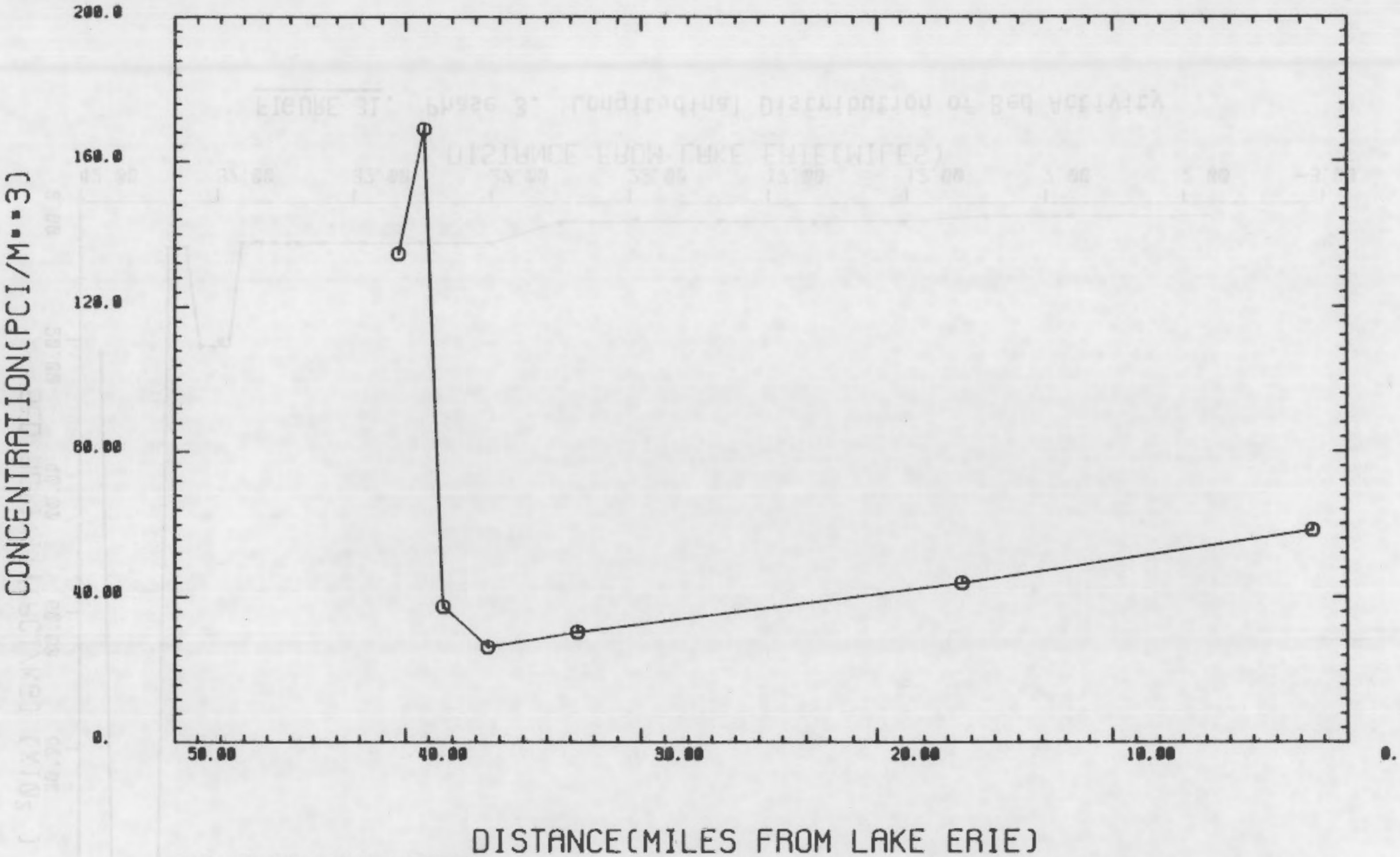

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FIGURE 5.30. Phase 3. Longitudinal Distribution of ^{137}Cs Total Concentration at Hour 72

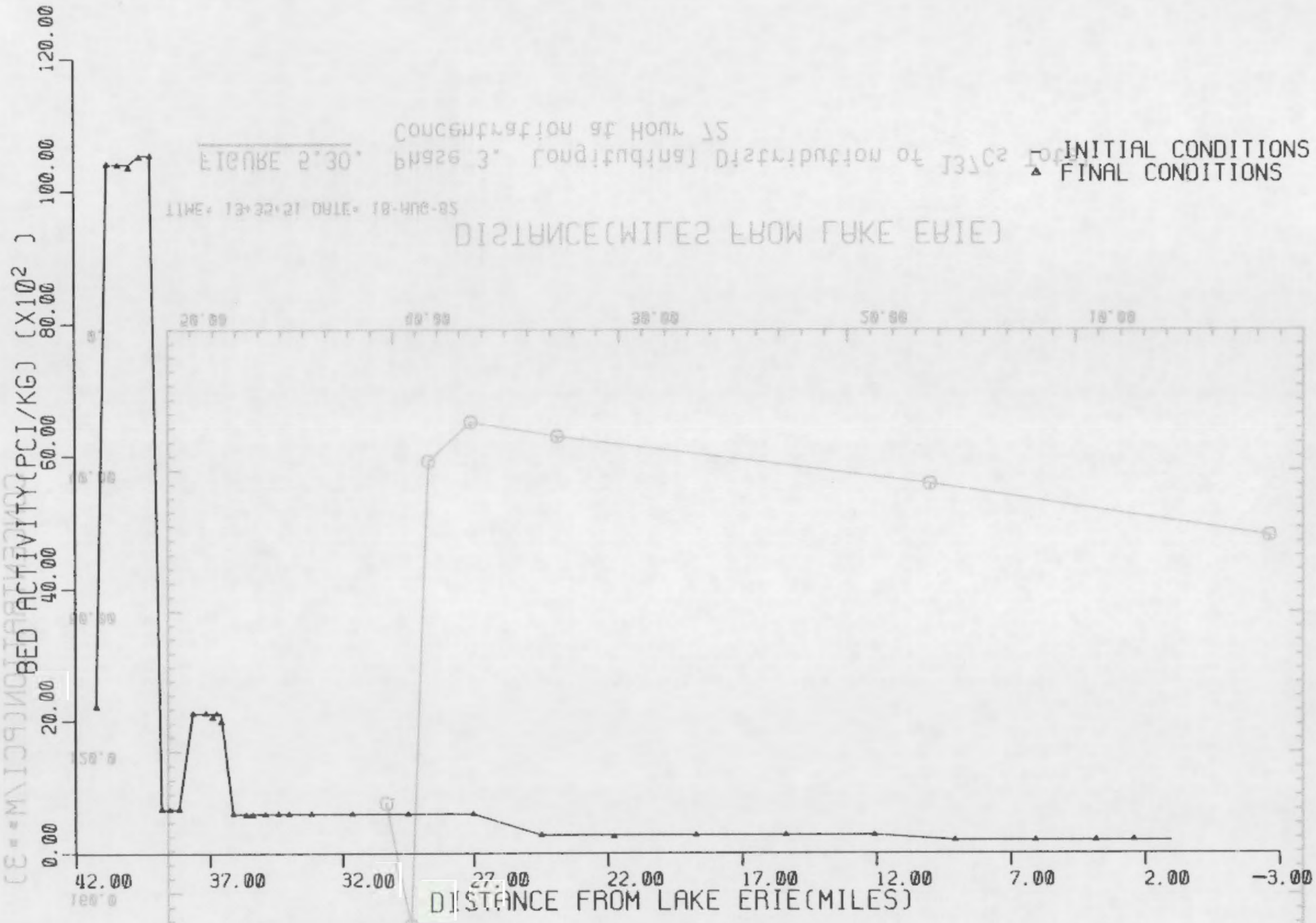


FIGURE 31. Phase 3. Longitudinal Distribution of Bed Activity

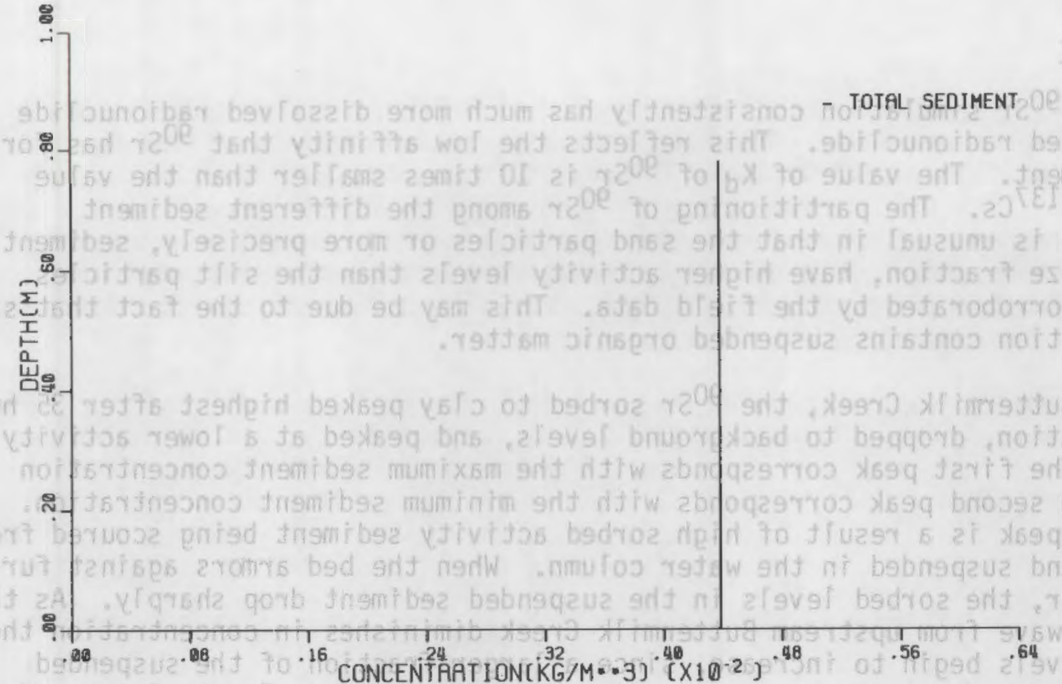


FIGURE 5.32. Phase 3. Vertical Distribution of Total Sediment at CC-3.

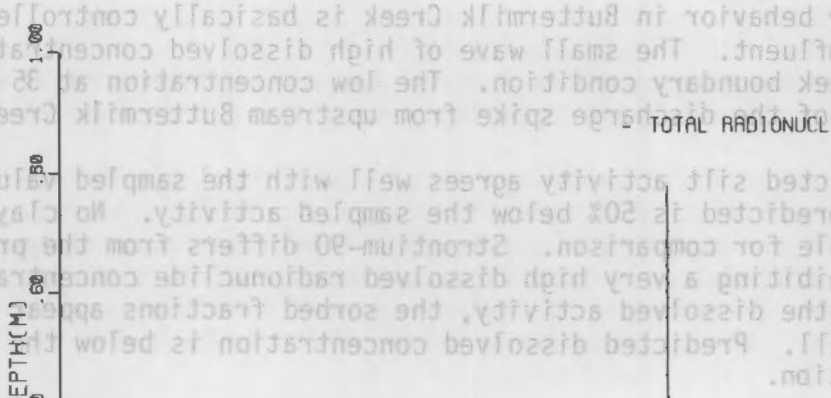


FIGURE 5.33. Phase 3 Vertical Distribution of ^{137}Cs at CC-3.

^{90}Sr

The ^{90}Sr simulation consistently has much more dissolved radionuclide than sorbed radionuclide. This reflects the low affinity that ^{90}Sr has for the sediment. The value of K_d of ^{90}Sr is 10 times smaller than the value of K_d of ^{137}Cs. The partitioning of ^{90}Sr among the different sediment fractions is unusual in that the sand particles or more precisely, sediment in a sand size fraction, have higher activity levels than the silt particles. This is corroborated by the field data. This may be due to the fact that sand size fraction contains suspended organic matter.

In Buttermilk Creek, the ^{90}Sr sorbed to clay peaked highest after 35 hr of simulation, dropped to background levels, and peaked at a lower activity at 60 hr. The first peak corresponds with the maximum sediment concentration while the second peak corresponds with the minimum sediment concentration. The high peak is a result of high sorbed activity sediment being scoured from the bed and suspended in the water column. When the bed armors against further clay scour, the sorbed levels in the suspended sediment drop sharply. As the sediment wave from upstream Buttermilk Creek diminishes in concentration the sorbed levels begin to increase, since a larger fraction of the suspended sediments are due to the more contaminated sediments from Franks Creek. Sand- and silt-sorbed ^{137}Cs display lowest concentration levels during the peak sediment concentrations which indicate that the corresponding upstream clear sediments dilute the sorbed activity.

Dissolved ^{90}Sr behavior in Buttermilk Creek is basically controlled by the Franks Creek influent. The small wave of high dissolved concentrations is from the Franks Creek boundary condition. The low concentration at 35 hr is due to the passing of the discharge spike from upstream Buttermilk Creek.

At BC-3, predicted silt activity agrees well with the sampled value while the sand activity predicted is 50% below the sampled activity. No clay activity is available for comparison. Strontium-90 differs from the previous ^{137}Cs result by exhibiting a very high dissolved radionuclide concentration. In comparison with the dissolved activity, the sorbed fractions appear to be insignificantly small. Predicted dissolved concentration is below the measured concentration.

Figure 5.34 is the sorbed activity plot at BC-4. The predicted sand value at 37 hr is one-third of the sampled activity for sand. Field and predicted silt values are fairly consistent with the predicted values being 250 pCi/kg higher. The clay activity from the 4-hr sample is approximated closely by the predicted graph. However, at 37 hr the sampled clay value is almost identical to the low silt value while the predicted clay activity is many times higher. Agreement with field-sampled dissolved concentrations is good for the 37- and 65-hr samples (Figure 5.35). The predicted dissolved concentration at 4 hr is considerably below the measured value.

As Buttermilk Creek enters Cattaraugus Creek sorbed concentrations decrease by a factor of three while dissolved concentrations decrease by a

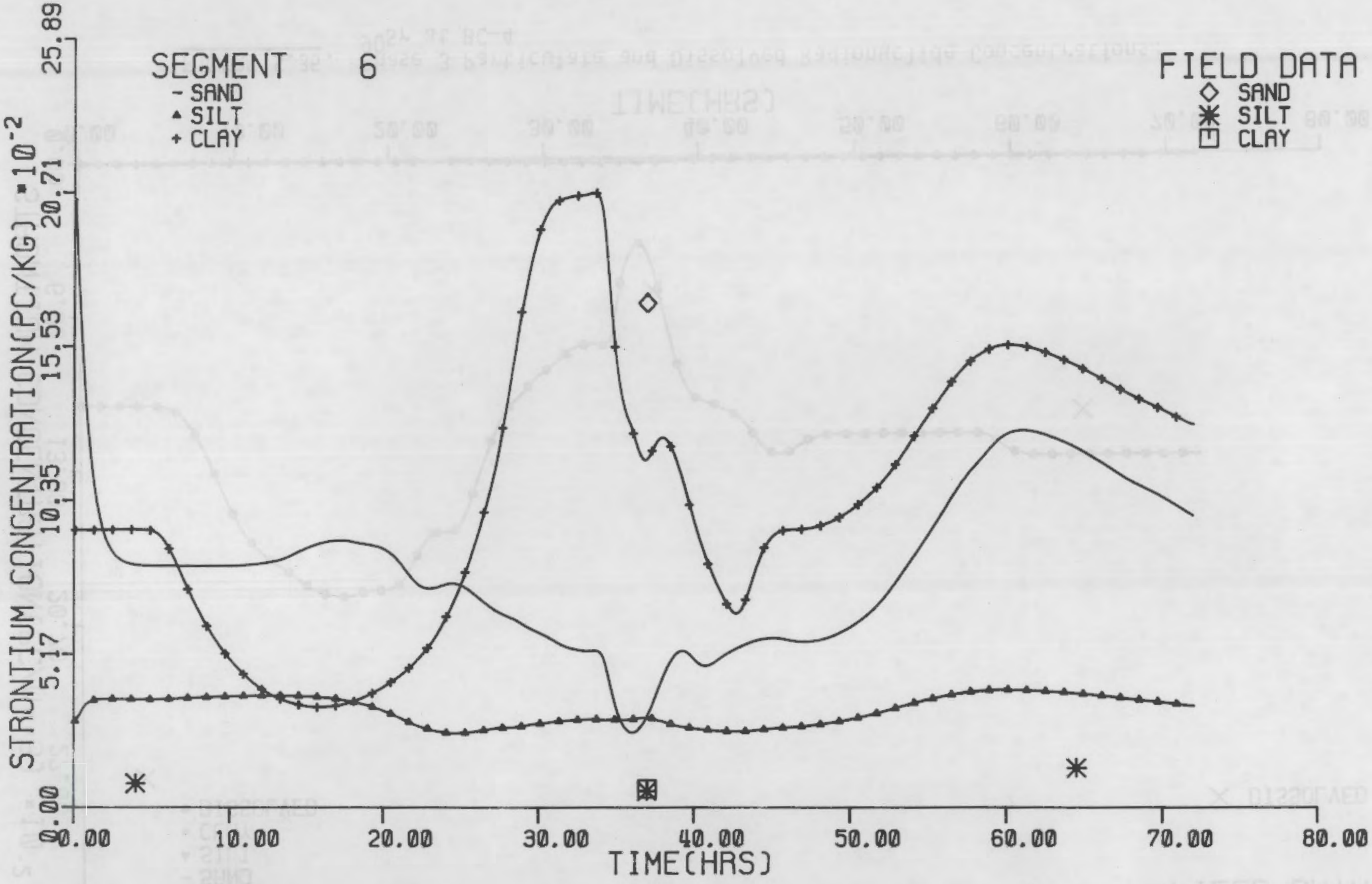


FIGURE 5.34. Phase 3 Particulate Radionuclide Concentrations: ^{90}Sr at BC-4

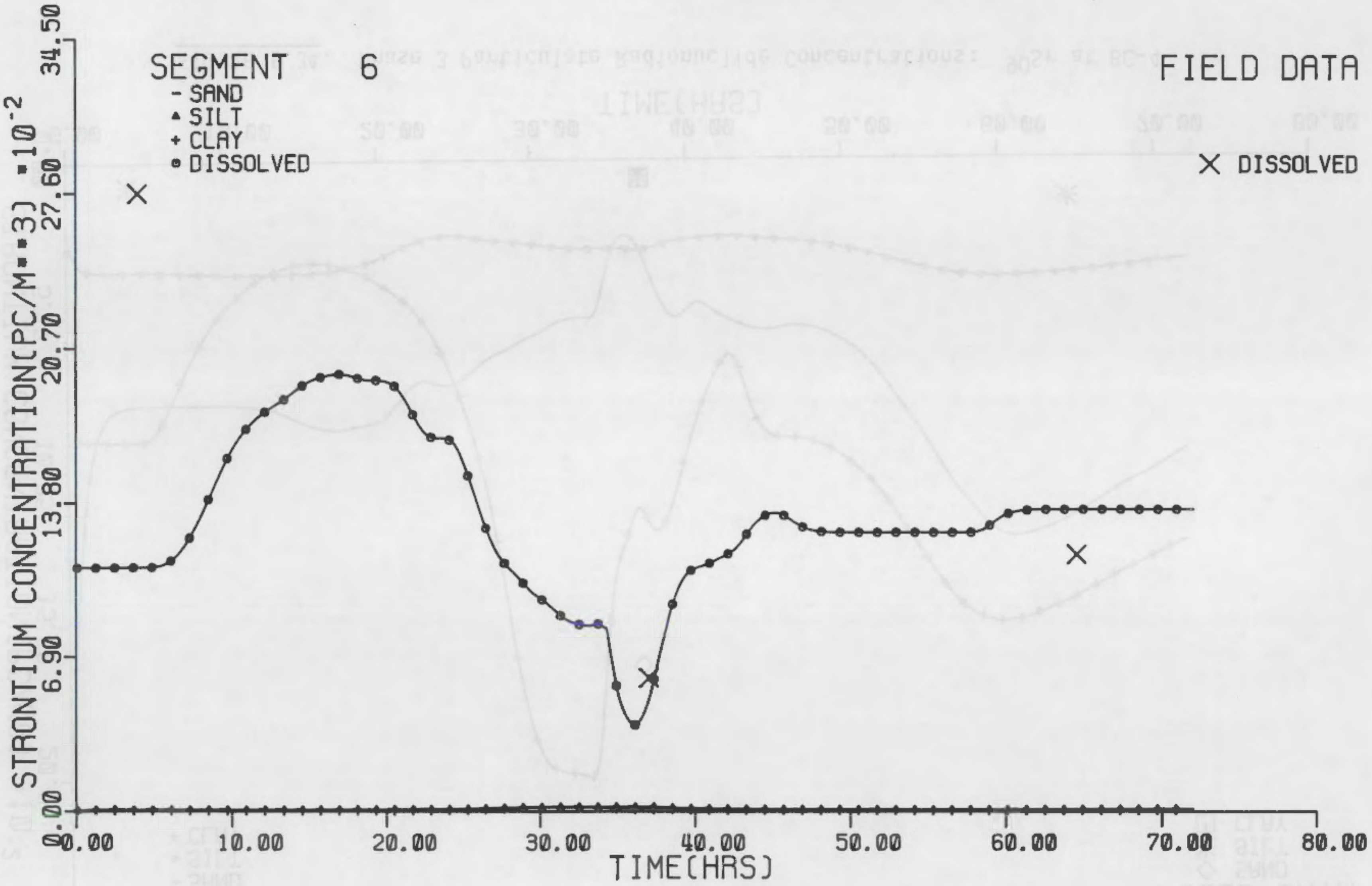


FIGURE 5.35. Phase 3 Particulate and Dissolved Radionuclide Concentrations: ^{90}Sr at BC-4

factor of 4. The sorbed ^{90}Sr behaves as it did in Buttermilk Creek. The dissolved ^{90}Sr in Cattaraugus Creek has a peak at 35 hr where there was a trough in Buttermilk Creek. This is because of the large volume of high activity water accompanying the discharge spike from Buttermilk Creek.

At CC-3, fairly good correlation is achieved with the sorbed activity. Predicted sand is slightly lower and predicted silt slightly higher. The computed dissolved concentration at CC-3 is fairly smooth with a sharp increase and decrease at the time the hydrograph peak passes through the segment. The field concentration of dissolved strontium is about 25% the predicted concentration at 25 hr.

At CC-5, extremely high sand activities found in the field are not duplicated. However, clay and silt activities are matched reasonably. The dissolved concentrations predicted by SERATRA are about the same as in CC-3. However, in this case the field-sampled concentrations are both higher than the predicted.

Downstream of Springville Dam, sorbed and dissolved ^{90}Sr exhibit no sharp peaks as dispersion and dilution create rather steady effects. At Fryge Bridge, CC-6, sand and clay activities are underestimated by the model. Predicted dissolved concentrations at 6, 32 and 58 hr are 10 to 60% lower than field data.

At CC-9, Segment 28, no dissolved field value is available for comparison. The only sorbed activity collected in the field is for silt. The predicted activity is many times smaller than that field value.

At CC-11, the trend of large field values for sorbed activity downstream of Springville Dam continues. Only the silt activity predicted by SERATRA is fairly close to a field data point; clay and sand field activities simply dwarf those predictions. The predicted dissolved concentration is 60% below the field data. This is fairly consistent with Segments 14 onward.

Figure 5.36 is the longitudinal distribution of ^{90}Sr. This illustrates the strong dilution of radionuclides from Buttermilk Creek to Cattaraugus Creek.

^{239,240}Pu

^{239,240}Pu has a K_d value 350 times that of ^{90}Sr. Given the sediment concentrations predicted in the Phase 3 study reach and the K_d value ^{239,240}Pu in sorbed form per unit volume of water should be on the same order of magnitude as the dissolved ^{239,240}Pu if equilibrium exists. As it happens this is the predicted result.

Partitioning of ^{239,240}Pu is quite dynamic. In Buttermilk Creek silt has the highest sorbed levels; strictly a result of the Franks Creek boundary condition. In Cattaraugus Creek above Springville Dam clay sediment has the highest sorbed levels while below Springville Dam silt retains the most activity. The background condition is for clay to be the most efficient at

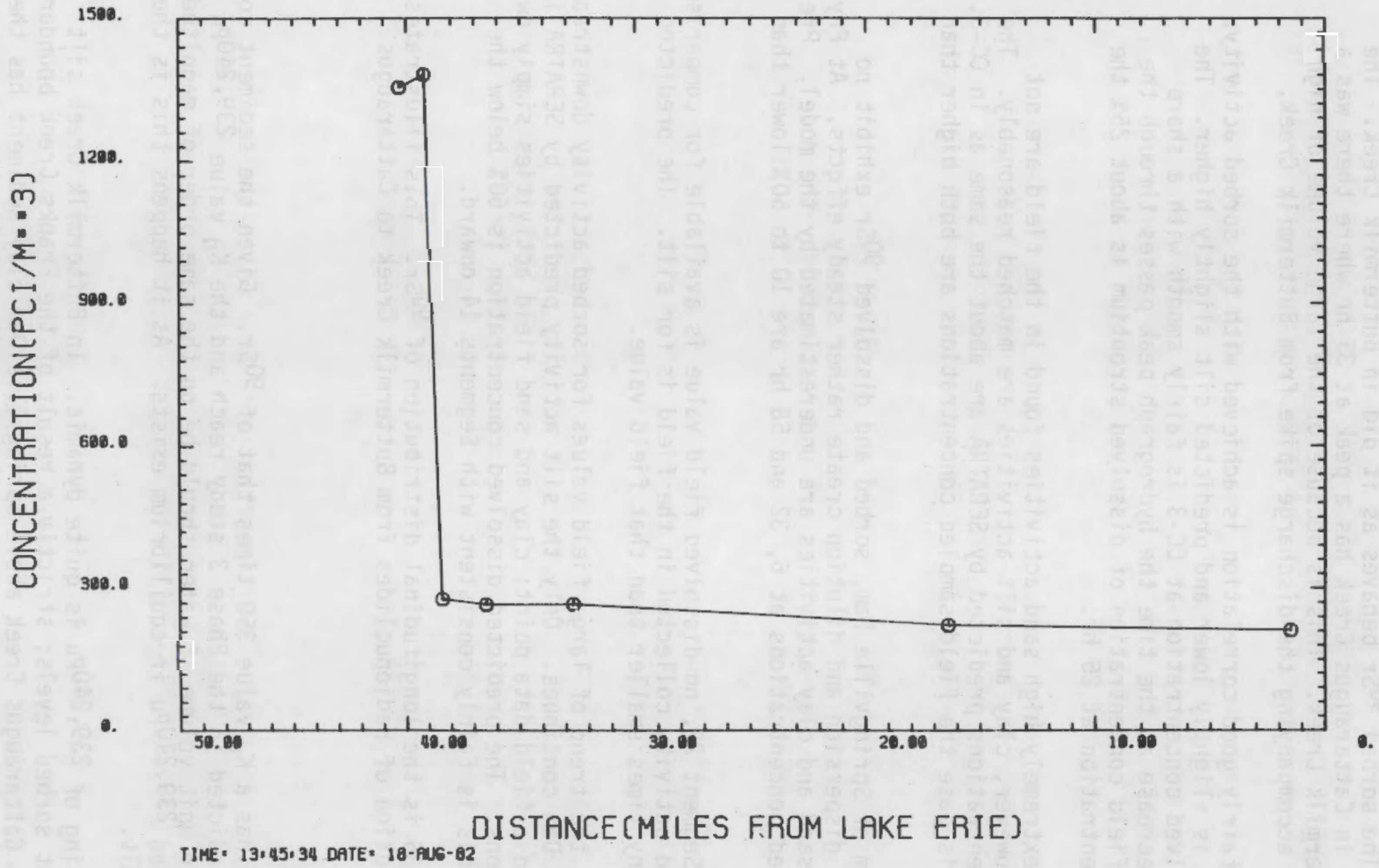


FIGURE 5.36. Phase 3, Longitudinal Distribution of ^{90}Sr Total Concentration of Hour 72

radionuclide uptake which explains the upstream Cattaraugus Creek results. In downstream Cattaraugus Creek, large amounts of high activity silt were suspended from the bed which increased the silt sorbed activity to be above the clay level in the water column.

In Buttermilk Creek, sorbed $^{239,240}Pu$ in sand and clay react inversely to the sediment wave from upstream Buttermilk Creek. Silt-sorbed radionuclides are fairly constant. Dissolved $^{239,240}Pu$ is virtually constant except for the passing of the discharge spike.

Unlike other radionuclides, predicted silt-sorbed plutonium concentrations are higher than those with clay. The computed silt activity is fairly steady while the computed sand and clay activity display a wider range of values. The relatively sharp peak of computed activity with sand and a valley in the clay activity at 35 hr coincides with the hydrograph spike. A single silt activity data point is available from the field study. The predicted silt activity at that point (28 hr) is about 0.7 pCi/kg greater than the field value. The trend of the $^{239,240}Pu$ radionuclide concentration is very similar to the sediment graphs in BC-3 (Segment 3); the dissolved concentration is very steady except for hour 35 in which the hydrograph spike passes through this segment. No field dissolved data points are availble for comparison.

At BC-4, Figure 5.37 is the sorbed activity plot. Field data at 37 hr has clay activity higher than silt activity. This is the opposite of the computed results. The predicted clay activity fairly approximates the field data point while the predicted silt activity is two times the sampled data. The radionuclide concentrations in Figure 5.38 are again very similar to the sediment discharges. The predicted dissolved concentration is steady and well above the field-sampled concentration at 65 hr.

In Cattaraugus Creek above Springville Dam clay sorbed $^{239,240}Pu$ increase gradually to a peak at 60 hr while sand- and silt-sorbed radionuclides remain steady. At CC-3, the predicted sorbed activity for clay is many times higher than sand and silt activities. The field point for silt activity lies very closely to the predicted silt activity. Radionuclide concentrations are reversed from Buttermilk Creek; radionuclides adsorbed to clay now provide the largest concentrations. No data are available to confirm this with the field.

At CC-5, measured sorbed activities include two silt activity points at 9 and 33 hr. Computed results are similar with one field data point above and one below predicted results. Radionuclide concentrations appear to be very similar to those shown previously at Segment CC-3. No dissolved data from the field is available for comparison. Downstream of Springville Dam, silt-sorbed $^{239,240}Pu$ scoured from the bed creates high activity on the water column. Other size fractions exhibit gently changing levels of radionuclide at much lower total concentrations.

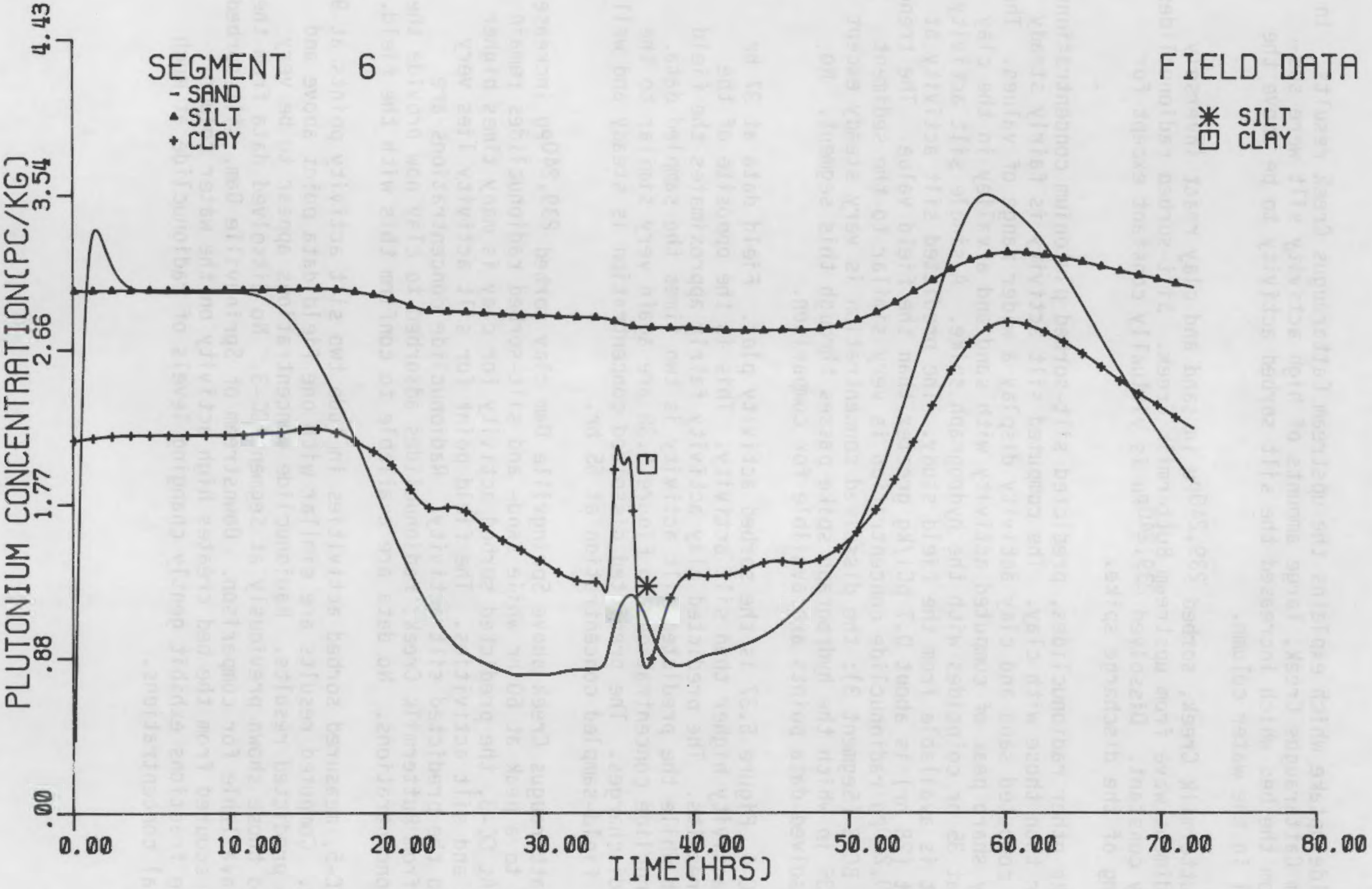


FIGURE 5.37. Phase 3 Particulate Radionuclide Concentrations: ^{239,240}Pu at BC-4

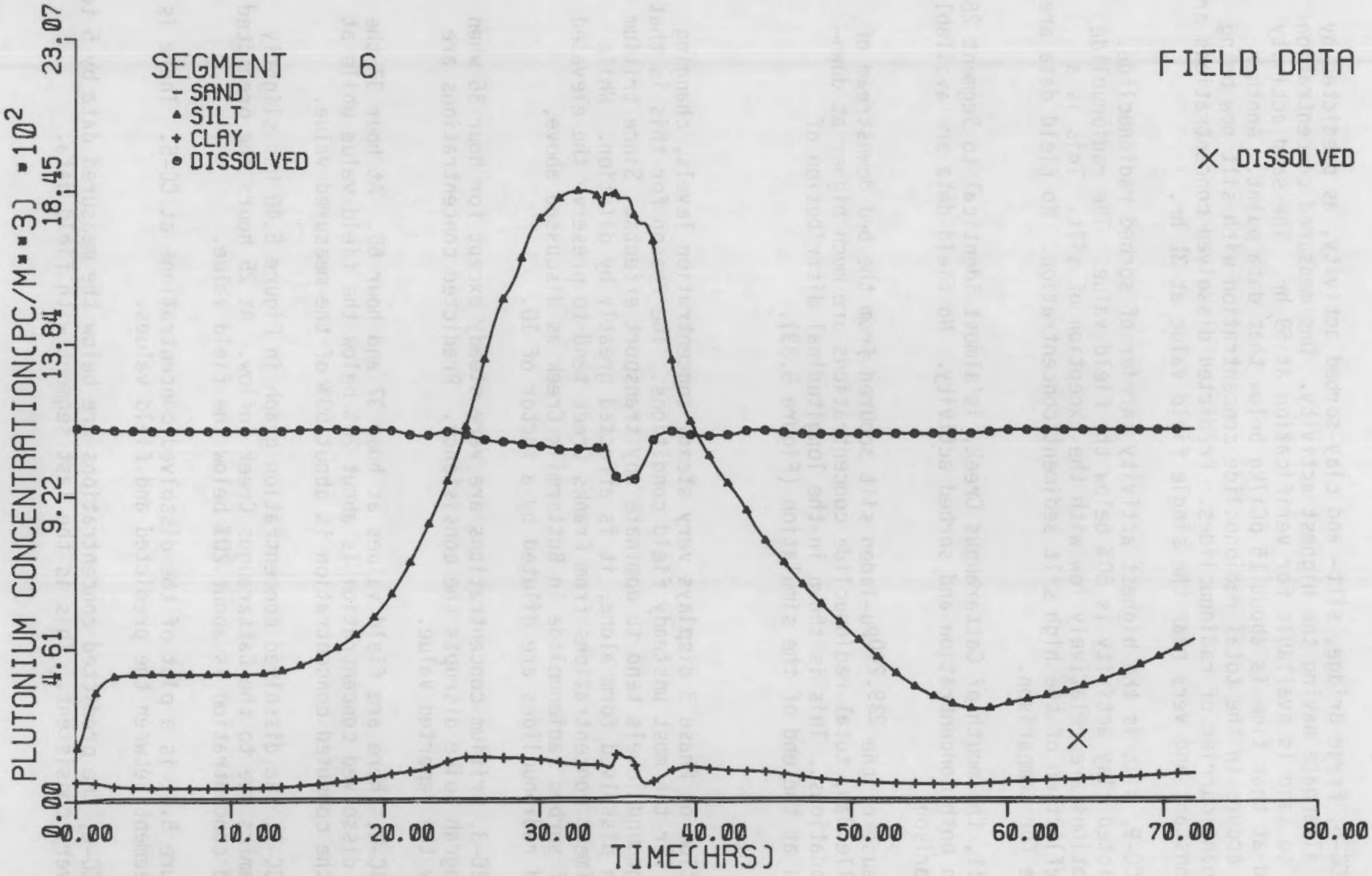


FIGURE 5.38. Phase 3 Particulate and Dissolved Radionuclide Concentrations: ^{239,240}Pu at BC-4

At CC-6, Fryge Bridge, silt- and clay-sorbed activity, as predicted by SERATRA, alternate having the highest activity. One measured concentration attached to sand is available for verification at 59 hr. The sand activity predicted at that time is about 15 pCi/kg below that data point. Another reversal occurs in the total radionuclide concentration with silt now being the dominant carrier of radionuclides. Predicted dissolved concentrations are almost constant and very near the single field value at 31 hr.

At CC-9, silt is the highest activity carrier of sorbed radionuclide. The predicted clay activity is 50% below the field value. The radionuclide concentrations are relatively low with the exception of silt. This is a direct reflection of the high silt sediment concentration. No field data are available for comparison.

CC-11, the mouth of Cattaraugus Creek, is almost identical to Segment 28 (CC-9) in both concentration and sorbed activity. No field data are available for comparison.

Because of the ^{239,240}Pu-laden silt scoured from the bed downstream of Springville Dam, total radionuclide concentrations are much higher at downstream locations.. This is shown in the longitudinal distribution of ^{239,249}Pu at the end of the simulation (Figure 5.39).

^{3}H

Tritium on Phase 3 displays very steady concentration levels, changing minutely for the most unsteady field conditions. The reason for this is that the background levels tend to dominate any transport effects. Since tritium exists in dissolved form alone, it is affected greatly by dilution. While high sediment concentrations from Franks Creek tend to preserve the elevated values of sorbed radionuclide in Buttermilk Creek as discussed above, dissolved radionuclides are diluted by a factor of 10.

At BC-3, tritium concentrations are very steady except for hour 35 when the hydrograh spike disrupts the consistency. Predicted concentrations are 40% below the reported value.

At BC-4, there are field values at hour 37 and hour 65. At hour 37 the computed dissolved concentration is about 20% below the field value while at hour-65 the computed concentration is about 50% of the measured value.

At CC-3, the dissolved concentration graph in Figure 5.40 has slightly more dynamics due to the Cattaraugus Creek inflow. At 25 hours the predicted dissolved concentration is about 20% below the field value.

Figure 5.41 is a plot of the dissolved concentrations at CC-5. There is good agreement between the predicted and field values.

At CC-6, the predicted concentrations are below the measured data by 5 to 25% and very consistent. This is the last segment with field data.

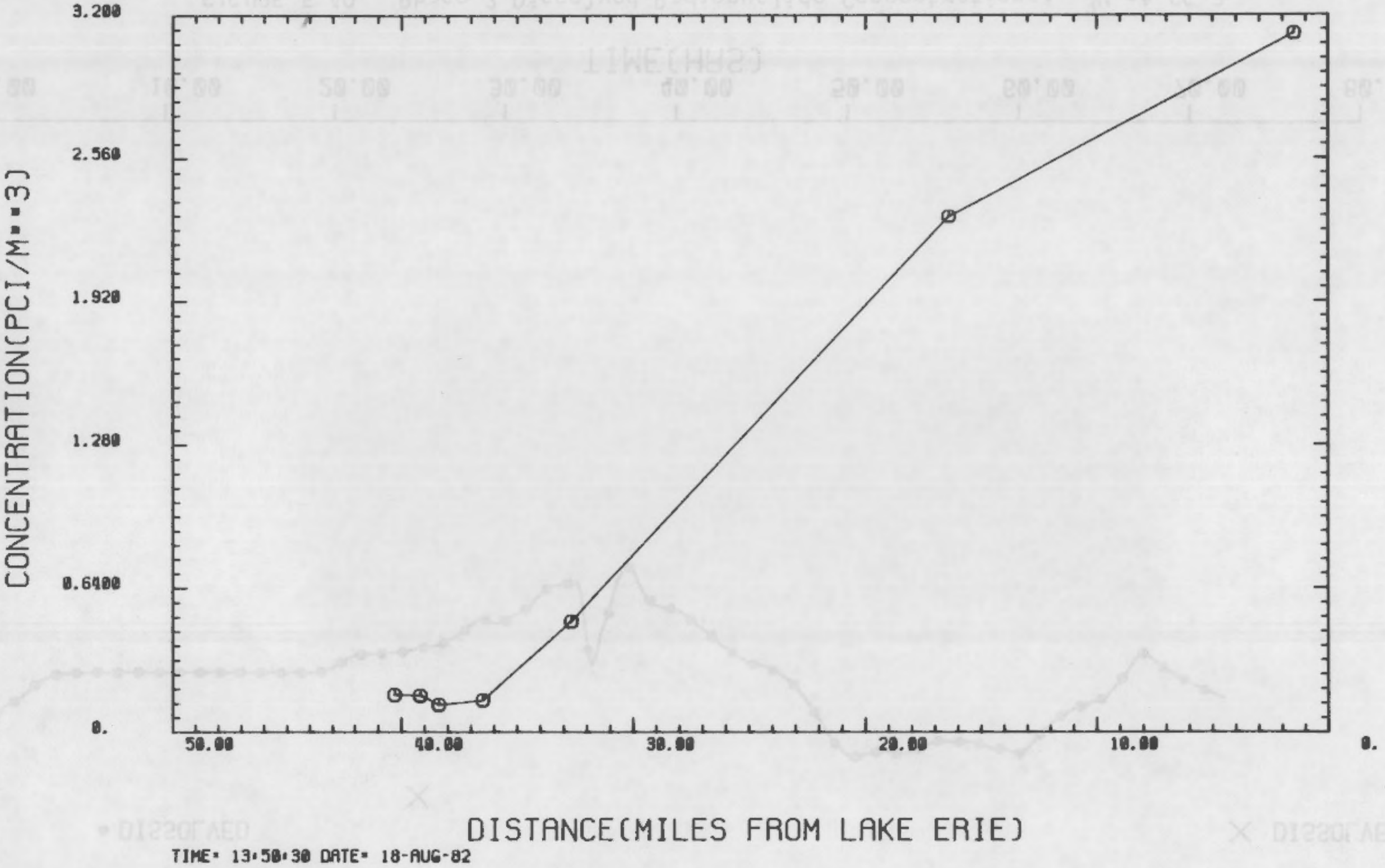


FIGURE 5.39. Phase 3 Longitudinal Distribution of $^{239-240}$Pu Total Concentration at Hour 72

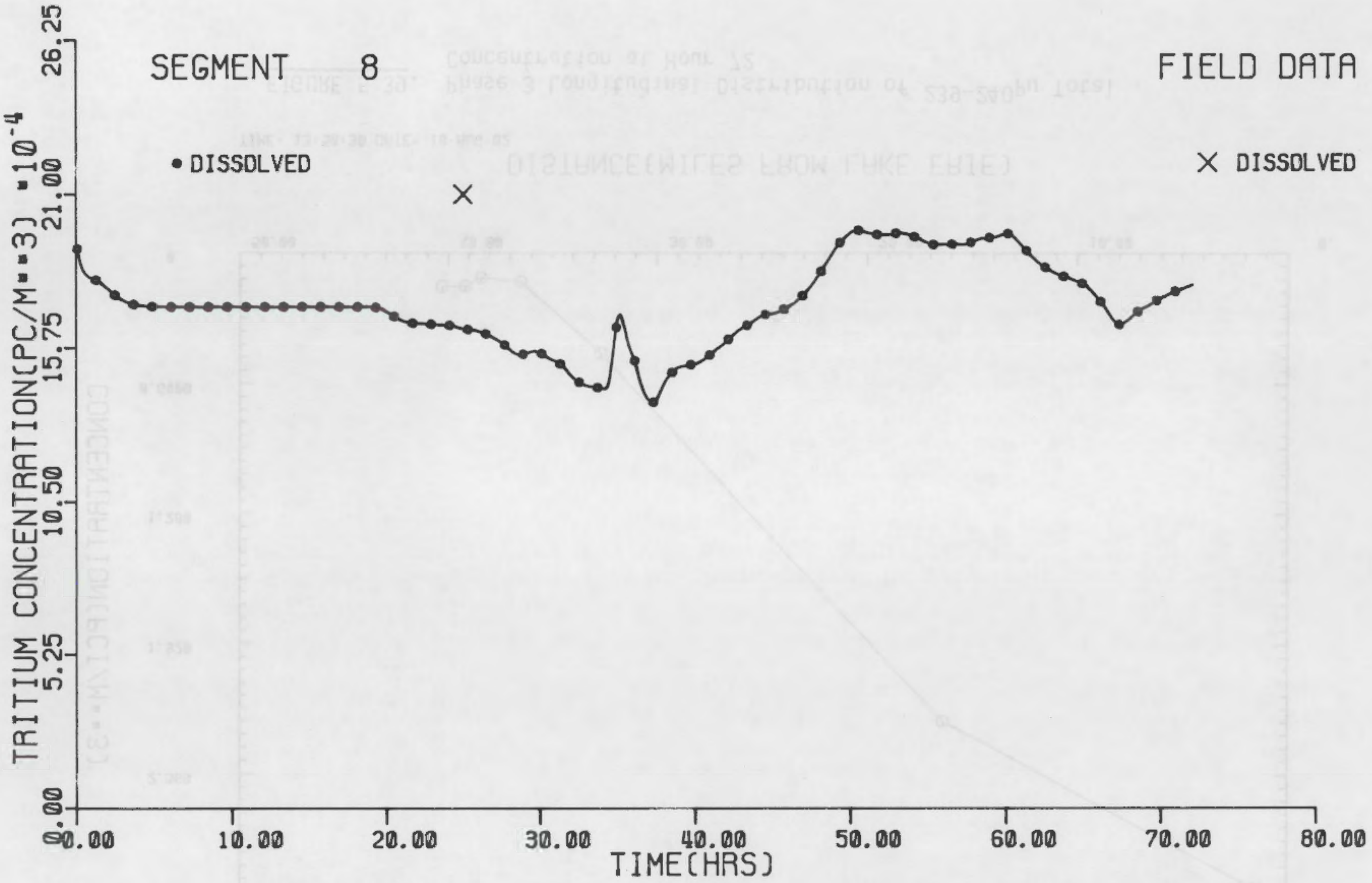


FIGURE 5.40. Phase 3 Dissolved Radionuclide Concentrations: ^{3}H at CC-3

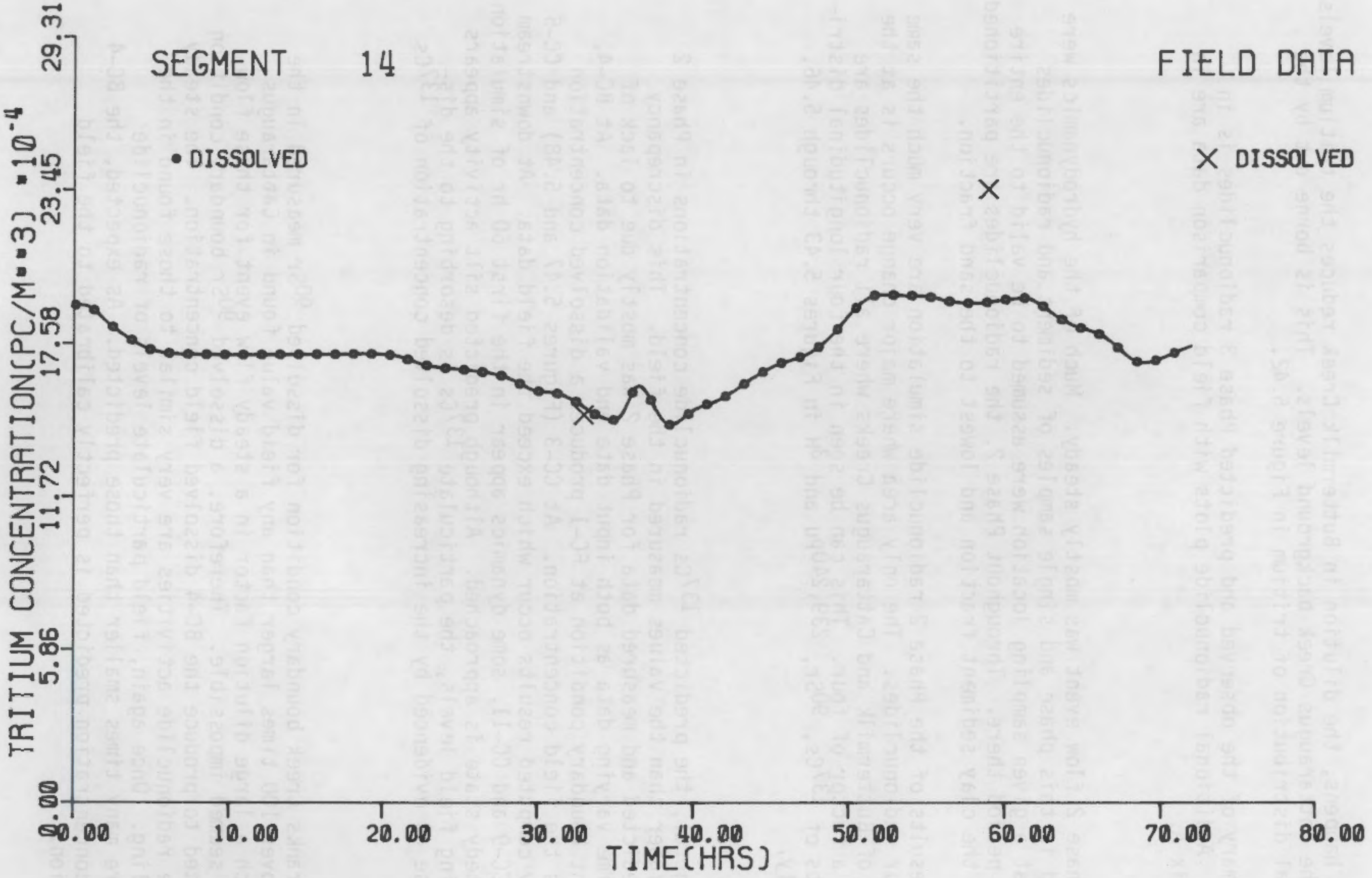


FIGURE 5.41. Phase 3 Dissolved Radionuclide Concentration: ^{3}H at CC-5

As it happens, the dilution in Buttermilk Creek reduces the tritium levels to below the Cattaraugus Creek background levels. This is borne out by the longitudinal distribution of tritium in Figure 5.42.

A summary of the observed and predicted Phase 3 radionuclides is in Table 5.8. Additional radionuclide plots with field comparison data are in the Appendix A.

Phase 2

The Phase 2 flow event was mostly steady. Much of the hydrodynamics were synthesized in this phase and single samples of sediment and radionuclides collected at a given sampling location were assumed to be valid to the entire simulation period there. Throughout Phase 2, the radionuclides are partitioned highest to the clay sediment fraction and lowest to the sand fraction.

The results of the Phase 2 radionuclide simulation are very much the same for all four radionuclides. The only area where major change occurs is at the confluence of Buttermilk and Cattaraugus Creeks where all radionuclides are diluted by a factor of four. This can be seen in the four longitudinal distribution plots of ^{137}Cs, ^{90}Sr, ^{239,240}Pu and ^{3}H in Figures 5.43 through 5.46, respectively.

^{137}Cs

In general, the predicted ^{137}Cs radionuclide concentrations in Phase 2 are much higher than the values measured in the field. This discrepancy between predicted and measured data for Phase 2 was mostly due to lack of accurate time varying data as both input data and validation data. At BC-4, the constant boundary condition at FC-1 produces a dissolved concentration three times the field concentration. At CC-3 (Figures 5.47 and 5.48) and CC-5 very steady computed results occur which exceed the field data. At downstream locations CC-9 and CC-11, some dynamics appear in the first 60 hr of simulation before a stedy state is approached. Although predicted silt activity appears to be nearing field levels, the particulate ^{137}Cs is desorbing to the dissolved phase as evidenced by the increasing dissolved concentration of ^{137}Cs at CC-11.

^{90}Sr

The Franks Creek boundary condition for dissolved ^{90}Sr measured in the field was over 100 times larger than any field value found in Cattaraugus Creek. Such a large dilution factor in a steady flow event for these flow conditions seemed impossible. Therefore, a dissolved ^{90}Sr boundary condition was estimated to produce the BC-4 dissolved field concentration. The steady particulate radionuclide activities are very similar to those found in the ^{137}Cs modeling. Once again, field particulate levels of radionuclide activity are many times smaller than those predicted. As expected, the BC-4 dissolved concentration predicted is perfectly calibrated to the field concentration.

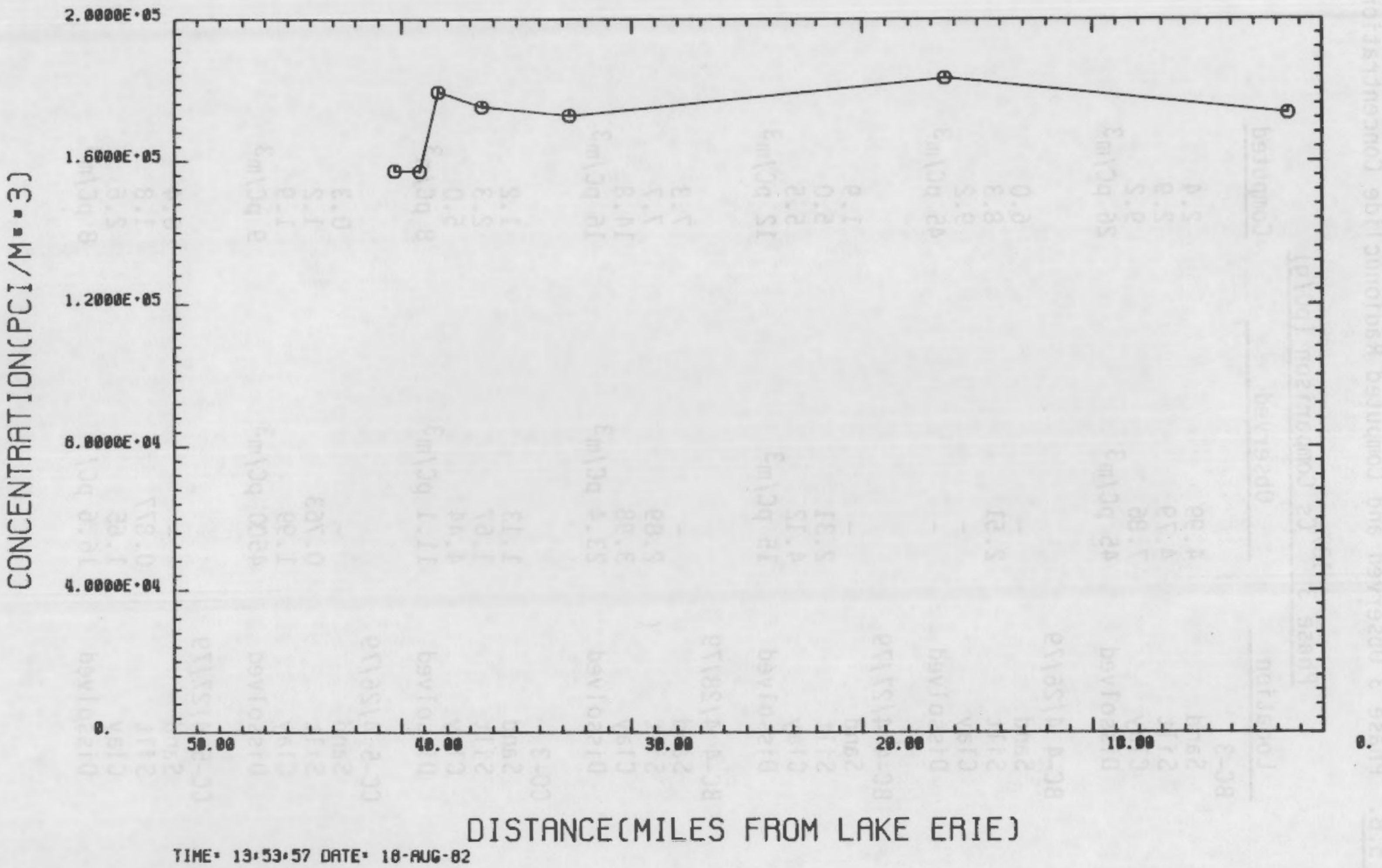


TABLE 5.42. Phase 3 Longitudinal Distribution of ^{3}H Concentration at Hour 72

TABLE 5.8. Phase 3 Observed and Computed Radionuclide Concentrations

Phase 3 ^{137}Cs Comparison (pC/g)

Location	Observed	Computed
BC-3		
Sand	4.99	2.4
Silt	4.79	2.9
Clay	7.86	9.2
Dissolved	45 pC/m^3	26 pC/m^3
BC-4 4/26/79		
Sand	–	6.0
Silt	2.51	8.3
Clay	–	9.2
Dissolved	–	45 pC/m^3
BC-4 4/27/79		
Sand	–	1.9
Silt	2.31	5.0
Clay	4.12	5.5
Dissolved	15 pC/m^3	12 pC/m^3
BC-4 4/28/79		
Sand	–	7.3
Silt	2.89	7.7
Clay	3.98	14.8
Dissolved	23.4 pC/m^3	16 pC/m^3
CC-3		
Sand	1.13	1.2
Silt	1.67	2.3
Clay	4.44	5.0
Dissolved	11.1 pC/m^3	8 pC/m^3
CC-5 4/26/79		
Sand	–	0.3
Silt	0.763	1.2
Clay	1.99	1.9
Dissolved	4500 pC/m^3	9 pC/m^3
CC-5 4/27/79		
Sand	–	0.4
Silt	0.877	1.8
Clay	1.65	2.6
Dissolved	16.6 pC/l	8 pC/m^3

TABLE 5.8. (contd)

Phase 3 ^{137}Cs Comparison (pC/g)

Location	Observed	Computed
CC-5 4/28/79		
Sand	–	0.2
Silt	0.966	0.5
Clay	–	1.6
Dissolved	–	5 pC/m^3
CC-6 4/26/79		
Sand	–	0.2
Silt	0.736	0.8
Clay	2.87	1.7
Dissolved	–	7 pC/m^3
CC-6 4/27/79		
Sand	–	0.4
Silt	1.42	1.0
Clay	1.35	2.6
Dissolved	–	9 pC/m^3
CC-6 4/28/79		
Sand	–	0.2
Silt	0.580	0.5
Clay	–	1.5
Dissolved	–	6 pC/m^3
CC-9		
Sand	2.33	0.2
Silt	2.26	0.5
Clay	2.78	1.7
Dissolved	–	7 pC/m^3
CC-11		
Sand	1.17	0.2
Silt	2.89	0.4
Clay	6.16	1.9
Dissolved	–	11 pC/m^3

Phase 3 ^{90}Sr Comparison (pC/g)

Location	Observed	Computed
BC-3		
Sand	1.44	0.7
Silt	0.136	0.2
Clay	–	1.5
Dissolved	1930 pC/m^3	1060 pC/m^3

TABLE 5.B. (contd)

Phase 3 ^{90}Sr Comparison (pC/g)

Location	Observed	Computed
BC–4 4/26/79		
Sand	–	0.8
Silt	0.081	0.4
Clay	–	0.9
Dissolved	2760 pC/m^3	1090 pC/m^3
BC–4 4/27/79		
Sand	1.70	0.3
Silt	0.055	0.3
Clay	0.062	1.2
Dissolved	596 pC/m^3	500 pC/m^3
BC–4 4/28/79		
Sand	–	1.2
Silt	0.133	0.4
Clay	–	1.5
Dissolved	1151 pC/m^3	1350 pC/m^3
CC–3		
Sand	0.392	0.3
Silt	0.070	0.1
Clay	–	0.5
Dissolved	67.6 pC/m^3	310 pC/m^3
CC–5 4/26/79		
Sand	1.41	0.1
Silt	–	0.1
Clay	0.264	0.4
Dissolved	429 pC/m^3	230 pC/m^3
CC–5 4/27/79		
Sand	–	0.2
Silt	0.060	0.1
Clay	–	0.7
Dissolved	382 pC/m^3	260 pC/m^3
CC–5 4/28/79		
Sand	3.82	0.1
Silt	–	0.1
Clay	–	0.4
Dissolved	–	250 pC/m^3

TABLE 5.8. (contd)

Phase 3 ^{90}Sr Comparison (pC/g)

Location	Observed	Computed
CC-6 4/26/79		
Sand	1.54	0.2
Silt	-	0.1
Clay	-	0.5
Dissolved	496 pC/m^3	220 pC/m^3
CC-6 4/27/79		
Sand	3.49	0.1
Silt	-	0.1
Clay	1.53	0.4
Dissolved	410 pC/m^3	270 pC/m^3
CC-6 4/28/79		
Sand	-	0.1
Silt	-	0.1
Clay	-	0.4
Dissolved	277 pC/m^3	240 pC/m^3
CC-9		
Sand	-	0.1
Silt	1.45	0.0
Clay	-	0.3
Dissolved	227 pC/m^3	220 pC/m^3
CC-11		
Sand	0.568	0.1
Silt	0.098	0.0
Clay	1.51	0.3
Dissolved	492 pC/m^3	200 pC/m^3

Phase 3 ^{239,240}Pu Comparison (pC/g)

Location	Observed	Computed
BC-3		
Sand	-	0.0004
Silt	0.002	0.0028
Clay	-	0.0015
Dissolved	0.551 pC/m^3	0.109 pC/m^3
BC-4/1		
Sand	-	0.0030
Silt	-	0.0030
Clay	-	0.0022
Dissolved	-	0.112 pC/m^3

TABLE 5.8. (contd)

Phase 3 ^{239,240}Pu Comparison (pC/g)

Location	Observed	Computed
BC-4/2		
Sand	–	0.0011
Silt	0.0013	0.0028
Clay	0.002	0.0009
Dissolved	–	0.104 pC/m^3
BC-4/3		
Sand	–	0.0030
Silt	–	0.0032
Clay	–	0.0027
Dissolved	0.019 pC/m^3	0.113 pC/m^3
CC-3		
Sand	–	0.0005
Silt	0.003	0.0019
Clay	–	0.0280
Dissolved	–	0.104 pC/m^3
CC-5/1		
Sand	–	0.0002
Silt	0.0007	0.0018
Clay	–	0.0075
Dissolved	–	0.102 pC/m^3
CC-5/2		
Sand	–	0.0002
Silt	0.0023	0.0019
Clay	–	0.0170
Dissolved	–	0.104 pC/m^3
CC-5/3		
Sand	–	0.0001
Silt	–	0.0015
Clay	–	0.0232
Dissolved	–	0.100 pC/m^3
CC-6/1		
Sand	–	0.0006
Silt	–	0.0308
Clay	–	0.0133
Dissolved	–	0.110 pC/m^3

TABLE 5.8. (contd)

Phase 3 ^{239,240}Pu Comparison (pC/g)

Location	Observed	Computed
CC-6/2		
Sand	–	0.0006
Silt	–	0.0251
CLay	–	0.0124
Dissolved	0.06 pC/m^3	0.103 pC/m^3
CC-6/3		
Sand	0.016	0.0005
Silt	–	0.0110
Clay	–	0.0264
Dissolved	–	0.099 pC/m^3
CC-9		
Sand	–	0.0023
Silt	–	0.0322
Clay	0.049	0.0215
Dissolved	–	0.115 pC/m^3
CC-11		
Sand	–	0.0021
Silt	–	0.0331
Clay	–	0.0219
Dissolved	–	0.174 pC/m^3

Phase 3 ^{3}H Comparison (pC/m^3)

Location	Observed	Computed
BC-3	290 x 10^3	160 x 10^3
BC-4/2	212 x 10^3	170 x 10^3
BC-4/3	315 x 10^3	160 x 10^3
CC-3	210 x 10^3	250 x 10^3
CC-5/2	148 x 10^3	150 x 10^3
CC-5/3	235 x 10^3	190 x 10^3
CC-6/1	197 x 10^3	180 x 10^3
CC-6/2	215 x 10^3	160 x 10^3
CC-6/3	234 x 10^3	190 x 10^3

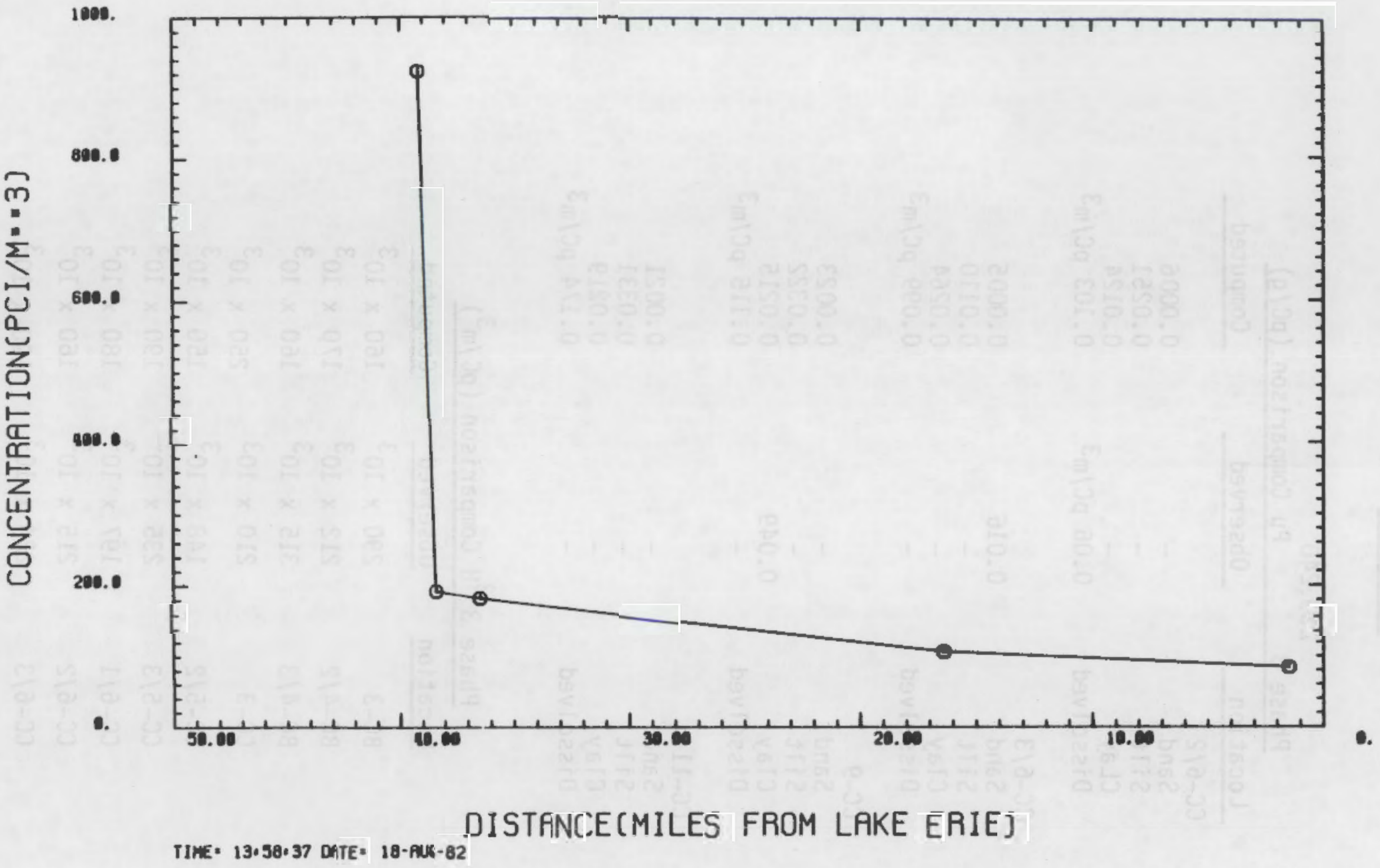


FIGURE 5.43. Phase 2 Longitudinal Distribution of ^{137}Cs Total Concentration at Hour 100

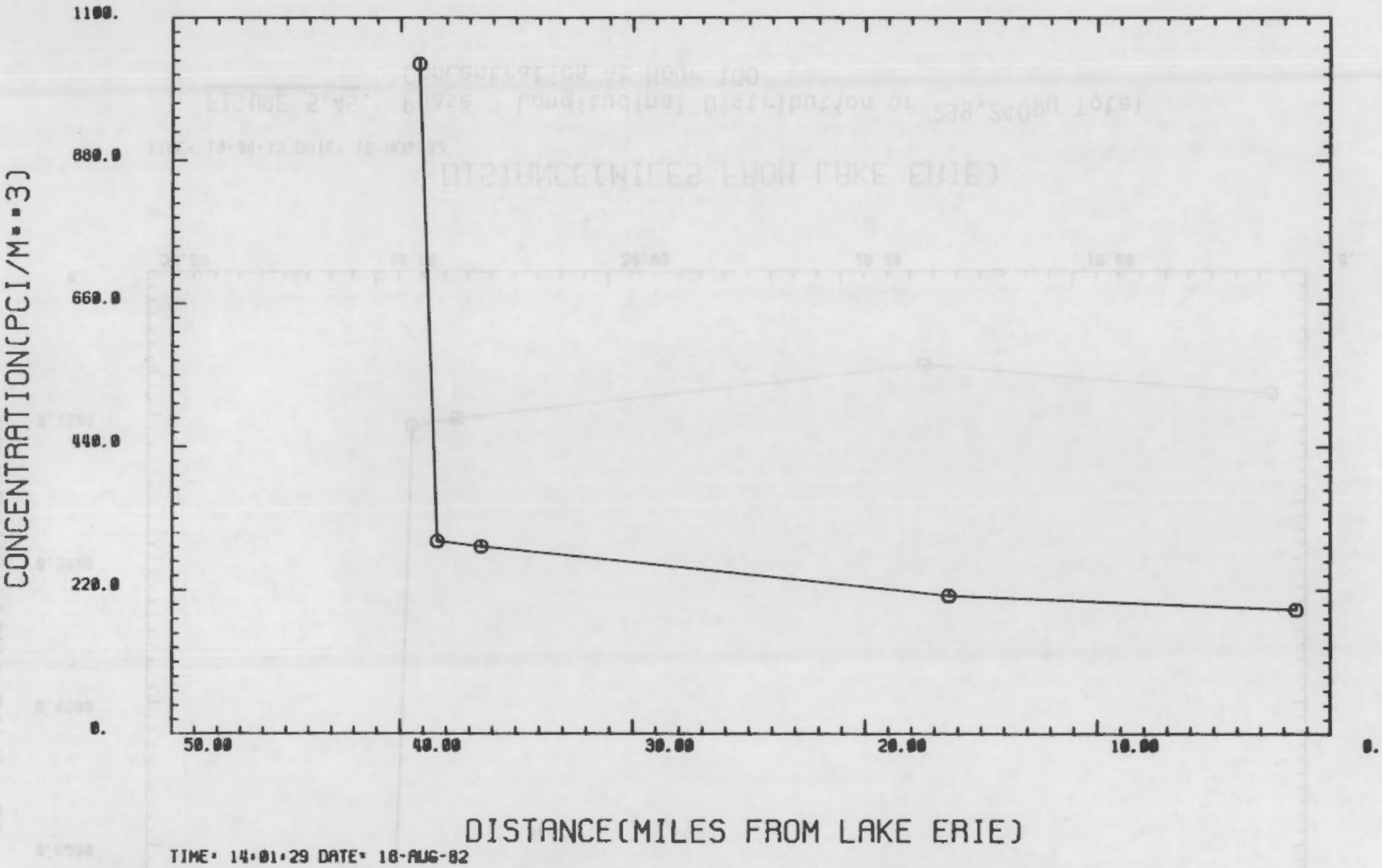


FIGURE 5.44. Phase 2 Longitudinal Distribution of ^{90}Sr Total Concentration at Hour 100

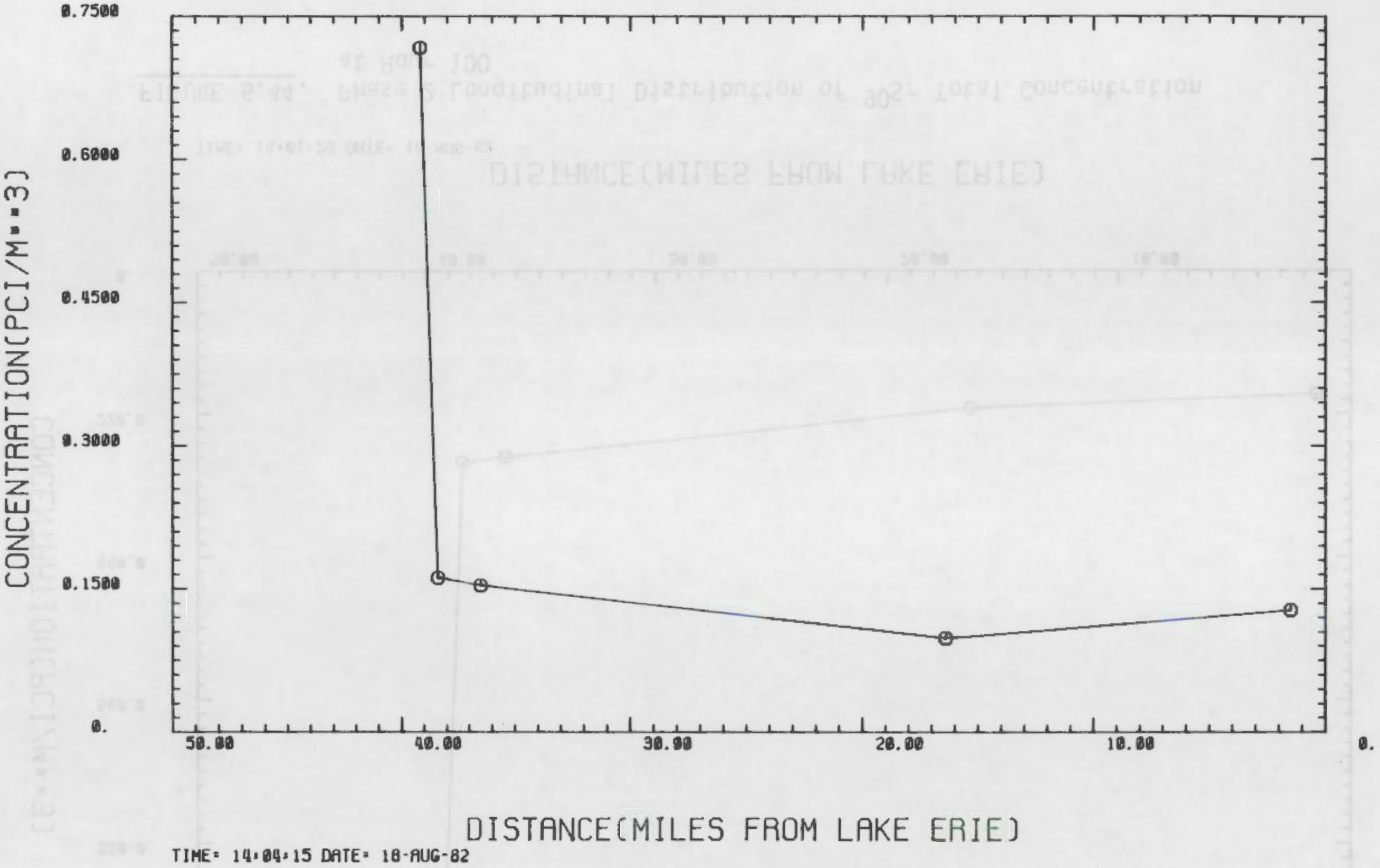


FIGURE 5.45. Phase 2 Longitudinal Distribution of ^{239,240}Pu Total Concentration at Hour 100

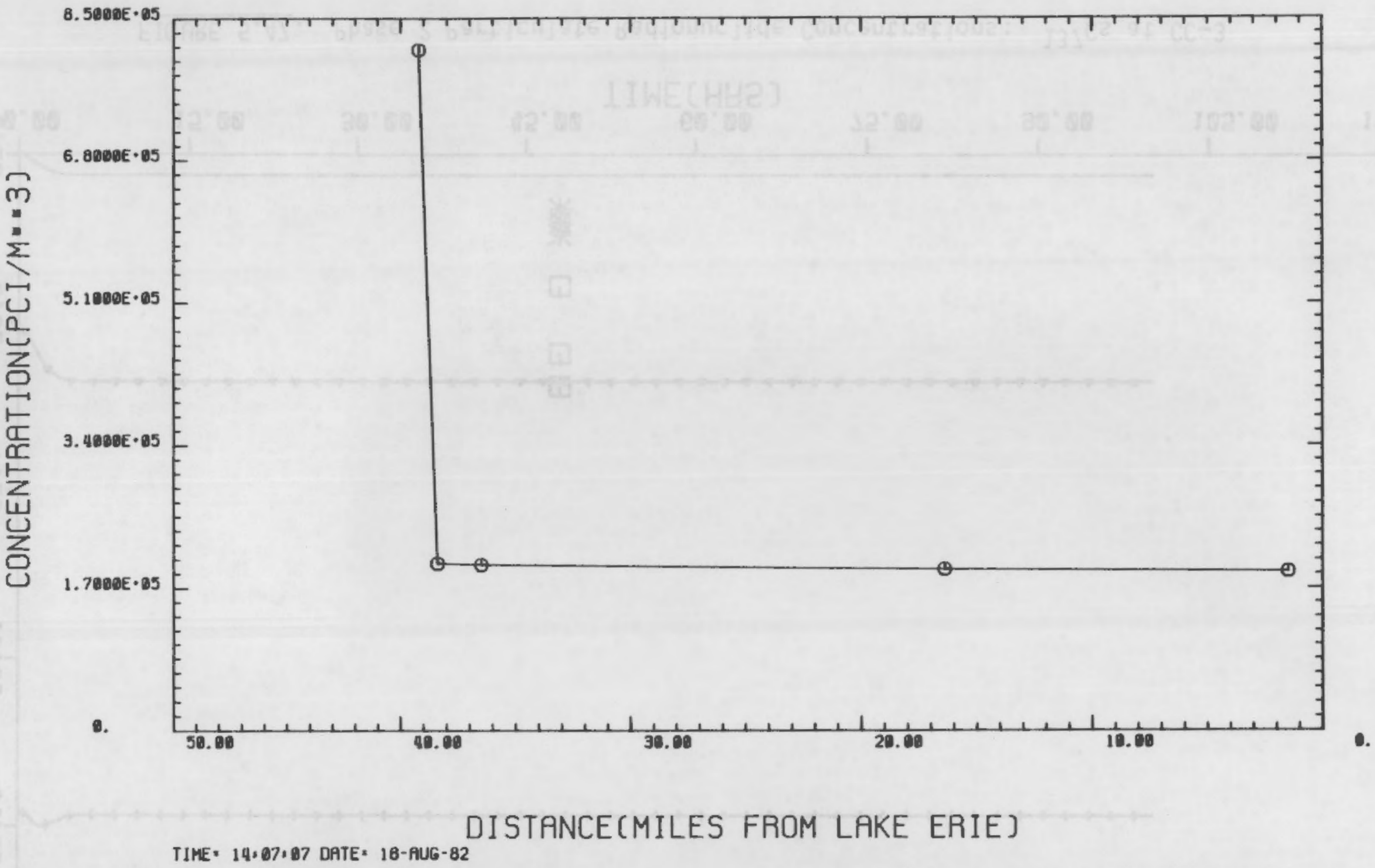


FIGURE 5.46. Phase 2 Longitudinal Distribution of ^3H Total Concentration at Hour 100

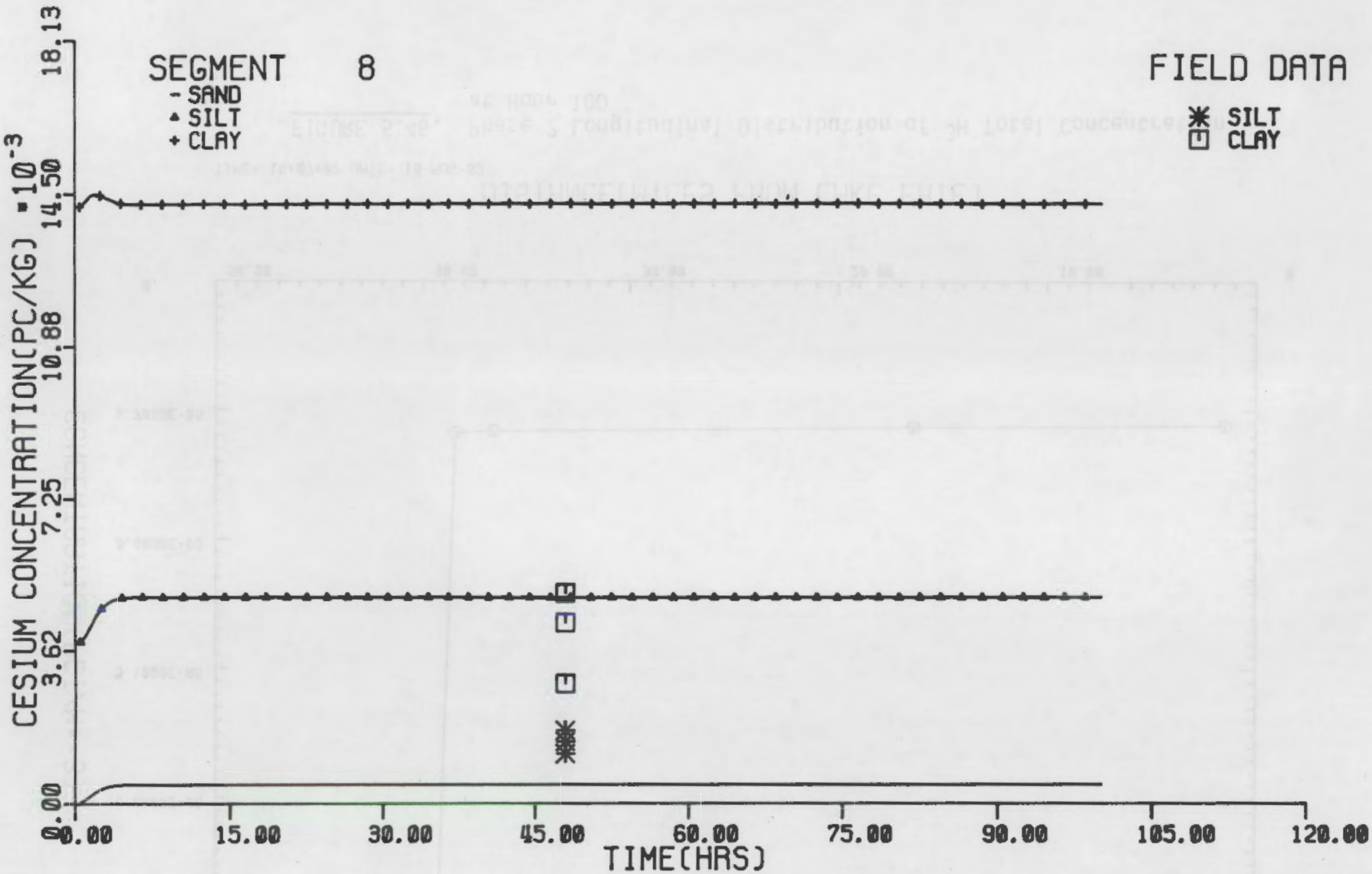


FIGURE 5.47. Phase 2 Particulate Radionuclide Concentrations: ^{137}Cs at CC-3

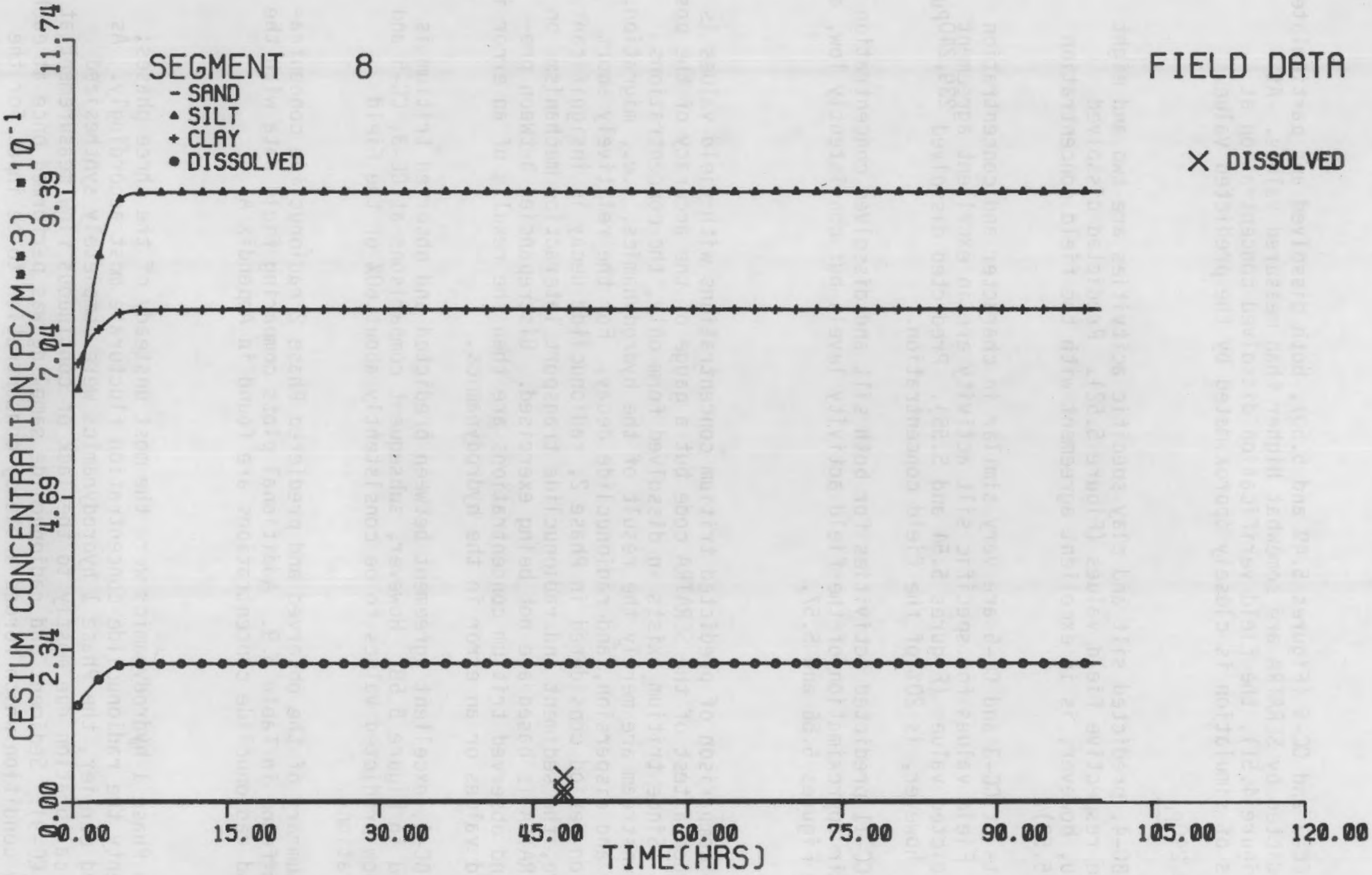


FIGURE 5.48. Phase 2 Particulate and Dissolved Radionuclide Concentrations: ^{137}Cs at CC-3

At CC-3 and CC-5 (Figures 5.49 and 5.50), both dissolved and particulate ^{90}Sr predicted by SERATRA are somewhat higher than measured values. At CC-11 (Figure 4.51), the field verification dissolved concentration at 100 hours of simulation is closely approximated by the predicted value.

$^{239,240}Pu$

At BC-4, predicted silt and clay specific acitvities are two and eight times the respective field values (Figure 5.52). Predicted dissolved $^{239,240}Pu$, however, is in excellent agreement with the field concentration (Figure 5.53).

Plots at CC-3 and CC-5 are very similar in character and concentration levels. Field values for specific silt activity are in excellent agreement with predicted values (Figures 5.54 and 5.55). Predicted dissolved $^{239,240}Pu$ at CC-3, however, is 20% of the field concentration.

At CC-11 predicted activities for both silt and dissolved concentration are a fair approximation of the field activity levels but consistently low, as shown in Figures 5.56 and 5.57.

^{3}H

The comparison of predicted tritium concentrations with field values is not so much a test of the SERATRA code but a gauge of the accuracy of the posed problem. Since tritium exists in dissolved form only, the concentrations found downstream are merely the result of the hydrodynamics, i.e., migration, dilution and dispersion, and radionuclide decay. For the relatively short simulation period considered in Phase 2, radionuclide decay is insignificant. Therefore, the sediment and radionuclide transport interaction mechanisms on which SERATRA is based are not being exercised. Discrepancies between predicted and observed tritium concentrations are then the results of an error in the field values or an error in the hydrodynamics.

At BC-4, excellent agreement between predicted and observed tritium is displayed in Figure 5.58. However, subsequent comparisons at CC-3, CC-5 and CC-11 show predicted values to be consistently about 60% of the field concentrations.

A summary of the observed and predicted Phase 2 radionuclide concentrations is found in Table 5.9. Additional plots comparing field data with the predicted radionuclide concentrations are found in Appendix A.

Phase 1

The Phase 1 hydrodynamics were the most unsteady of the three phases; consequenty the radionuclide concentration flucturate most accordingly. As mentioned earlier, the Phase 1 hydrodynamics were completely synthesized without calibration due mostly to the lack of continuous flow measurement at Gowand (CC-9). Sediment and radionuclide sampling was performed once at each boundary condition which forced a steady concentration to be input for the very unsteady case.

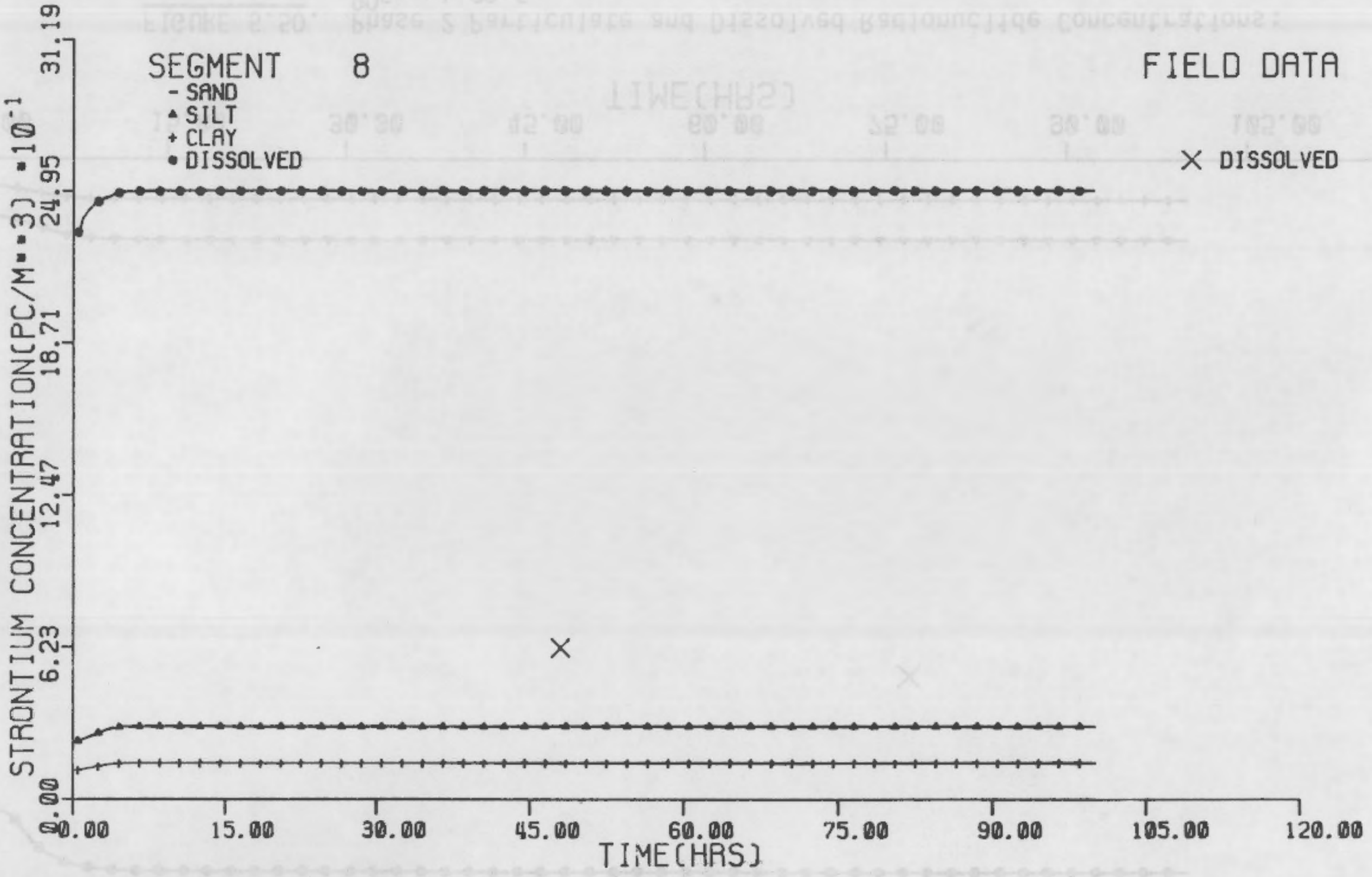


FIGURE 5.49. Phase 2 Particulate and Dissolved Radionuclide Concentrations: ^{90}Sr at CC-3

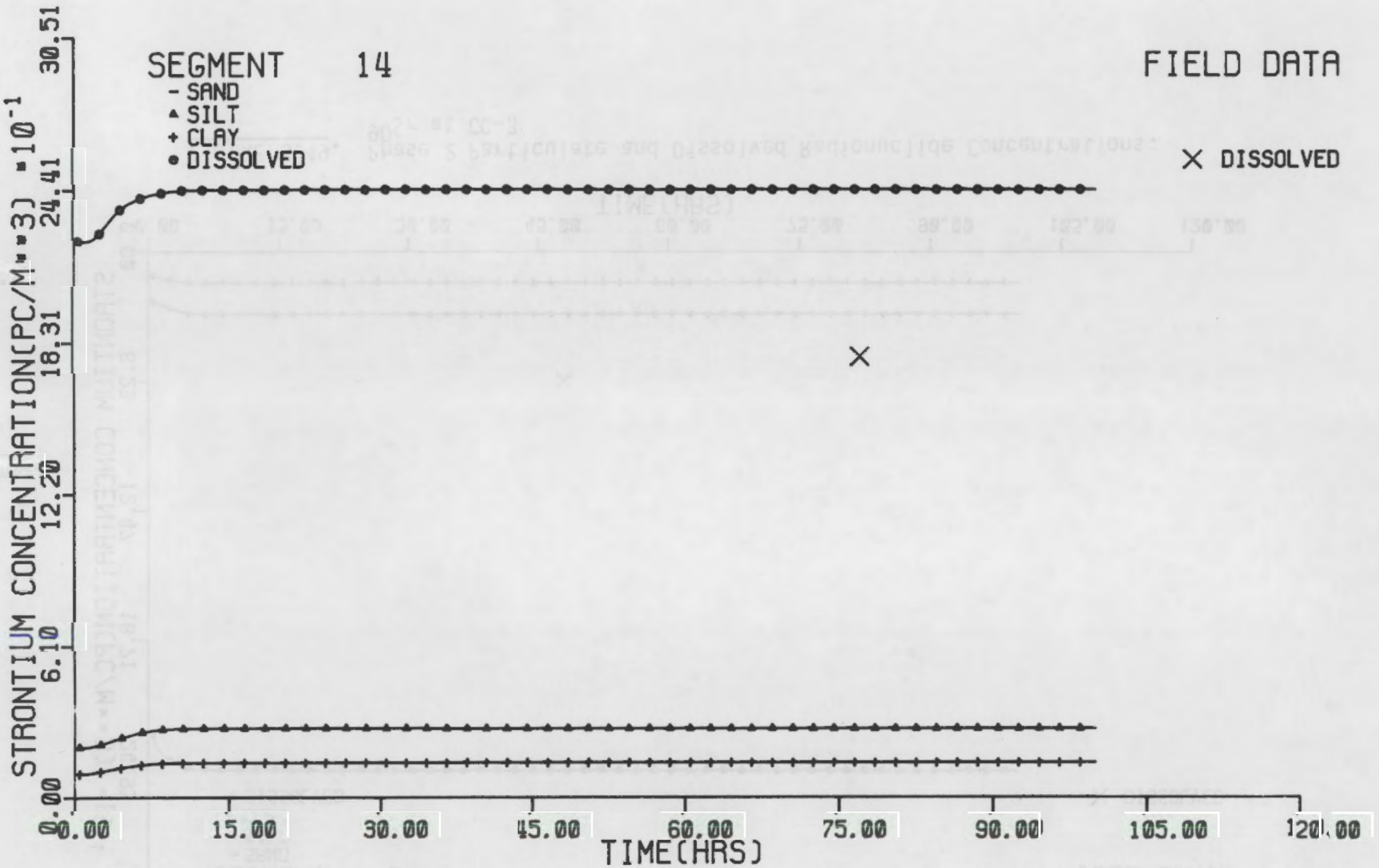


FIGURE 5.50. Phase 2 Particulate and Dissolved Radionuclide Concentrations: ^{90}Sr at CC-5

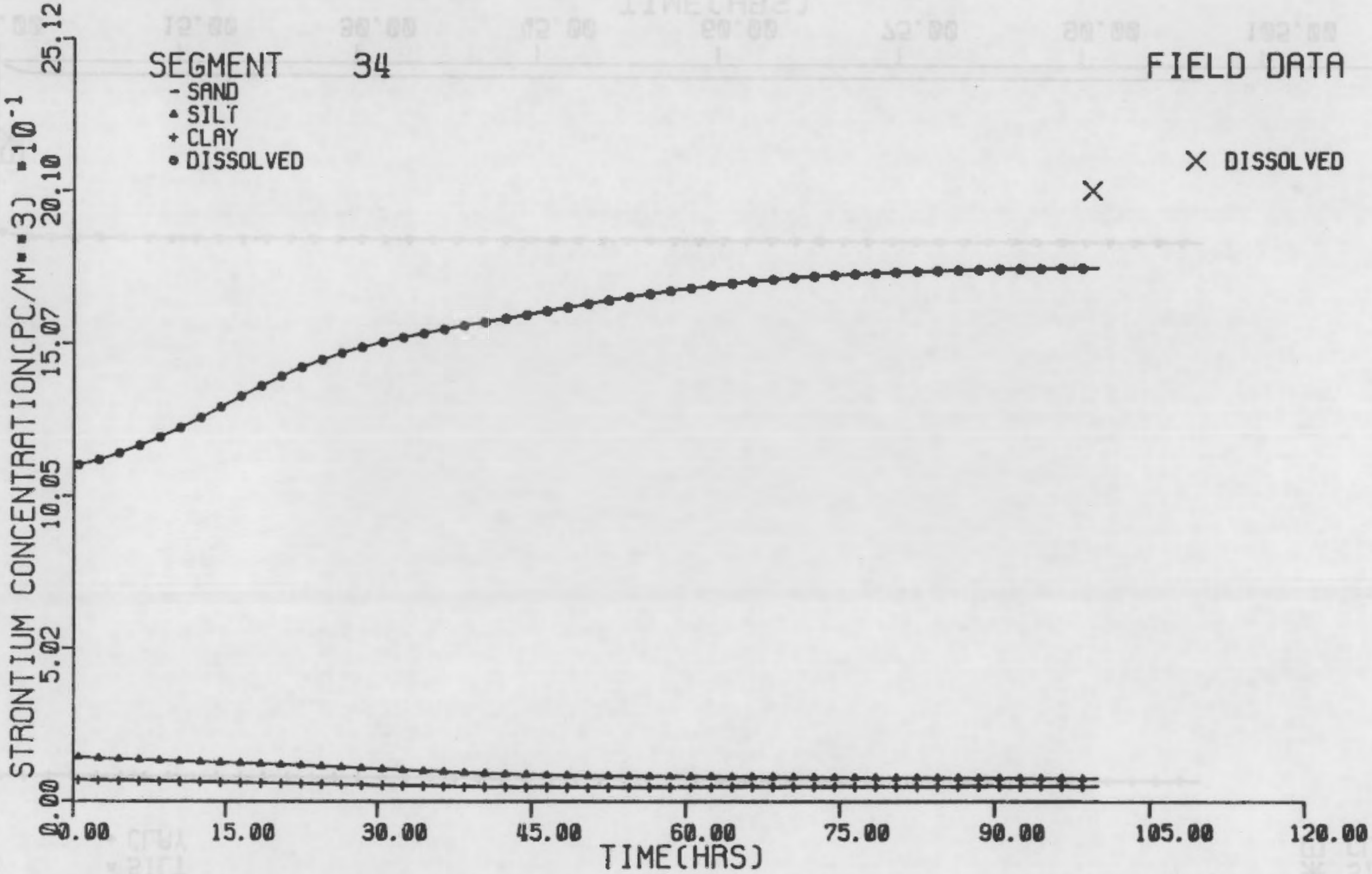


FIGURE 5.51. Phase 2 Particulate and Dissolved Radionuclide Concentration: ^{90}Sr at CC-11

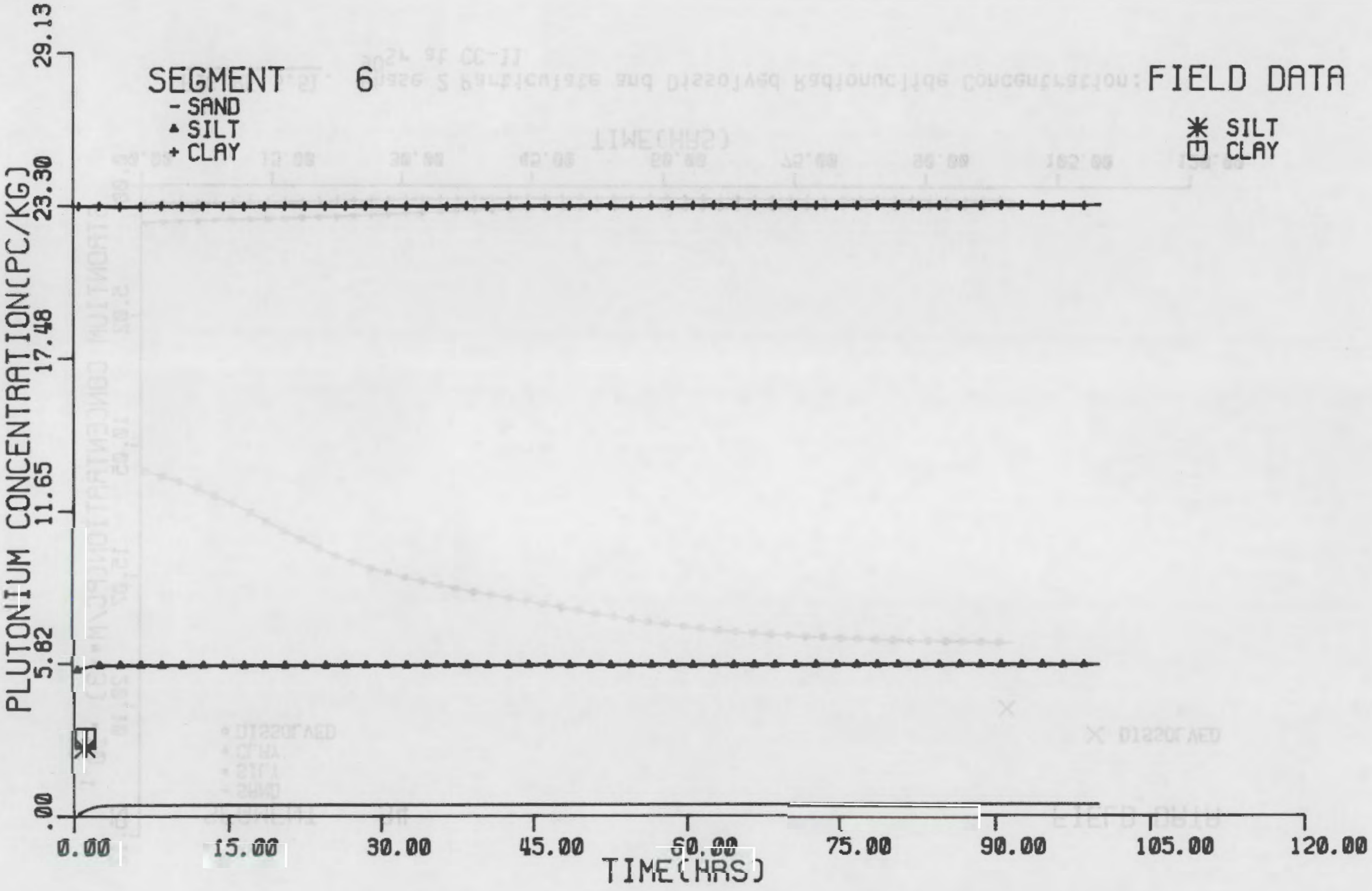


FIGURE 5.52. Phase 2 Particulate Radionuclide Concentrations: ^{239,240}Pu at BC-4

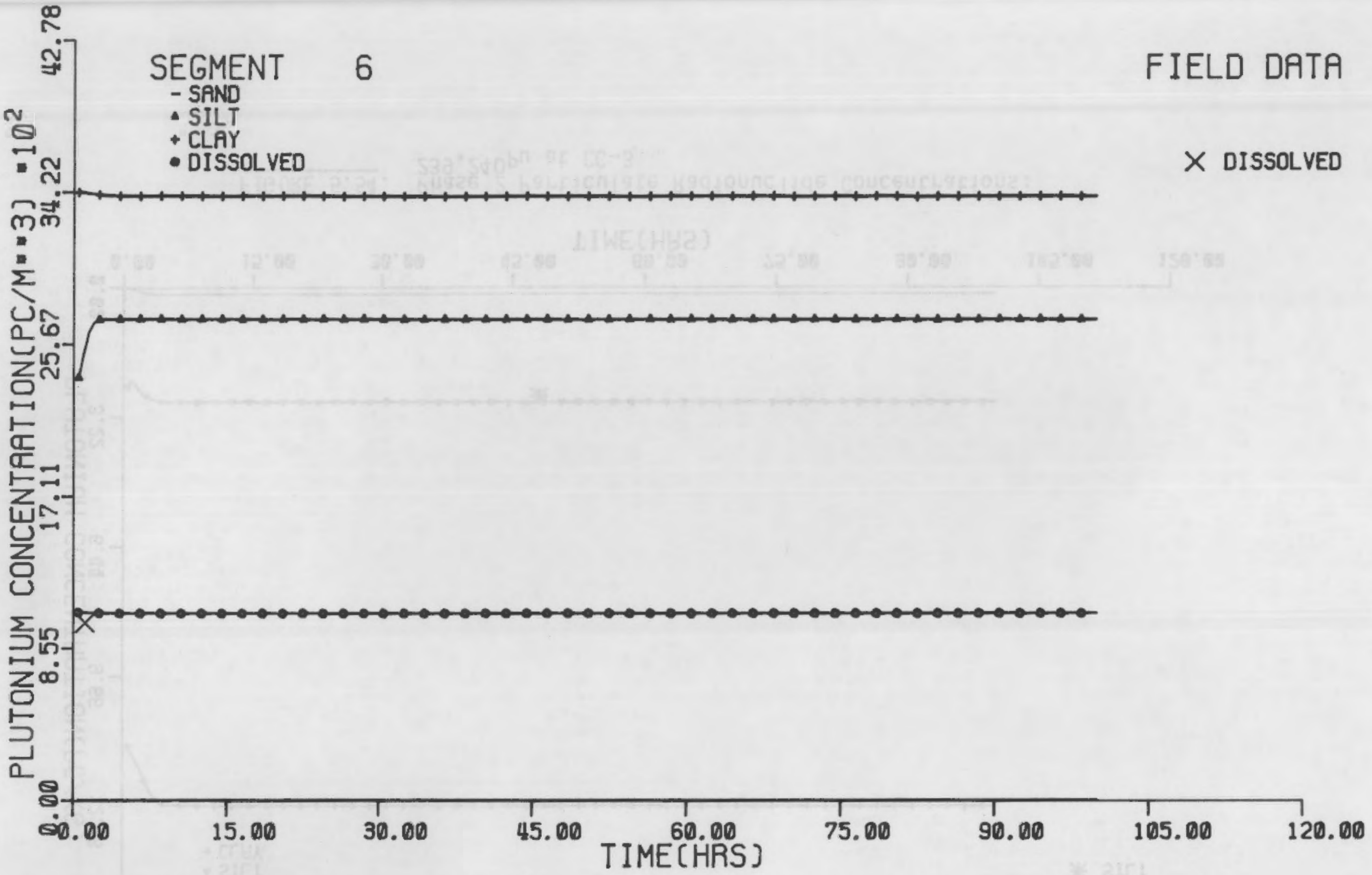


FIGURE 5.53. Phase 2 Particulate and Dissolved Radionuclide Concentrations: $^{239,240}Pu$ at BC-4

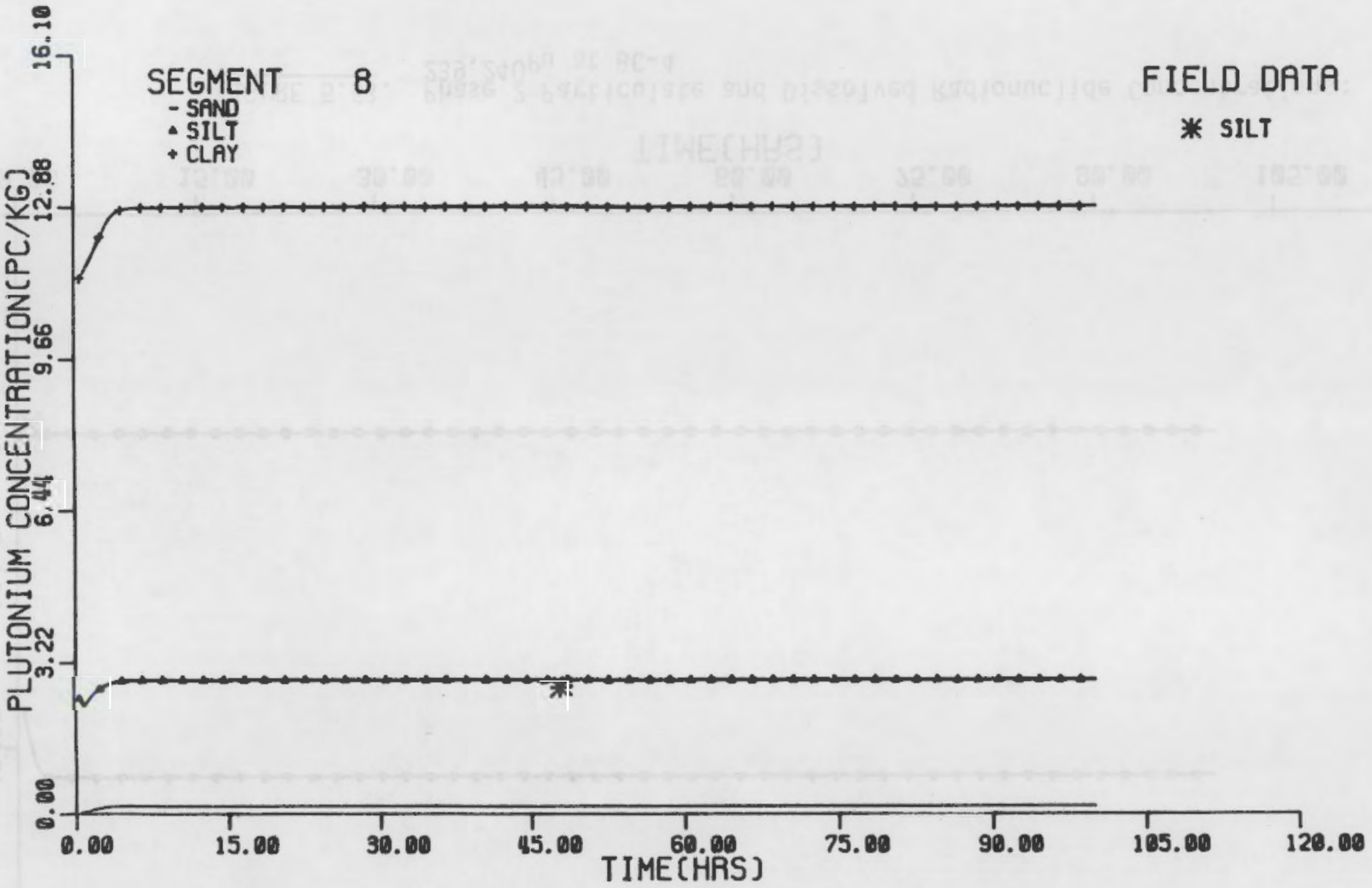
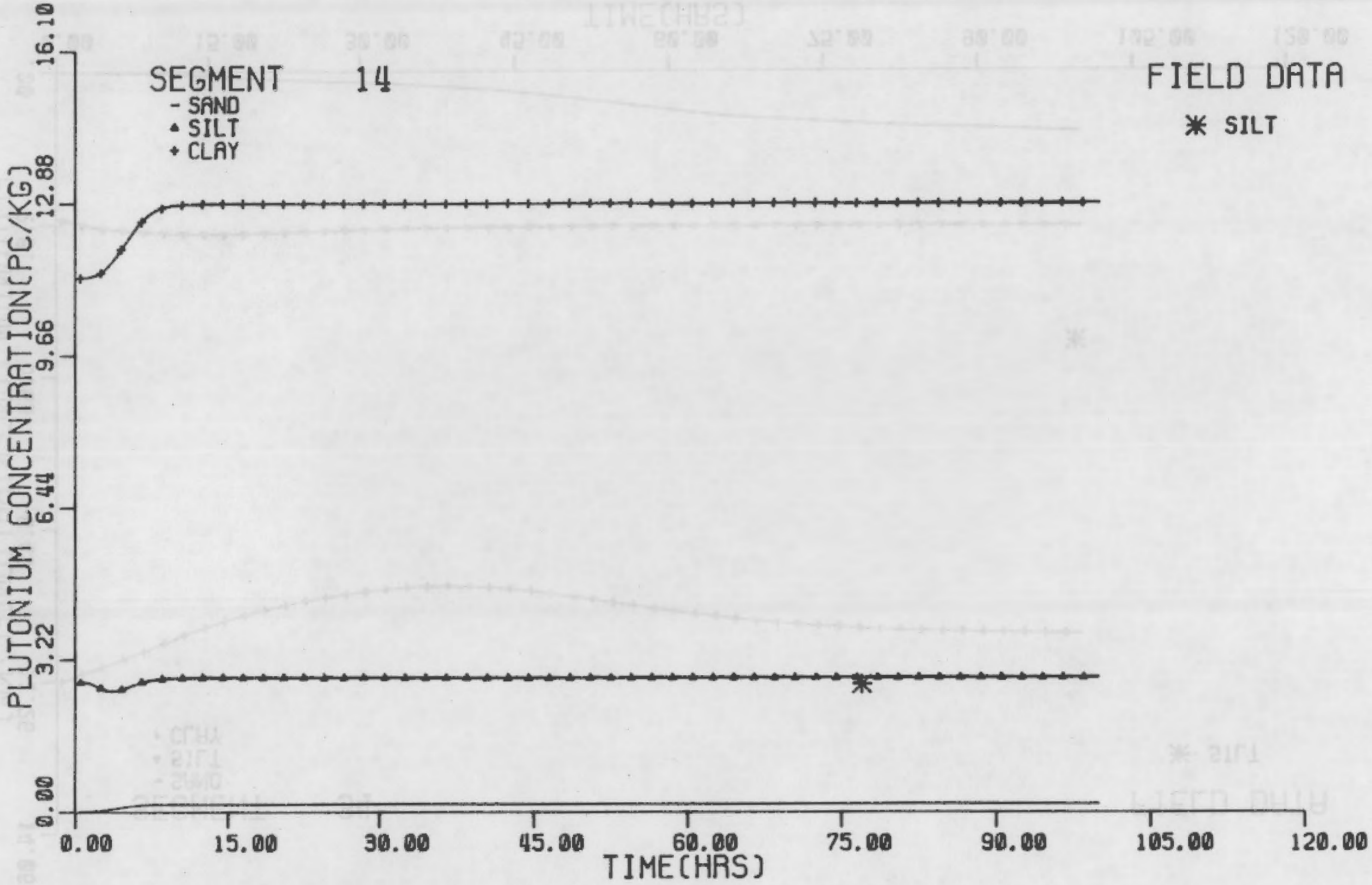


FIGURE 5.54. Phase 2 Particulate Radionuclide Concentrations: $^{239,240}Pu$ at CC-3



<u>FIGURE 5.55</u>. Phase 2 Particulate Radionuclide Concentrations: ^{239,240}Pu at CC-5

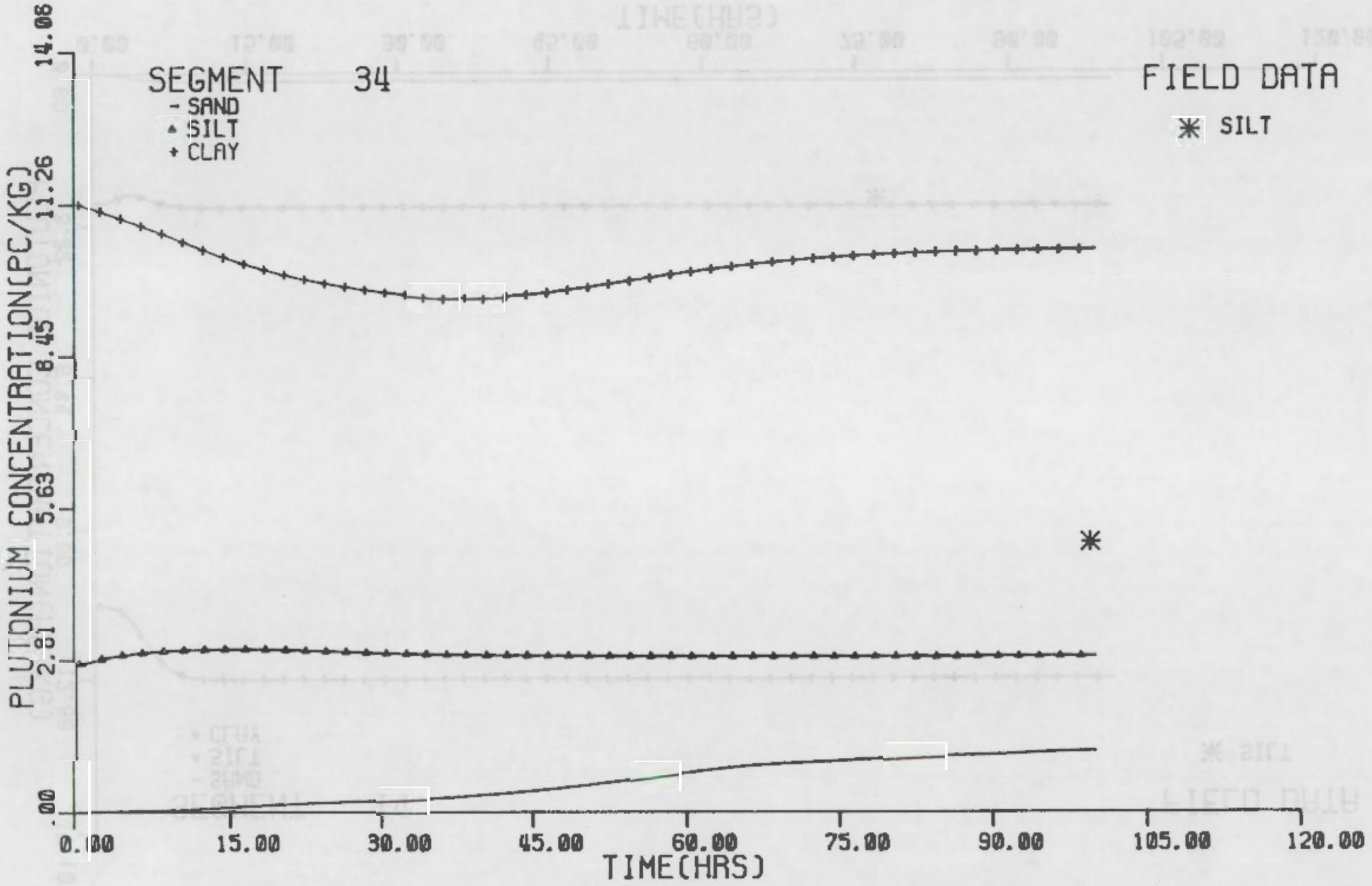


FIGURE 5.56. Phase 2 Particulate Radionuclide Concentrations: ^{239,240}Pu at CC-11

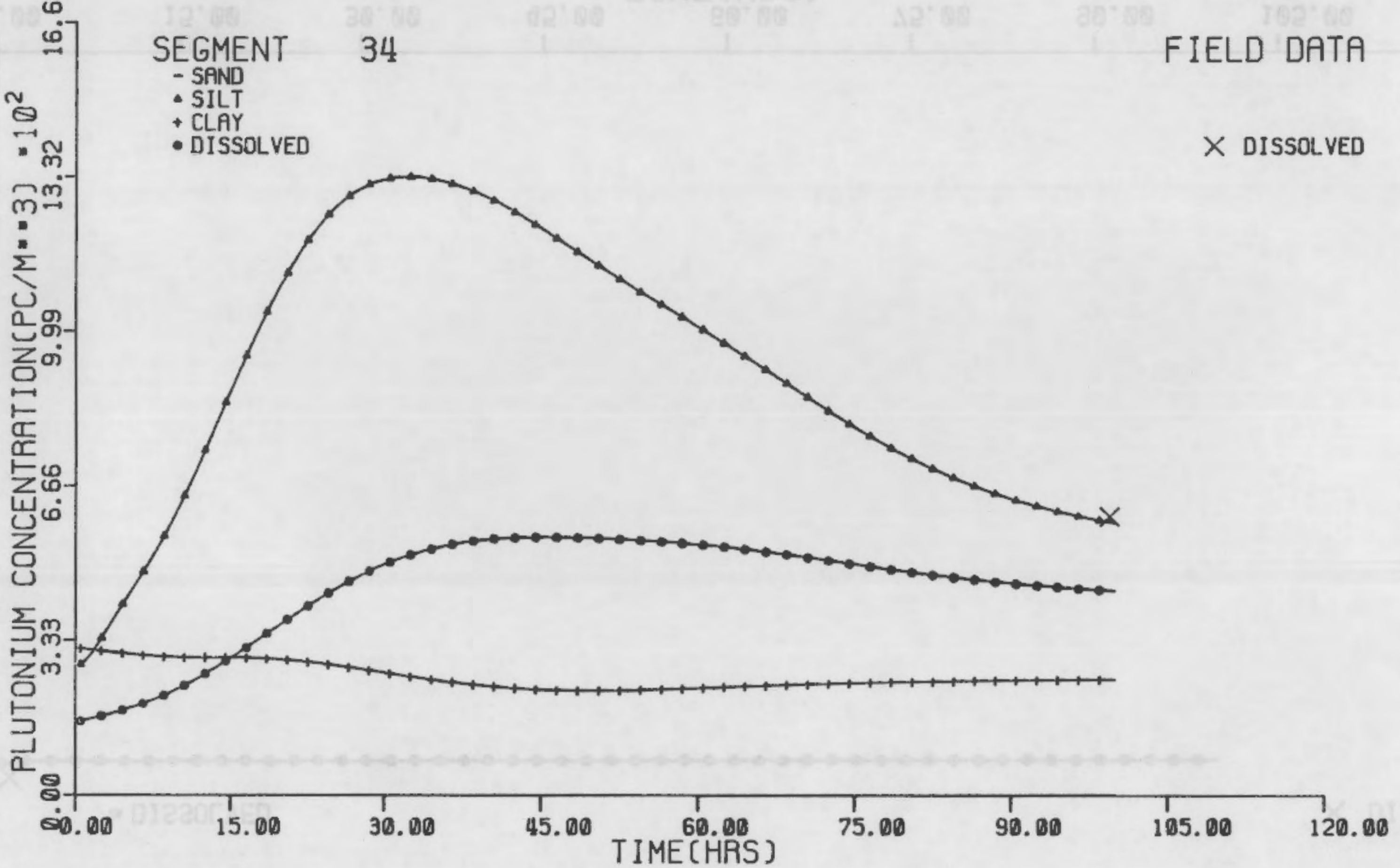


FIGURE 5.57. Phase 2 Particulate and Dissolved Radionuclide Concentrations: ^{239,240}Pu at CC-11

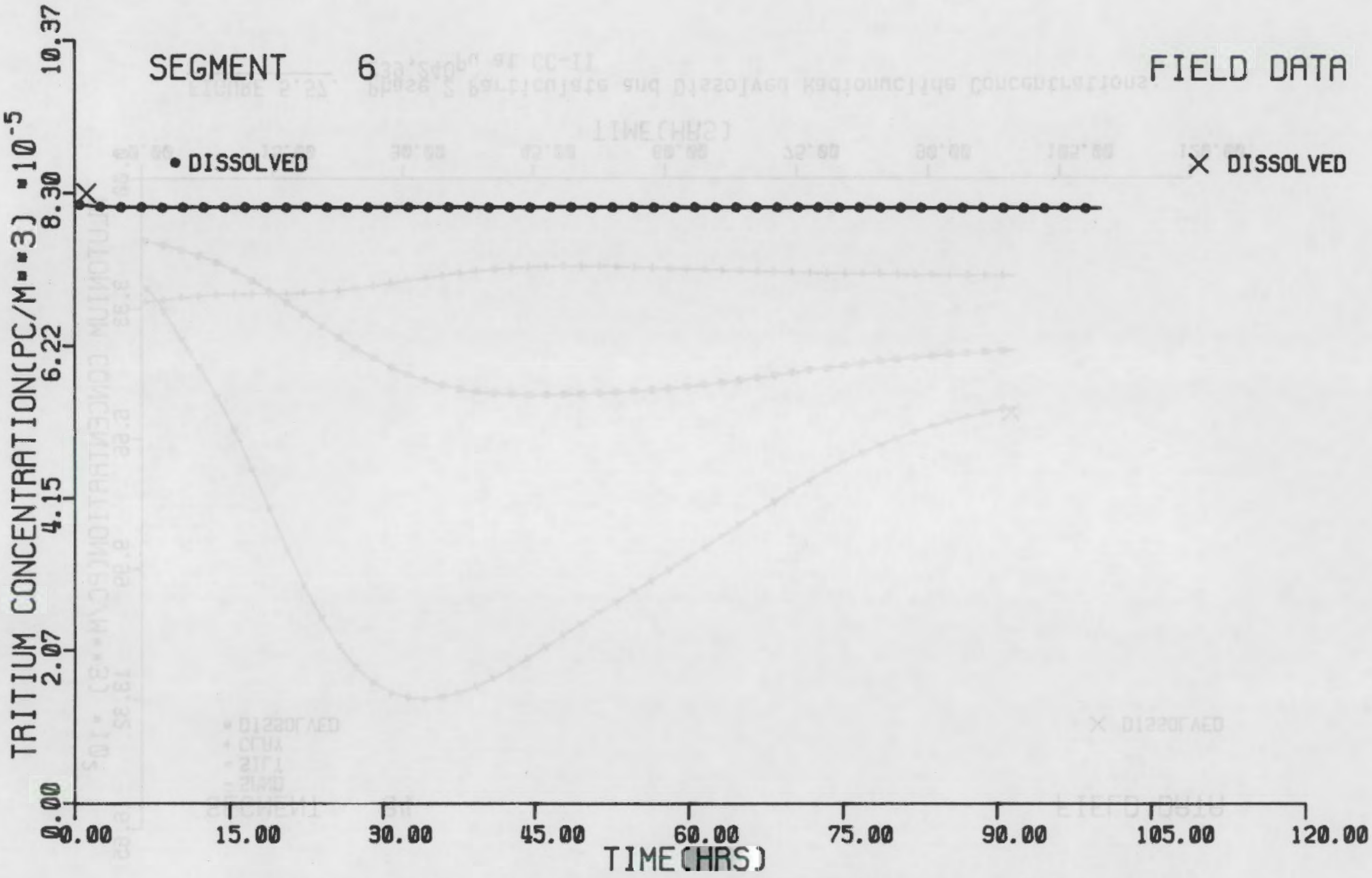


FIGURE 5.58. Phase 2 Dissolved Radionuclide Concentrations: ^{3}H at BC-4

TABLE 5.9. Phase 2 Observed and Computed Radionuclide Concentrations

Phase 2 Cs^{137} Comparison (pC/g)

Location	Observed	Computed
BC-4		
Sand	---	0.6
Silt	---	9.5
Clay ---	27.8	
Dissolved	28 pC/m^3	94 pC/m^3
CC-3		
Sand	---	0.4
Silt	1.46/1.17/1.72	4.9
Clay	2.84/4.29/5.0	14.3
Dissolved	1.0/2.0/4.0 pC/m^3	21 pC/m^3
CC-5		
Sand	---	0.4
Silt	1.17/1.09/1.20	4.8
Clay	1.90/2.10/2.36	14.1
Dissolved	3.0 pC/m^3	24 pC/m^3
CC-9		
Sand	---	0.4
Silt	1.85	4.2
Clay	2.74	12.2
Dissolved	---	26 pC/m^3
CC-11		
Sand	---	0.3
Silt	1.41	1.4
Clay	2.51	10.2
Dissolved	---	32 pC/m^3

Phase 2 ^{90}Sr Comparison (pC/g)

Location	Observed	Computed
BC-4		
Sand	–	0.0
Silt	–	3.3
Clay	0.327	5.1
Dissolved	868 pC/m^3	880 pC/m^3
CC-3		
Sand	–	0.0
Silt	–	1.6
Clay	0.359	2.8
Dissolved	62 pC/m^3	250 pC/m^3

TABLE 5.9. (contd)

Phase 2 ^{90}Sr Comparison (pC/g) (contd)

Location	Observed	Computed
CC-5		
Sand	–	0.0
Silt	0.192	1.5
Clay	–	2.8
Dissolved	177 pC/m^3	240 pC/m^3
C-11		
Sand	–	0.1
Silt	0.185	0.4
Clay	–	2.1
Dissolved	201 pC/m^3	180 pC/m^3

Phase 2 ^{239,240}Pu Comparison (pC/g)

Location	Observed	Computed
BC-4		
Sand	–	0.0
Silt	0.0026	0.0057
Clay	0.003	0.0233
Dissolved	0.1 pC/m^3	0.11 pC/m^3
CC-3		
Sand	–	0.0002
Silt	0.0027	0.0028
Clay	–	0.0129
Dissolved	0.2 pC/m^3	0.04 pC/m^3
CC-5		
Sand	–	0.0002
Silt	0.0027	0.0028
Clay	–	0.0129
Dissolved	–	0.04 pC/m^3
CC-11		
Sand	–	0.0011
Silt	0.005	0.0029
Clay	–	0.0104
Dissolved	0.06 pC/m^3	0.04 pC/m^3

TABLE 5.9. (contd)

Phase 2 ^{3}H Comparison (pC/m^{3})

Location	Observed	Computed
BC-4	830×10^{3}	810×10^{3}
CC-3	$356 \times 10^{3}/383 \times 10^{3}/1056 \times 10^{3}$	200×10^{3}
CC-5	$312 \times 10^{3}/365 \times 10^{3}$	200×10^{3}
CC-11	298×10^{3}	190×10^{3}

Because of the high flows in this phase, large amounts of sediment were removed from the bed into the water column accompanying the sorbed radionuclides. As most of the channel bed became armored against further silt and clay erosion, the contribution of the suspended radionuclides from the contaminated bed was stopped resulting in falling sediment and radionuclide levels.

^{137}Cs

Because of the constant sediment and radionuclide concentrations used at the Franks Creek boundary condition, the radionuclide levels in Buttermilk Creek are generally proportional to the discharges from Franks Creek. Therefore, as in the hydrodynamic case, two trains of peak concentrations in both sorbed and dissolved forms are visible in Buttermilk Creek. ^{137}Cs sorbed clay exhibits the highest radionuclide concentrations while sorbed sand has the lowest radionuclide concentrations.

The predicted specific activity levels of particulate ^{137}Cs at BC-2 are highly dynamic with the clay-sorbed activity being consistently twice as large as those adsorbed by sand and silt. Correlation with measured particulate ^{137}Cs with silt and clay is good while the field activity with sand is five times the predicted value.

At BC-3 and BC-4, the time-dependent profiles of specific activity levels have changed little from those appearing at BC-2. However, the field values at these locations, despite being taken at times less than three hours apart, are widely divergent. At BC-3, measured ^{137}Cs adsorbed by suspended sand is the highest particulate activity. Predicted silt and clay activities are 60% of the corresponding field values. At BC-4, the sand field activity lies well below the lowest predicted values. The predicted sand and silt activity levels compare favorably with the field values, activities appearing to be 5 hr out of phase with field data.

The two sets of peaks diffuse and coalesce into two general peaks at the radionuclides are transported to Lake Erie. Dilution from Buttermilk Creek to

Cattaraugus Creek reduces total concentrations of ^{137}Cs by a factor of four while sorbed activity levels are reduced very slightly. High silt-sorbed ^{137}Cs concentrations in the water column near the mouth of Cattaraugus Creek are a result of silt-sorbed sediment being scoured from the bed between the mouth of the creek at Gowanda and Lake Erie.

The character of the predicted particulate activity in Buttermilk Creek is preserved in the plots at CC-3 and CC-5 (Figure 5.59). At CC-3, the sand activity field value is much higher than the magnitude of the sampled silt and clay activities. The entire range of predicted results at 80 hours of simulation is between the activity values measured at CC-3. At CC-5, the silt activity correlation between predicted and sampled values is good while the predicted value associated with clay is 40% below the field clay activity. Predicted dissolved ^{137}Cs levels at the end of the simulation are four times the value in the field (Figure 5.60).

The predicted particulate activity levels at CC-9 display more gradual dynamics than the upstream sites. The silt activity predicted at 108 hours of simulation is twice as high as the field value.

At CC-11, the sudden increase and decrease of the predicted clay specific activity appears due to high activity-bearing clay being scoured from the bed followed by the onset of bed armoring. At 105 hours of simulation, predicted silt activity is fairly close to the field-sampled value while predicted clay activity is 40% of the field value.

The longitudinal distribution of ^{137}Cs in the water column (Figure 5.61) shows a large dilution effect from Buttermilk Creek to Cattaraugus Creek. Radionuclides in the water column decrease steadily in concentrations as flow moves toward Lake Erie.

^{3}H

Tritium does not interact with the sediment and is therefore influenced only by the hydrodynamics with some dispersion and radioactive decay. Since ^{3}H concentrations at FC-1, BC-1 and CC-1 were not sampled during the Phase 1 data collection effort, a boundary condition at FC-1 was estimated to match the measured ^{3}H concentration at BC-4. Background concentrations were taken from the Phase 3 ^{3}H field collection data.

The dynamic behavior found in Buttermilk Creek is preserved in form in Cattaraugus Creek above Springville Dam. However, concentrations are reduced by a factor of two. Downstream of Springville Dam, the tritium concentrations tend to slowly oscillate about an average value as the sharply peaked ^{3}H concentrations are diffused into two gently curved waves. Predicted values of tritium at BC-4, CC-3 (Figures 5.62 and 5.63) and CC-11 are in excellent agreement with the field values. The longitudinal distribution of ^{3}H at hour 120 is shown in Figure 5.64.

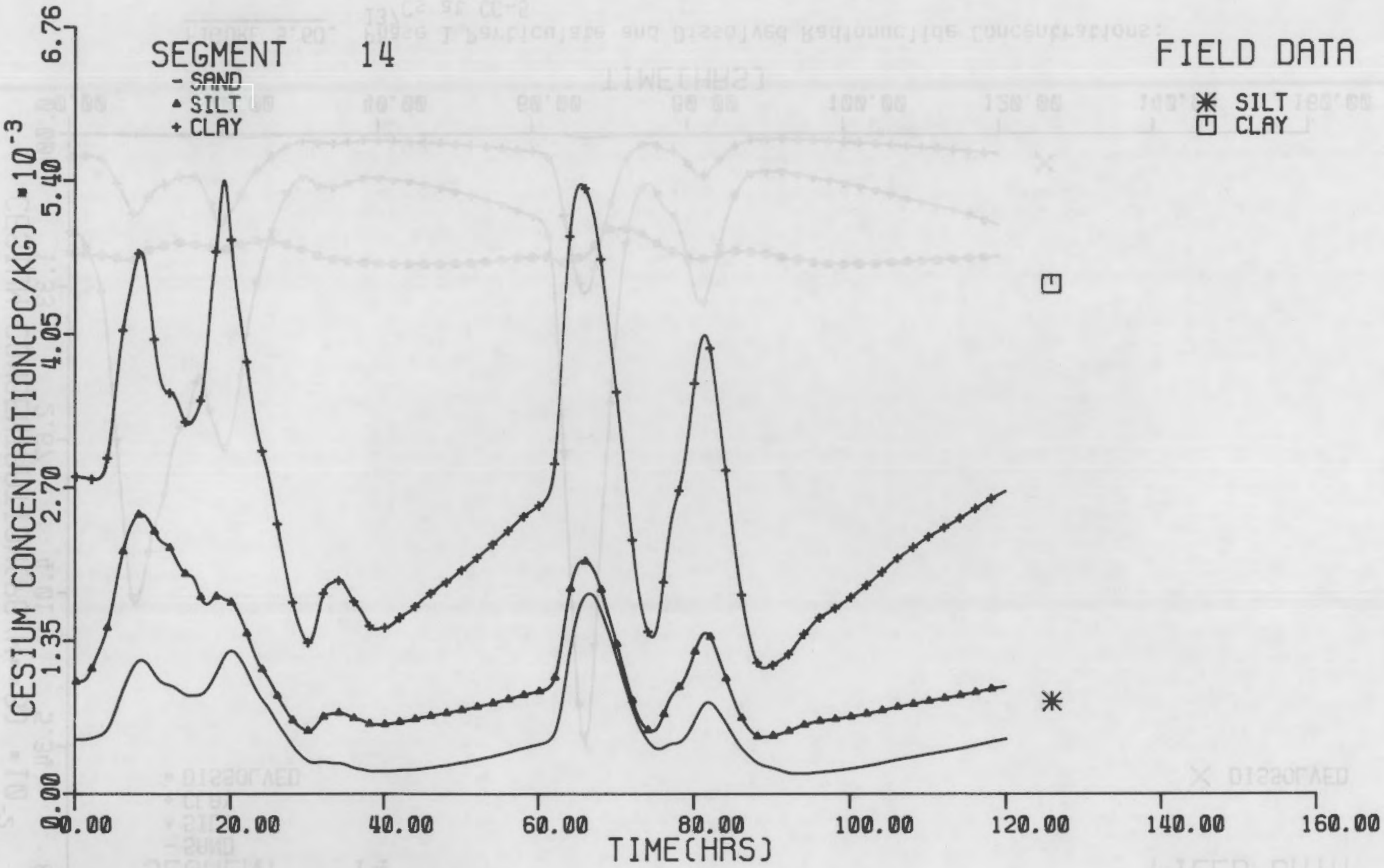


FIGURE 5.59. Phase 1 Particulate Radionuclide Concentrations: ^{137}Cs at CC-5

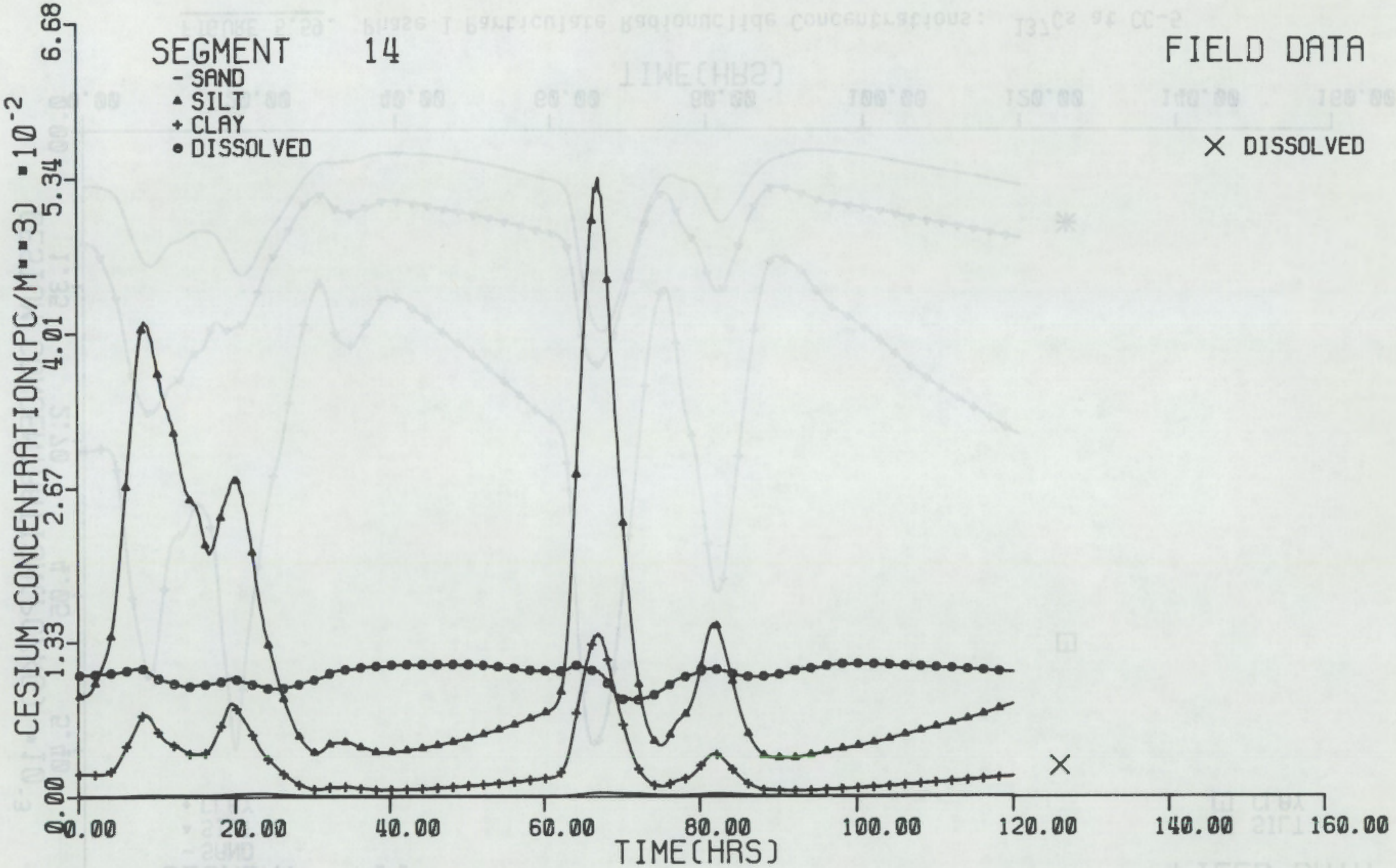


FIGURE 5.60. Phase 1 Particulate and Dissolved Radionuclide Concentrations: ^{137}Cs at CC-5

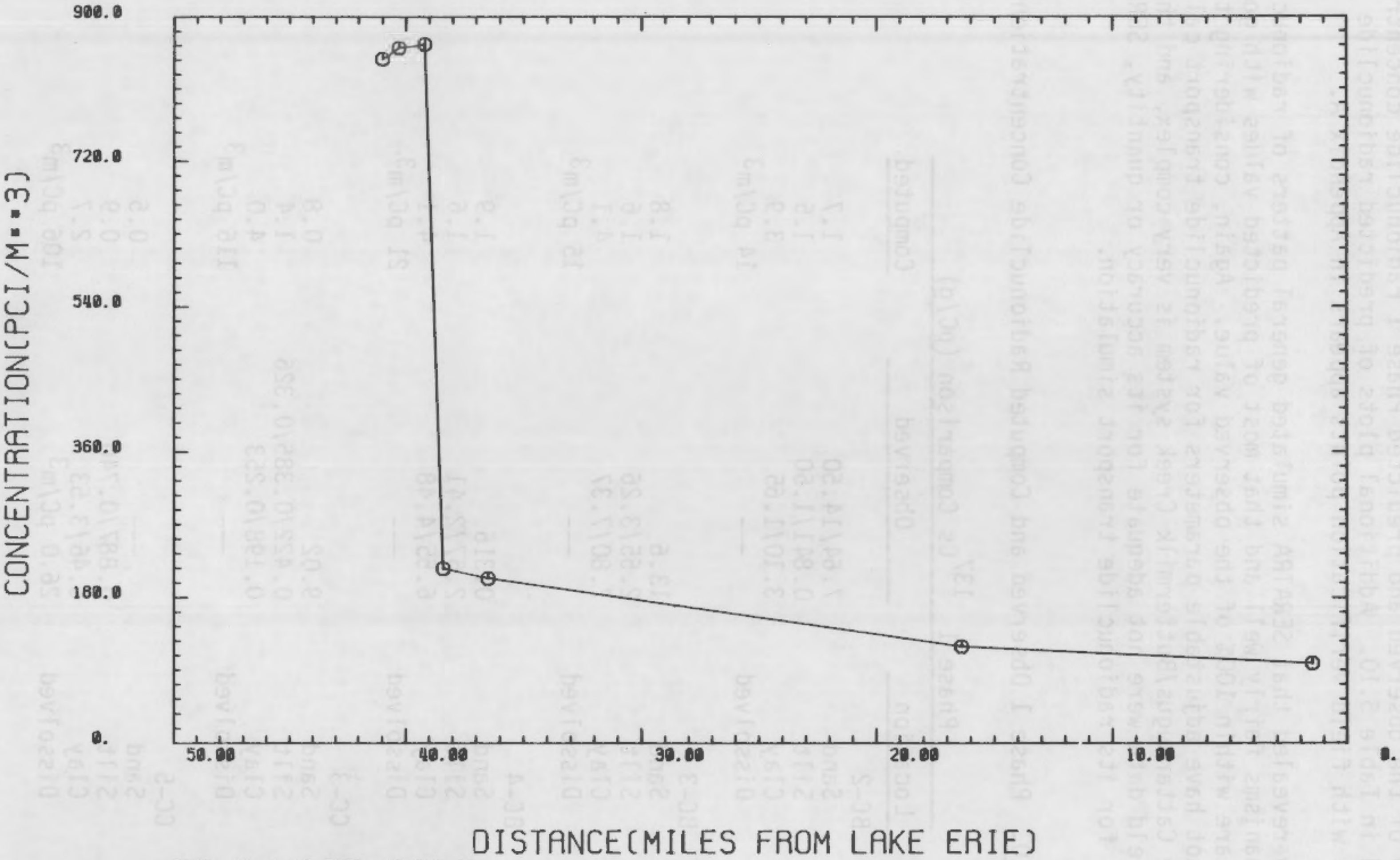


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FIGURE 5.61. Phase 1 Longitudinal Distribution of ^{137}Cs Total Concentration at Hour 120

A summary of the observed and predicted Phase 1 radionuclide concentrations is found in Table 5.10. Additional plots of predicted radionuclide concentrations with field verification points appears in Appendix A.

The study revealed that SERATRA simulated general patters of radionuclide transport mechanisms fairly well and that most of predicted values with good measured data are within 100% of the observed value. Again, considering that SERATRA does not have adjustable parameters for radionuclide transport calibration, that the Cattaraugus/Buttermilk Creek system is very complex, and that some of the field data were not adequate for its accuracy or quantity, SERATRA performed well for its radionuclide transport simulation.

TABLE 5.10. Phase 1 Observed and Computed Radionuclide Concentrations

Phase 1 ^{137}Cs Comparison (pC/g)		
Location	Observed	Computed
BC-2		
Sand	7.64/14.50	1.7
Silt	0.841/1.50	1.5
Clay	3.10/1.65	3.9
Dissolved	---	14 pC/m^3
BC-3		
Sand	13.6	1.8
Silt	2.55/3.26	1.6
Clay	7.80/7.37	4.1
Dissolved	---	15 pC/m^3
BC-4		
Sand	0.316	1.9
Silt	2.67/2.41	1.6
Clay	6.55/4.48	4.1
Dissolved	---	21 pC/m^3
CC-3		
Sand	9.02	0.8
Silt	0.422/0.385/0.326	1.4
Clay	0.198/0.253	4.0
Dissolved	---	116 pC/m^3
CC-5		
Sand	---	0.5
Silt	0.887/0.740	0.9
Clay	5.46/3.53	2.7
Dissolved	26.0 pC/m^3	106 pC/m^3

--- = below detection.

TABLE 5.10. (contd)

Phase 1 ^{137}Cs Comparison (pC/g)

Location	Observed	Computed
CC-9		
Sand	---	0.2
Silt	0.290	0.6
Clay	---	1.5
Dissolved	---	80 pC/m^3
CC-11		
Sand	---	0.4
Silt	0.454/0.571	0.8
Clay	5.50	2.2
Dissolved	---	63 pC/m^3

Phase 1 ^{3}H Comparison (pC/g)

Location	Observed	Computed
BC-4	461 x 10^3	460 x 10^{10}
CC-3	305 x 10^3	290 x 10^3
CC-11	206 x 10^3	210 x 10^3

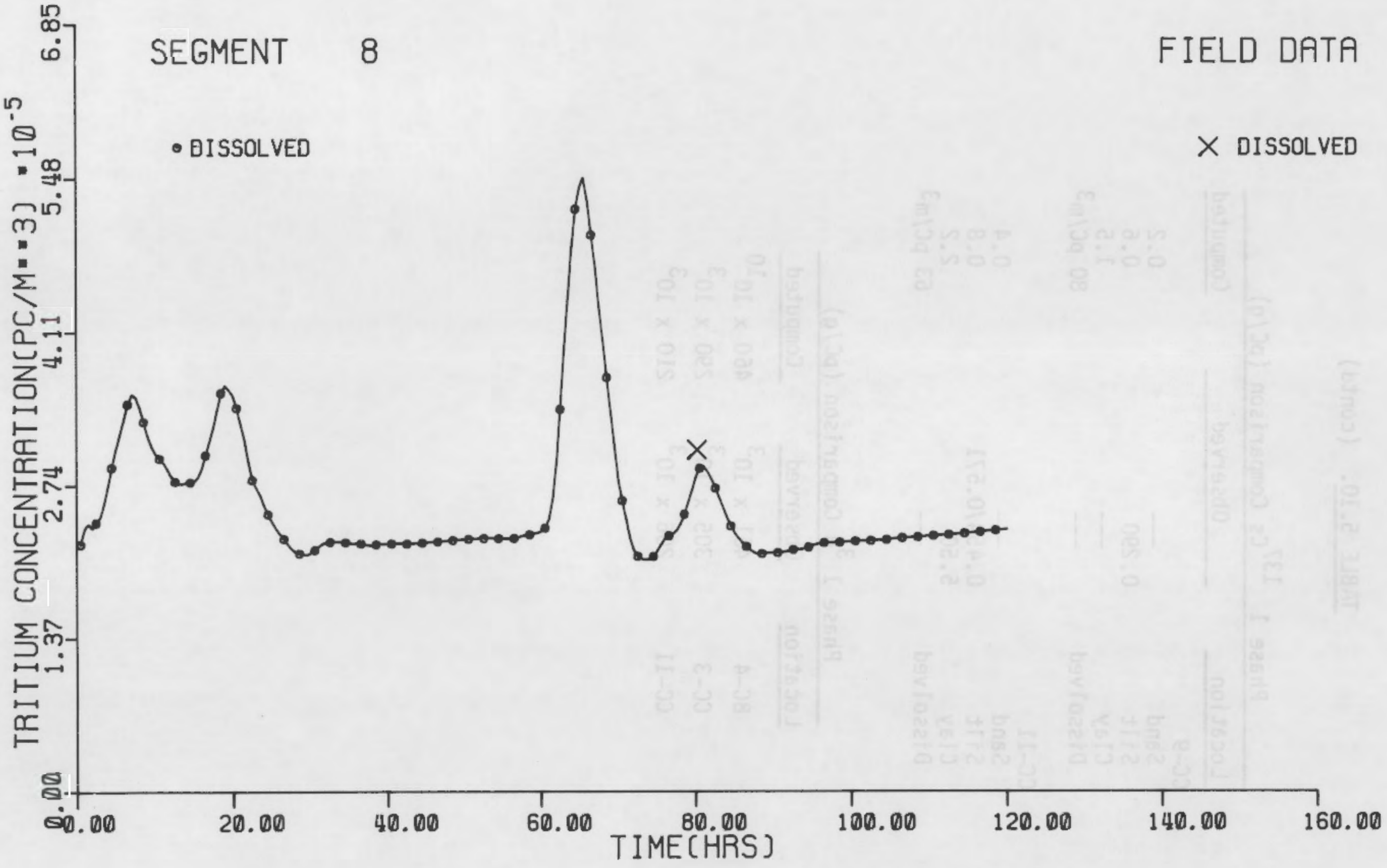

FIGURE 5.62 Phase 1 Dissolved Radionuclide Concentration: ^{3}H at CC-3

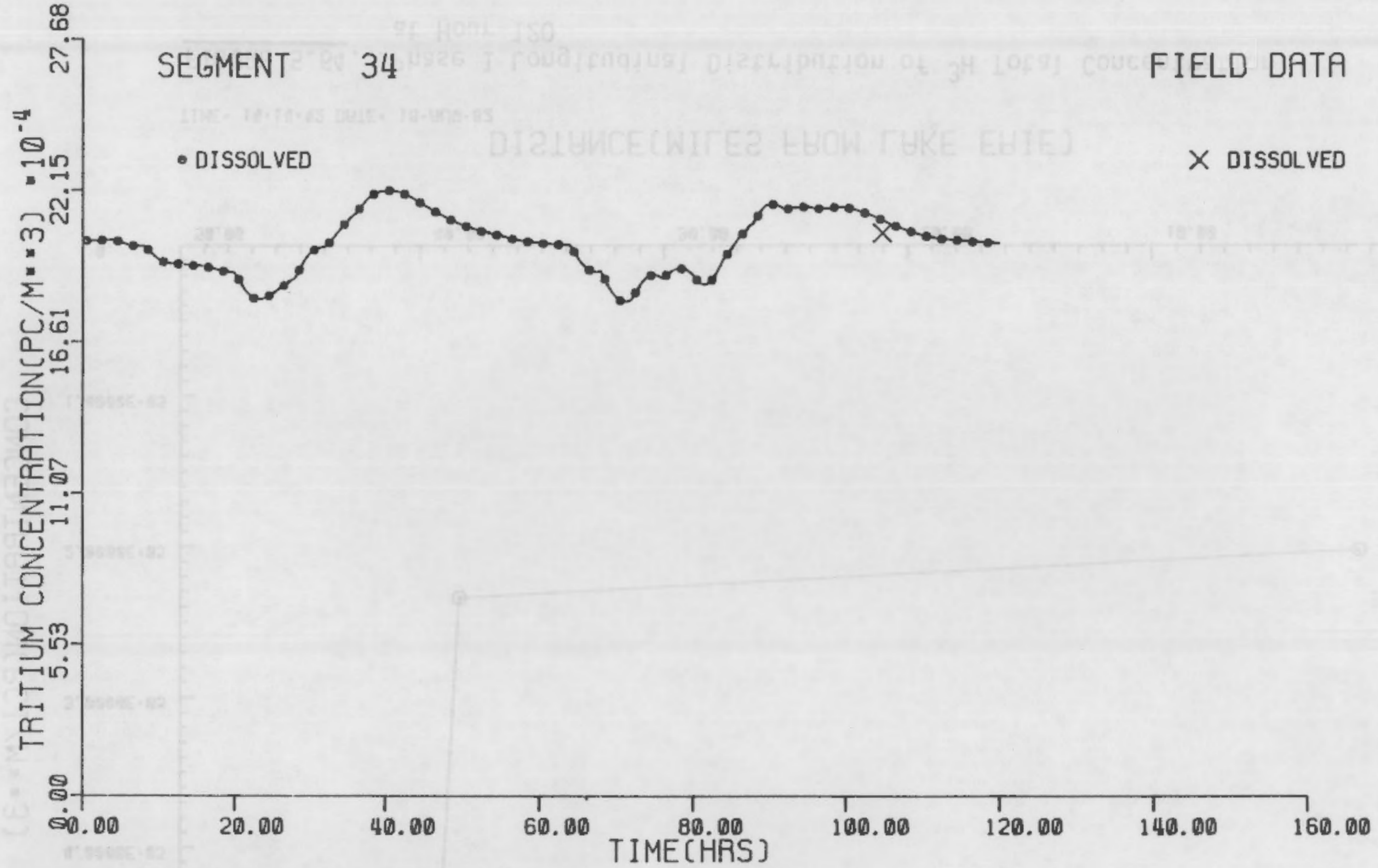

FIGURE 5.63. Phase 1 Dissolved Radionuclide Concentration: ^{3}H at CC-11

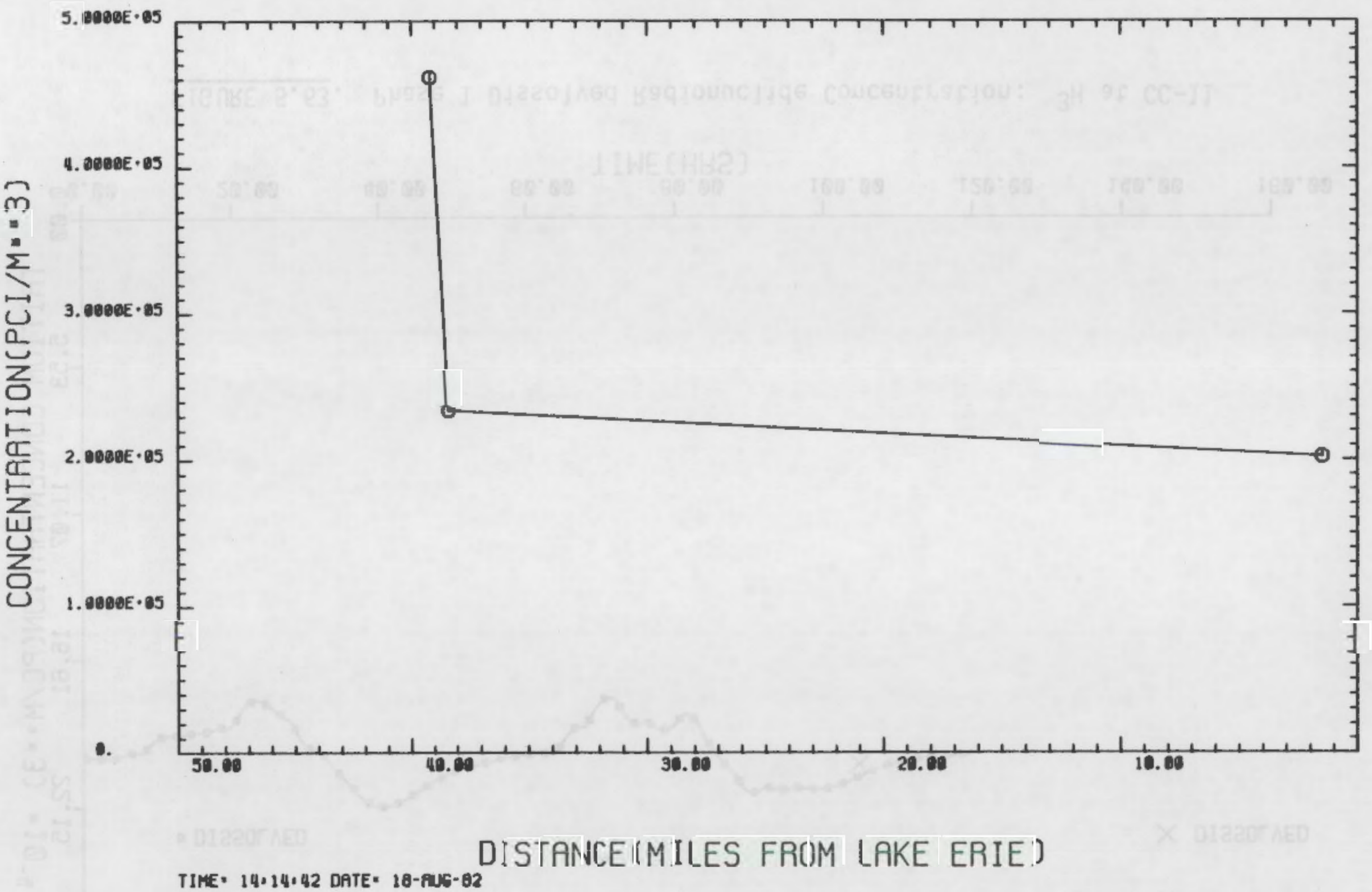

FIGURE 5.64. Phase 1 Longitudinal Distribution of ^3H Total Concentration at Hour 120

6.0 HYPOTHETICAL TEST CASES

After SERATRA was tested in the Cattaraugus Creek system as discussed in Chapter 5, SERATRA was then applied to the same site for two hypothetical cases. These cases of instantaneous radionuclide releases were conducted to illustrate how SERATRA can be used as a site assessment tool.

Case 1. Instantaneous Release of X Dissolved Radionuclide

An instantaneous release of X (highly sorptive but short-lived) radionuclide to Buttermilk Creek at the confluence of Franks Creek was simulated as an example. The assumed conditions for this case are shown in Table 6.1.

TABLE 6.1. Assumed Conditions for Case 1

Half Life = 6 hrs
Release Amount = 333 pCi
K_d for Sand = 2000 ml/g
K_d for Silt = 10000 ml/g
K_d for Clay = 20000 ml/g

Computed results at BC-2 and the mouth of Buttermilk (BC-4) Creek for this case are presented in Figures 6.1 through 6.4. The instantaneous release dispersed longitudinally to form a bell-shaped wave with a 10-hour duration. The three particulate radionuclide waves are each slightly out of phase, with the smaller diameter particles arriving before the heavier sediment. Clay is the most efficient in concentrating radionuclide on particle surfaces while the sand particles are the least efficient.

Case 2. Instantaneous Release of Y Dissolved Radionuclide

The second hypothetical case was instantaneous release of Y (less sorptive but long lived) dissolved radionuclide at FC-1. The conditions used for this case are shown in Table 6.2.

At BC-2 and BC-4 in Buttermilk Creek, predicted results are shown in Figures 6.5 through 6.8. Comparison of Cases 1 and 2 reveals that sorbed Y radionuclide concentrations are 100 times higher than those of Case 1 and that the total Y radionuclides (sum of dissolved and sorbed radionuclide concentrations) after 10 hr are approximately twice as much as those of Case 1. These are reflections of half-lives and distribution coefficients selected for Cases 1 and 2. These two hypothetical cases demonstrate the usefulness of SERATRA as a site assessment tool.

TABLE 6.2. Assumed Conditions for ^{129}I (Case 2)

Half Life 1.7 x 10^7 years

Release Amounts = 333 pCi

K_d for Sand = 20 ml/g

K_d for Silt = 100 ml/g

K_d for Clay = 200 ml/g

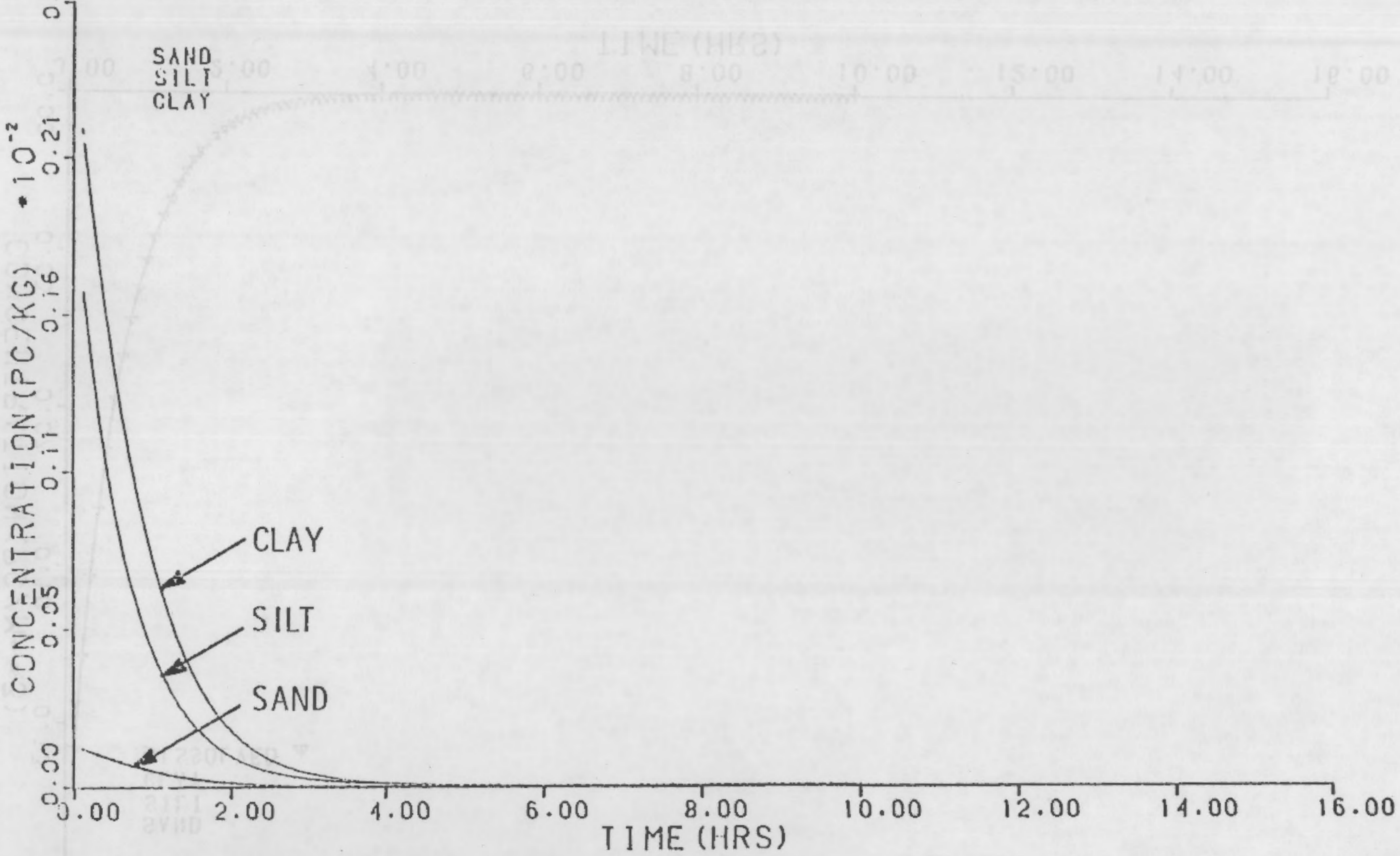

FIGURE 6.1. Computed Sorbed X Radionuclide Concentrations at Buttermilk Creek RM 2.26 for Case 1

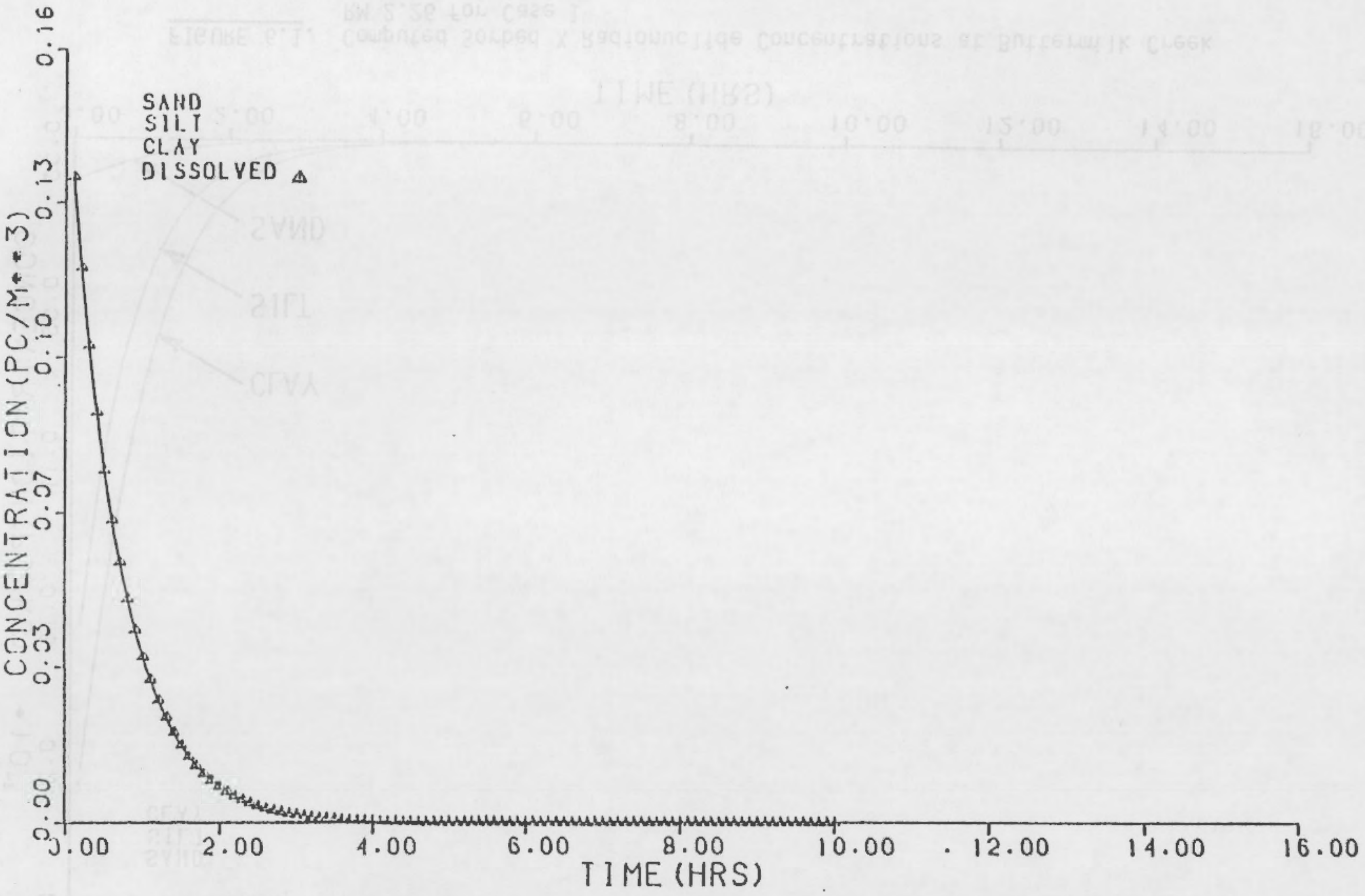

FIGURE 6.2. Computed Sorbed and Dissolved X Radionuclide Concentrations at Buttermilk Creek RM 2.26 for Case 1

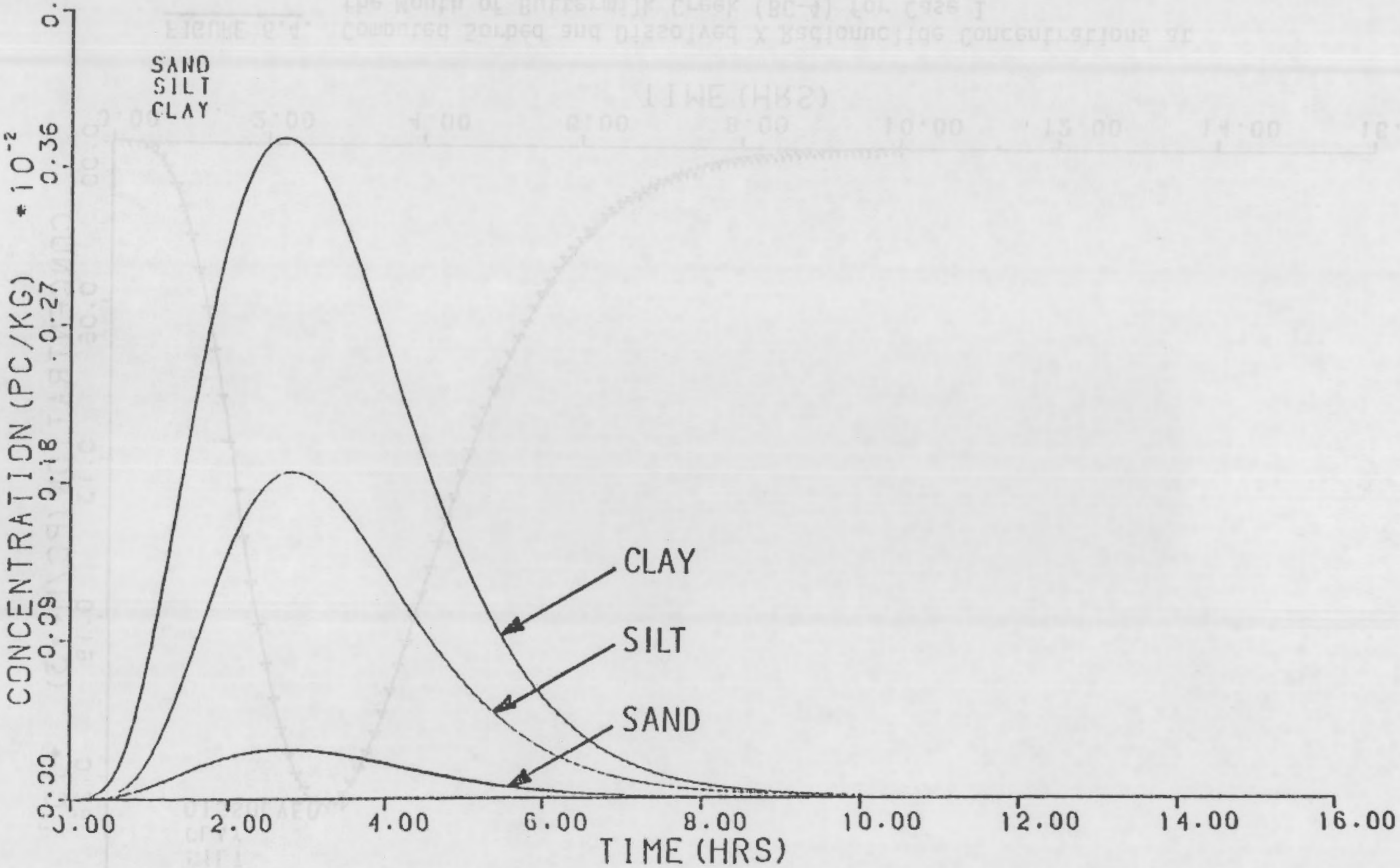

FIGURE 6.3. Computed Sorbed X Radionuclide Concentrations at the Mouth of Buttermilk Creek (BC-4) for Case 1

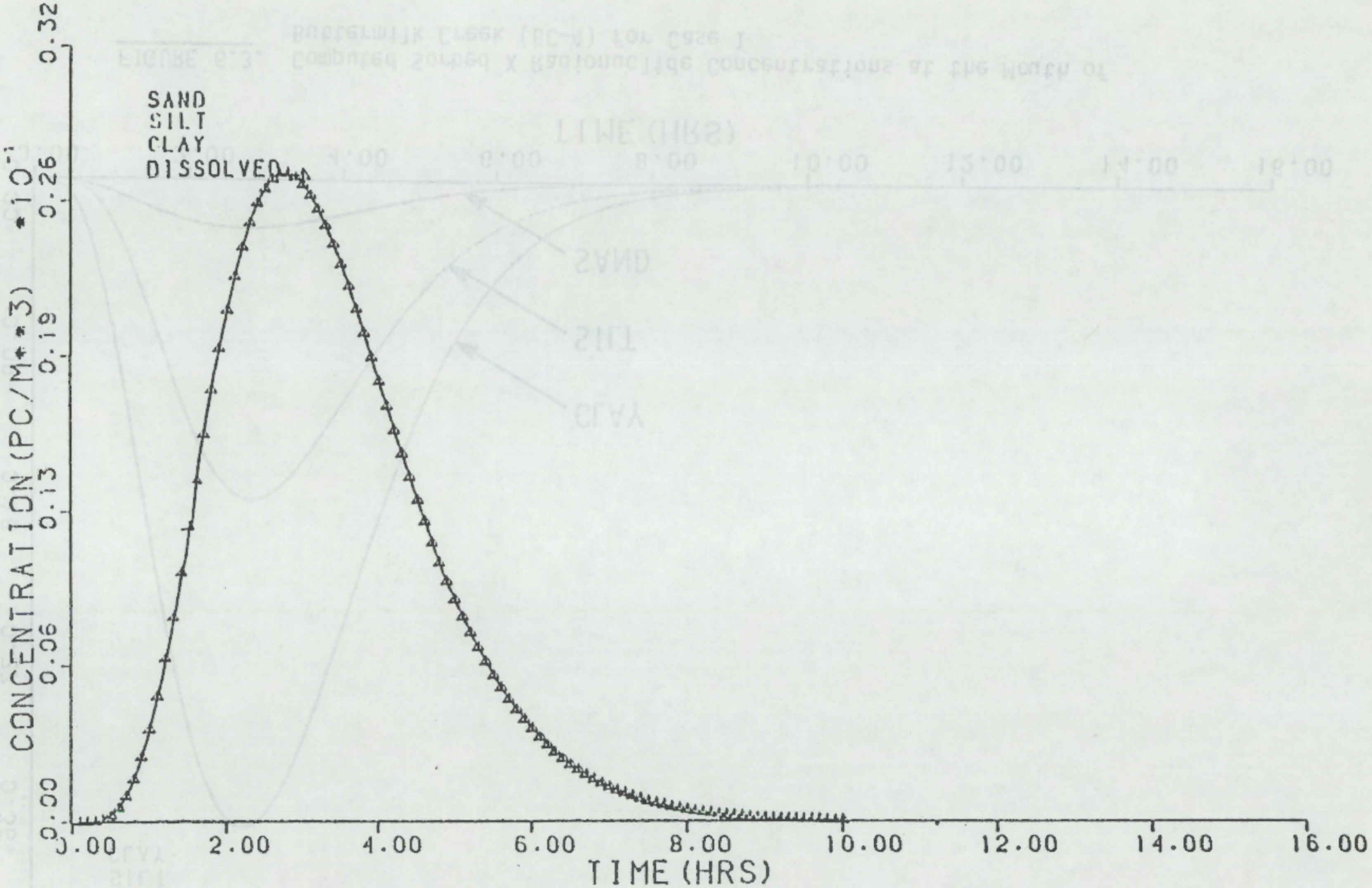

FIGURE 6.4. Computed Sorbed and Dissolved X Radionuclide Concentrations at the Mouth of Buttermilk Creek (BC-4) for Case 1

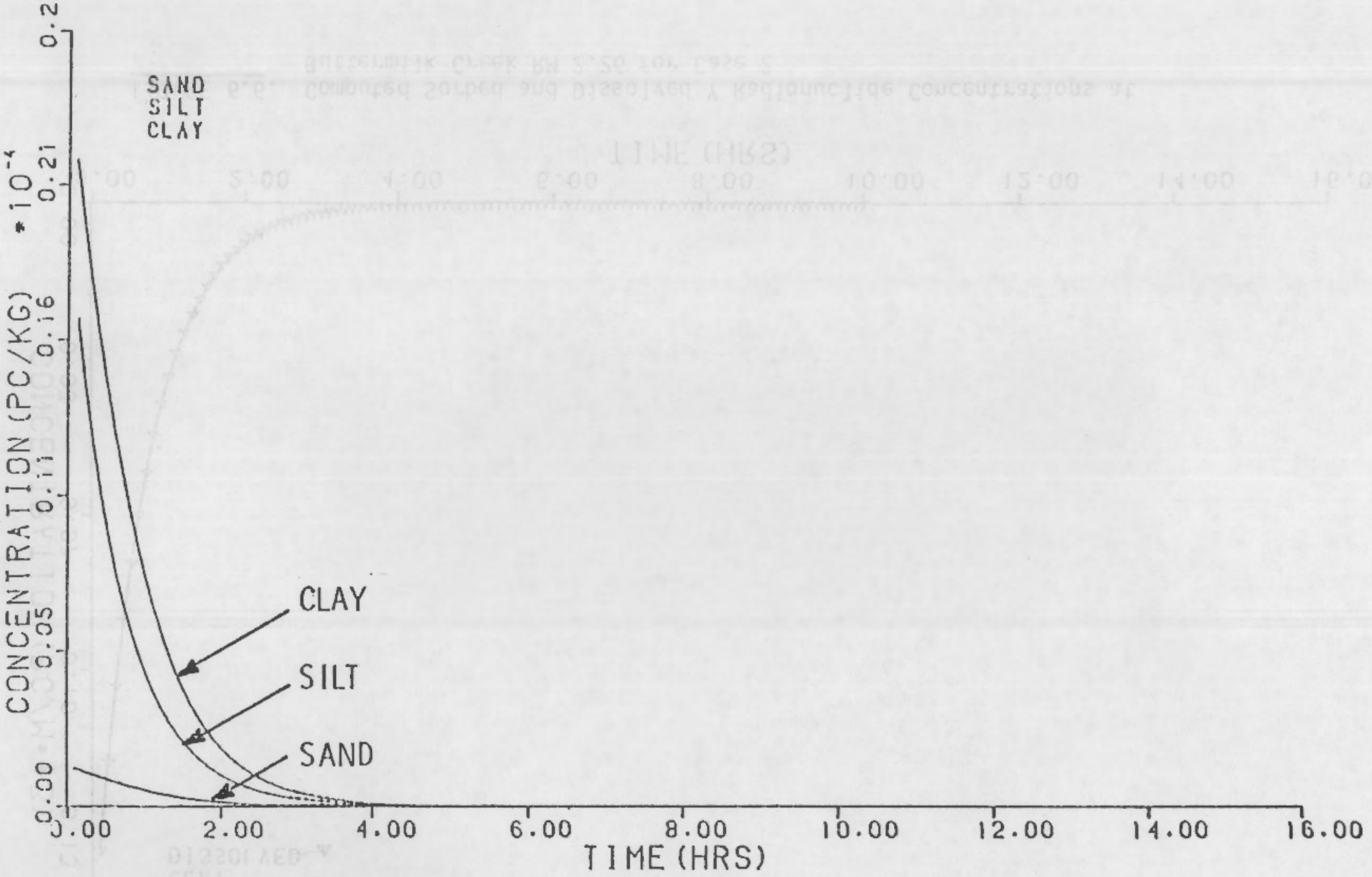

FIGURE 6.5. Computed Sorbed Y Radionuclide Concentrations at Buttermilk Creek RM 2.26 for Case 2

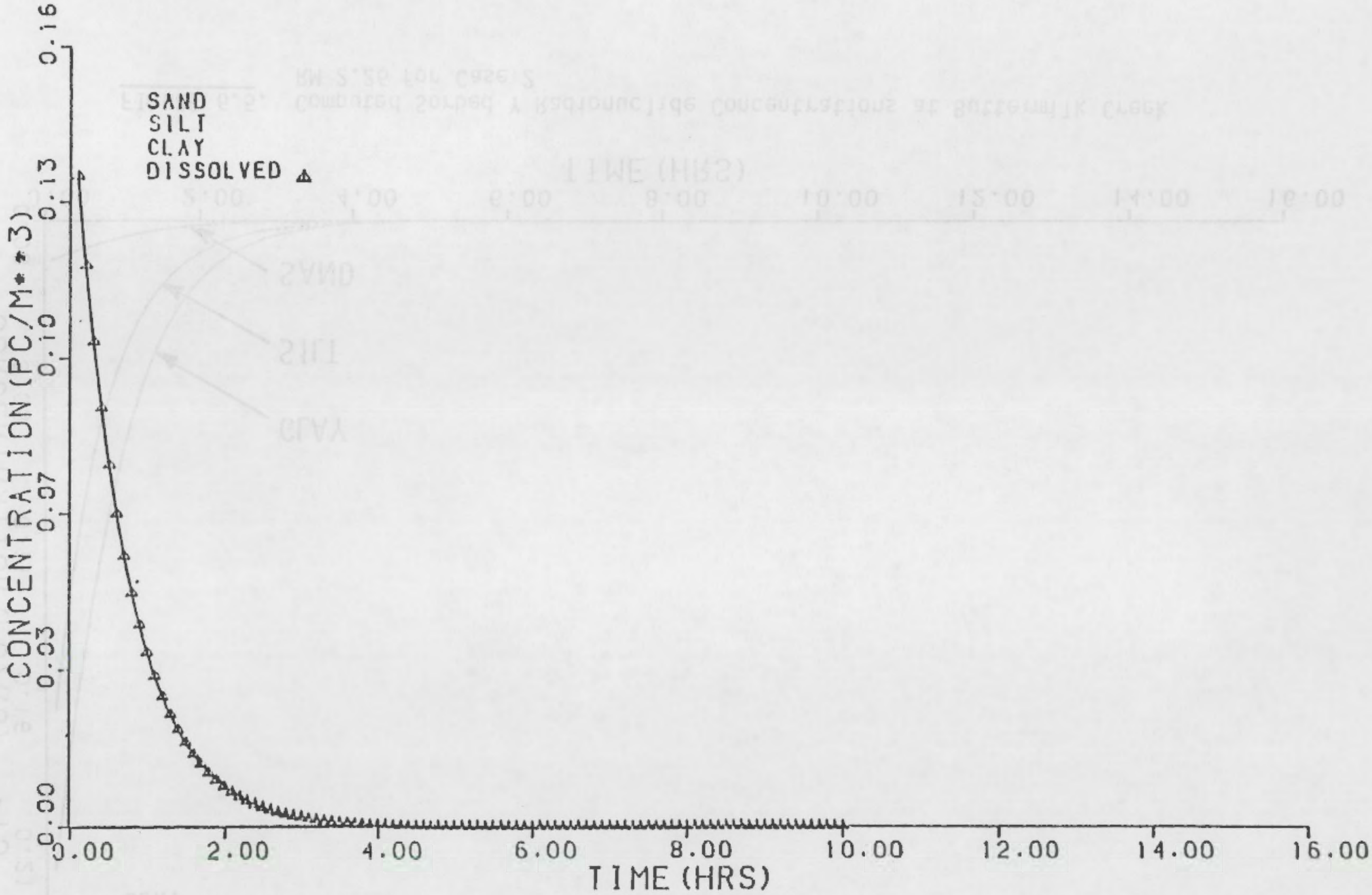

FIGURE 6.6. Computed Sorbed and Dissolved Y Radionuclide Concentrations at Buttermilk Creek RM 2.26 for Case 2

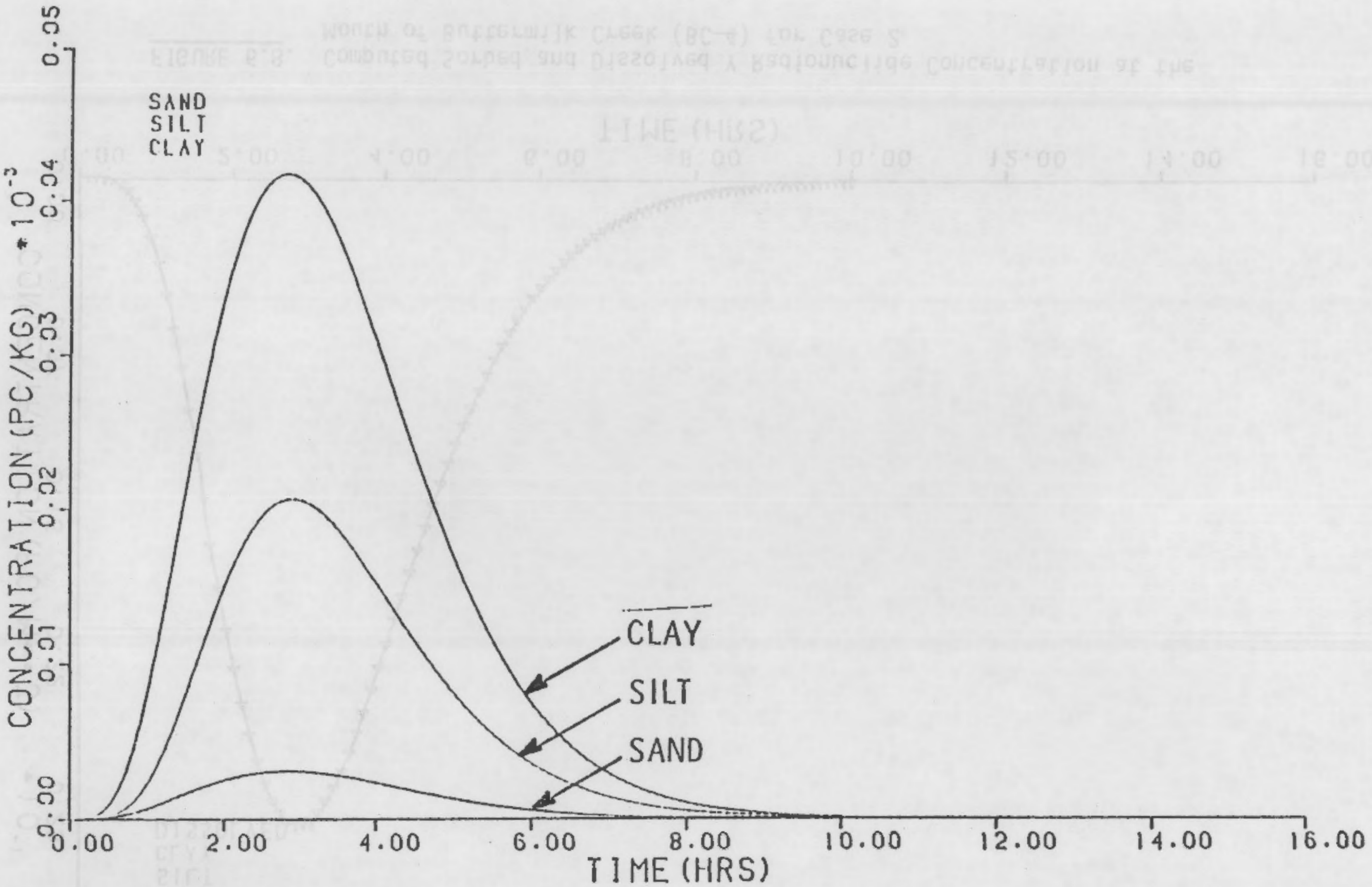

FIGURE 6.7. Computed Sorbed Y Radionuclide Concentrations at the Mouth of Buttermilk Creek (BC-4) for Case 2

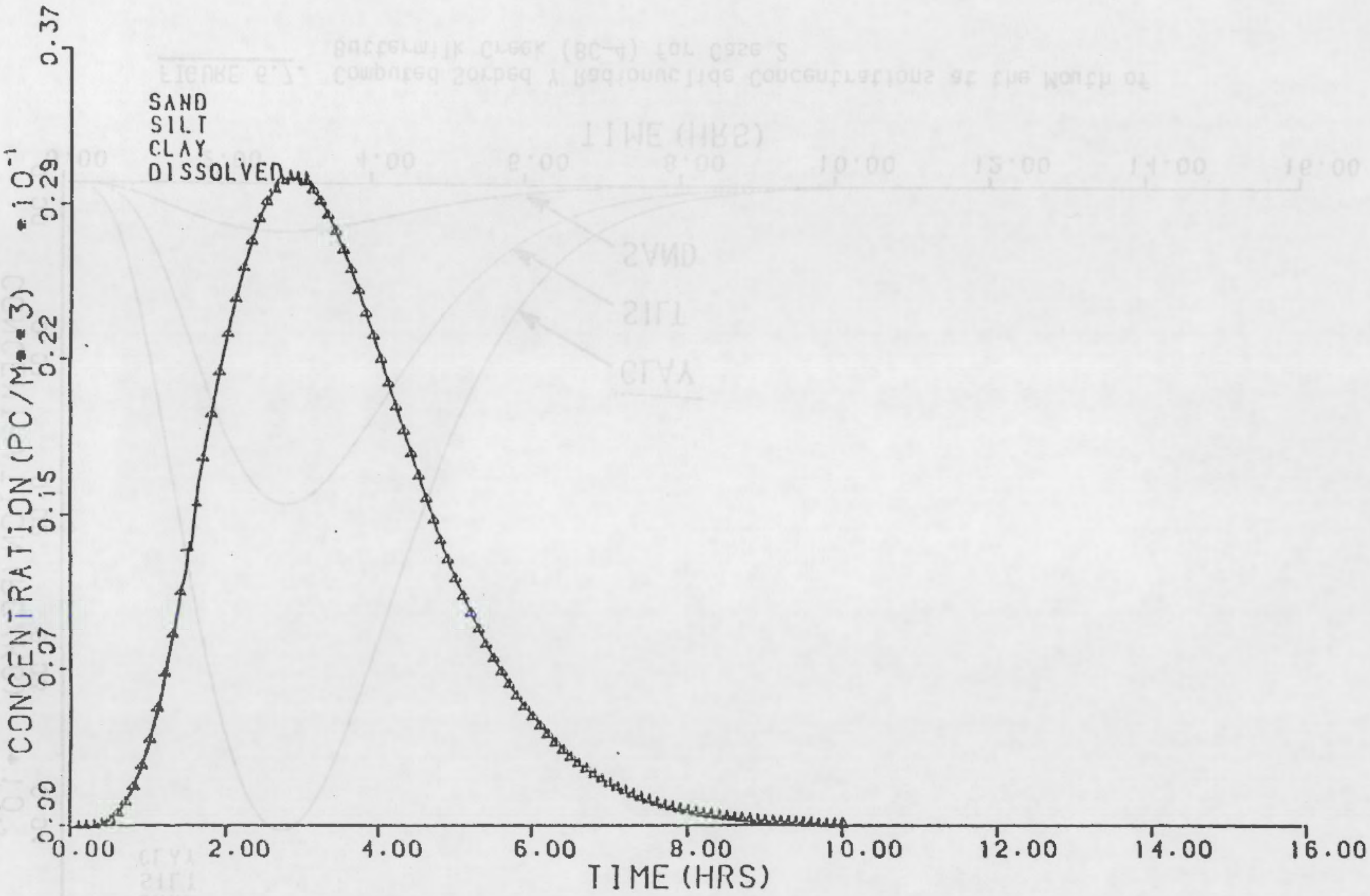

FIGURE 6.8. Computed Sorbed and Dissolved Y Radionuclide Concentration at the Mouth of Buttermilk Creek (BC-4) for Case 2

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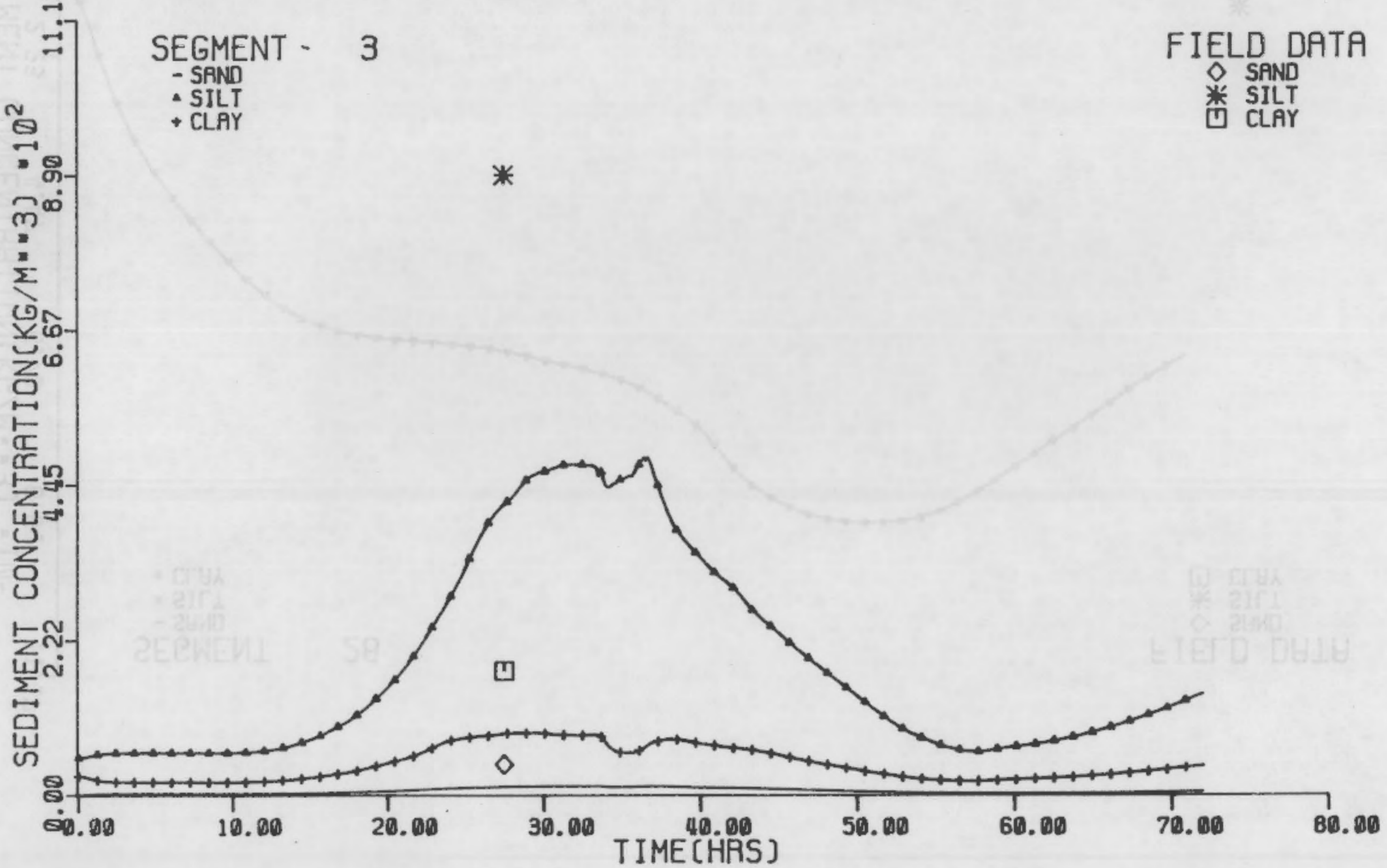
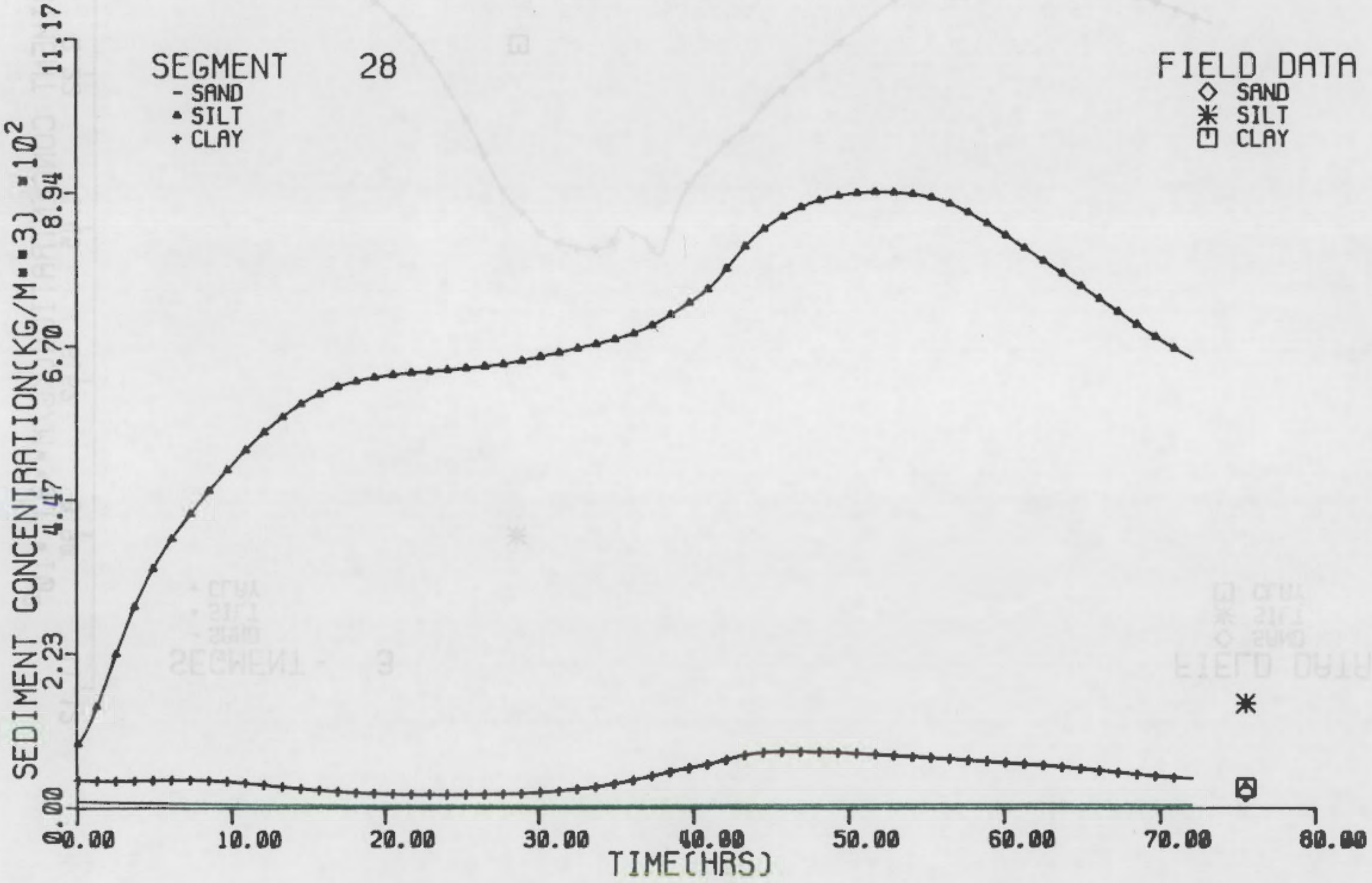
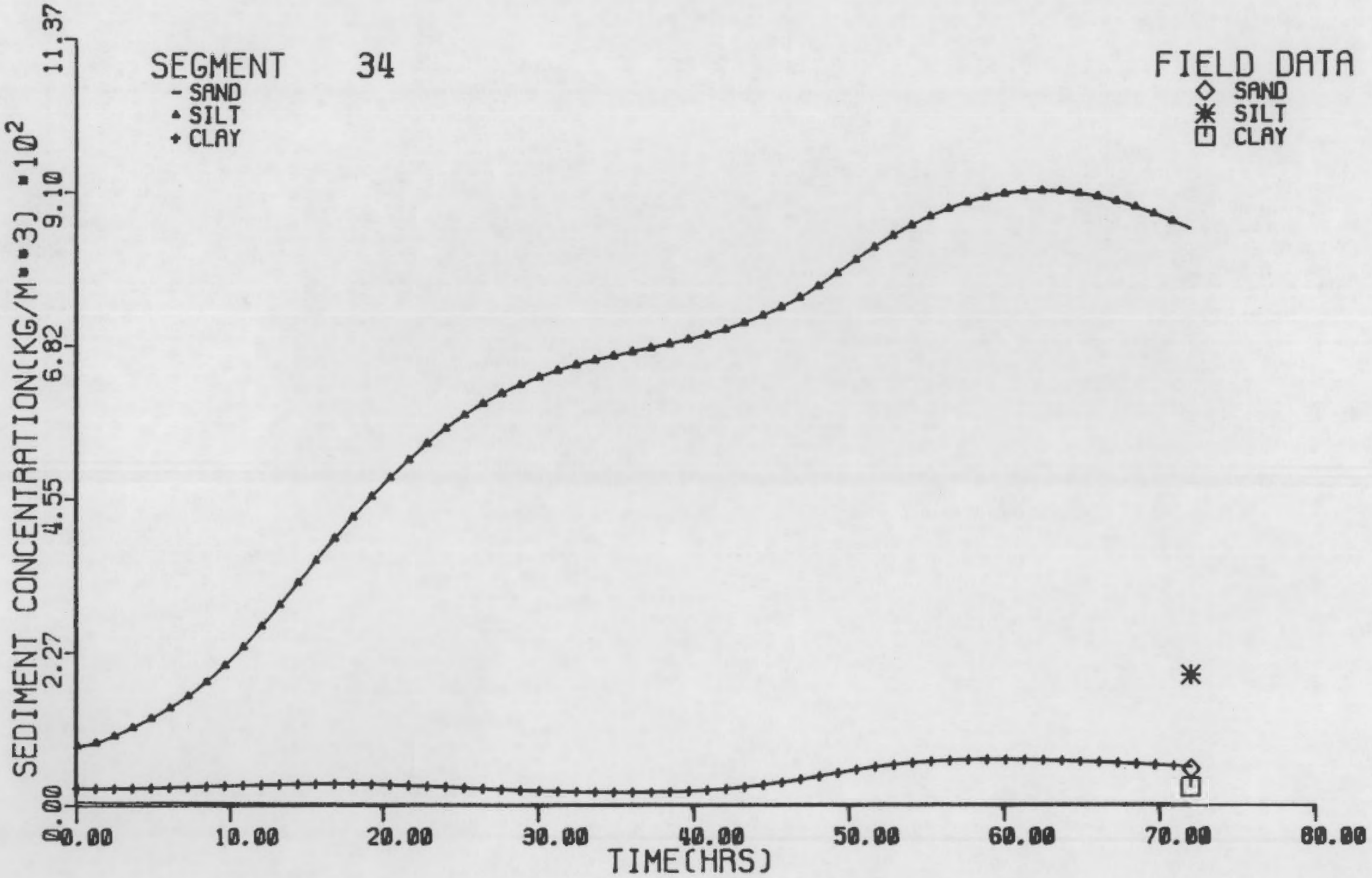
APPENDIX A

COMPARISONS OF COMPUTED AND MEASURED CONCENTRATIONS OF SEDIMENT AND RADIONUCLIDES

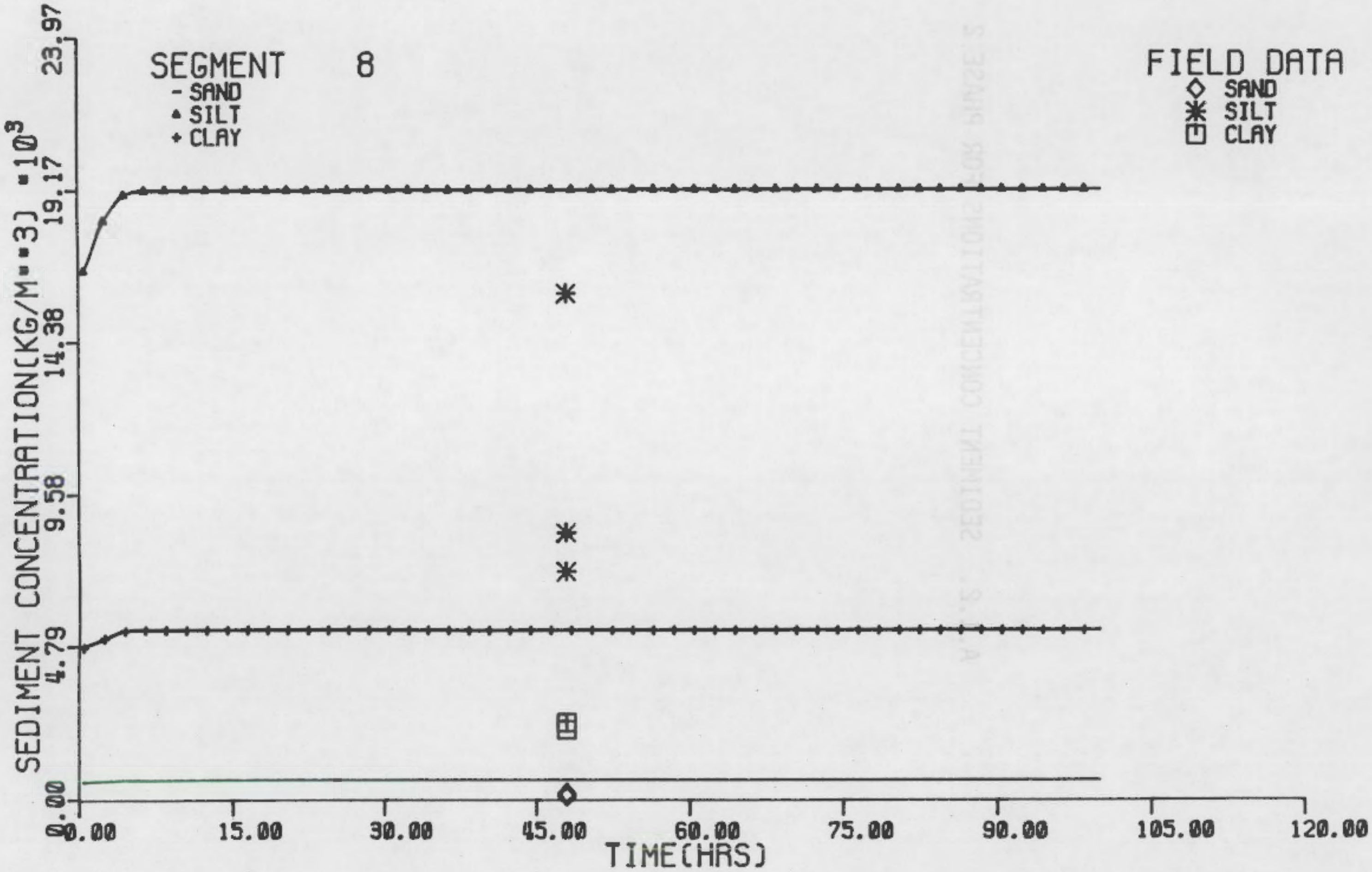
A.1.1. SEDIMENT CONCENTRATIONS FOR PHASE 3

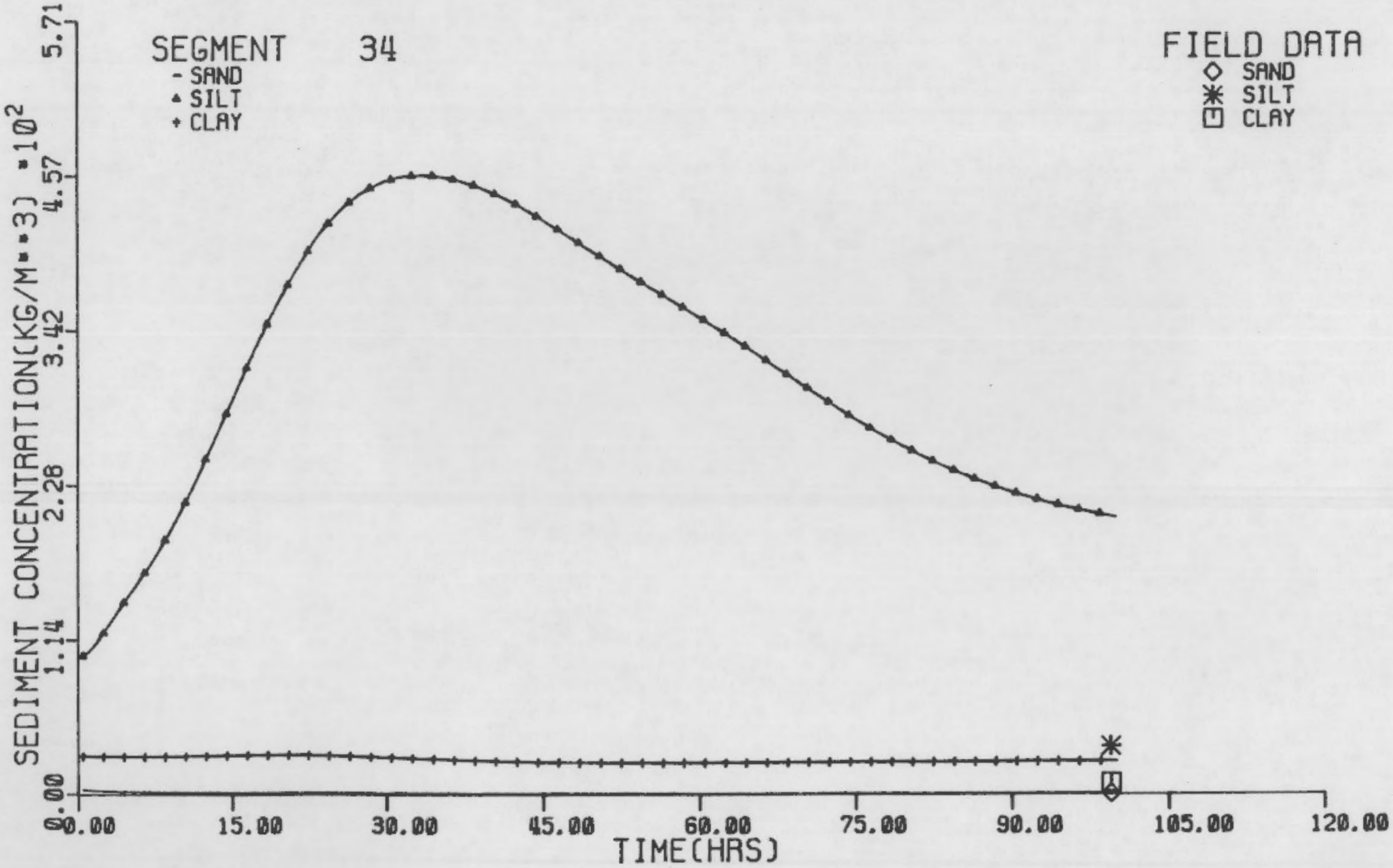

SEGMENT - 3
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
SEDIMENT CONCENTRATION(KG/M**3) *10²
0.00
2.22
4.45
6.67
8.90
11.12
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)


SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
SEDIMENT CONCENTRATION(KG/M**3) *10^2
0.00
2.23
4.47
6.70
8.94
11.17
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

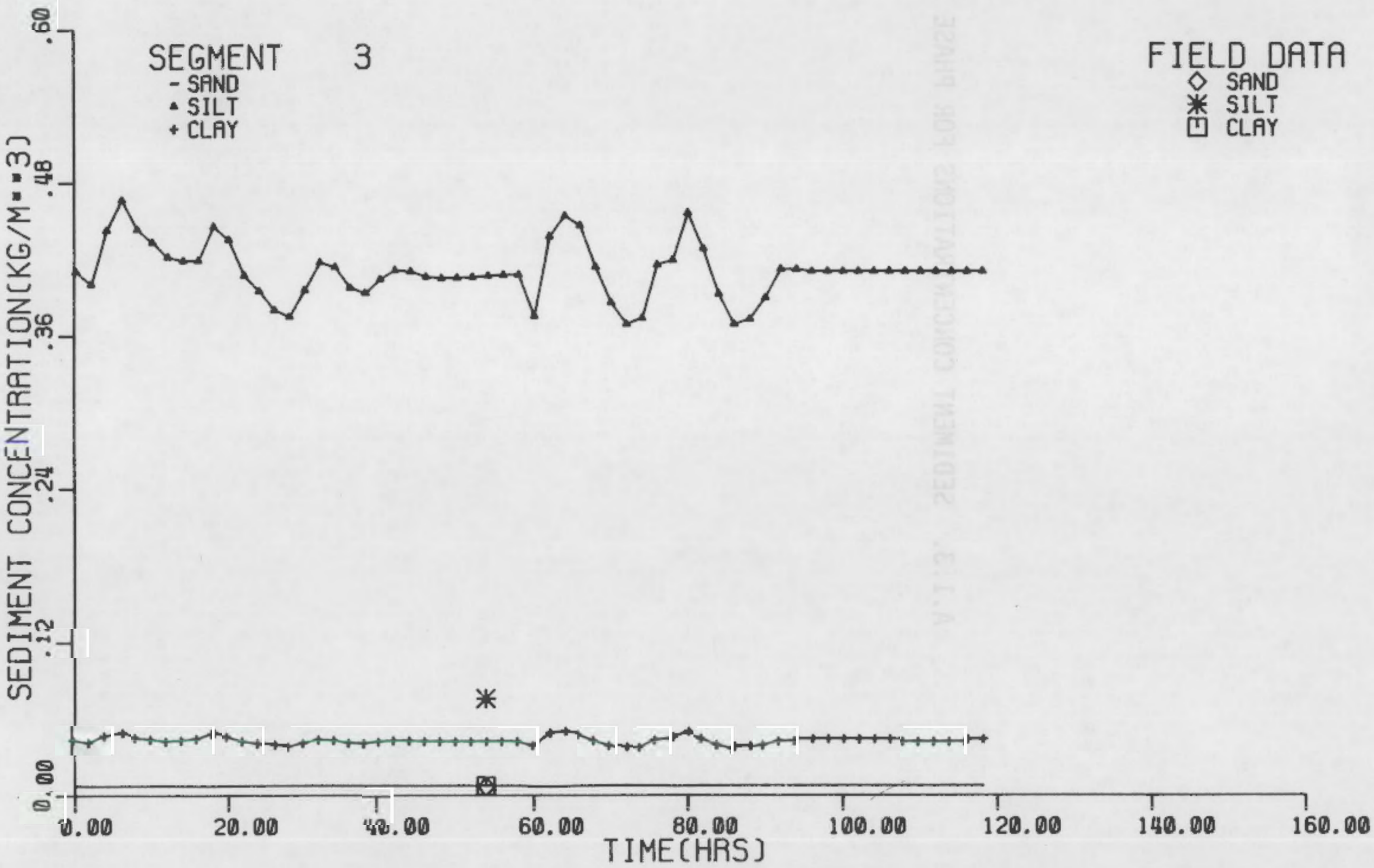

SEGMENT 34
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
□ CLAY
SEDIMENT CONCENTRATION(KG/M**3) *10²
0.00
2.27
4.55
6.82
9.10
11.37
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

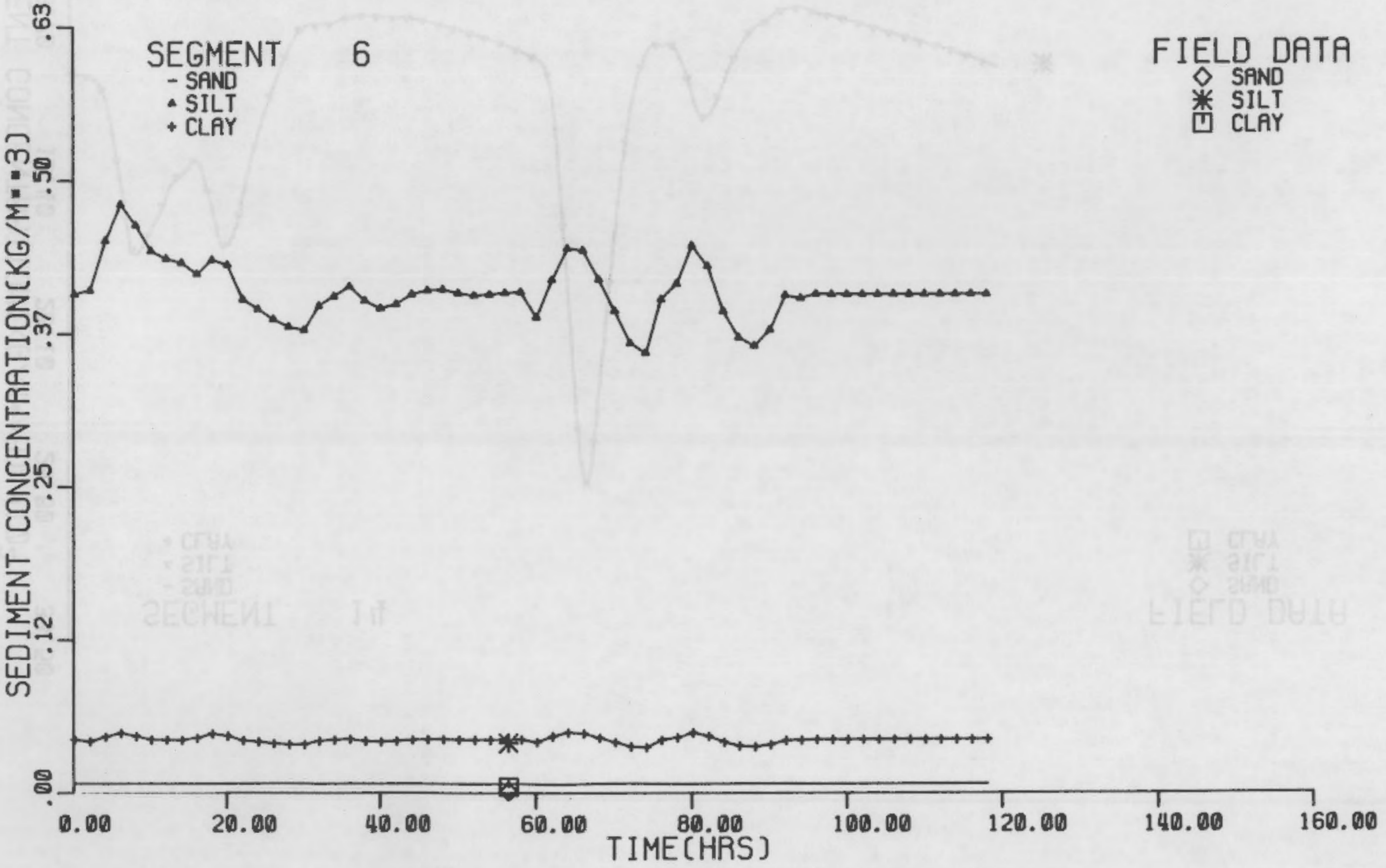
A.1.2. SEDIMENT CONCENTRATIONS FOR PHASE 2

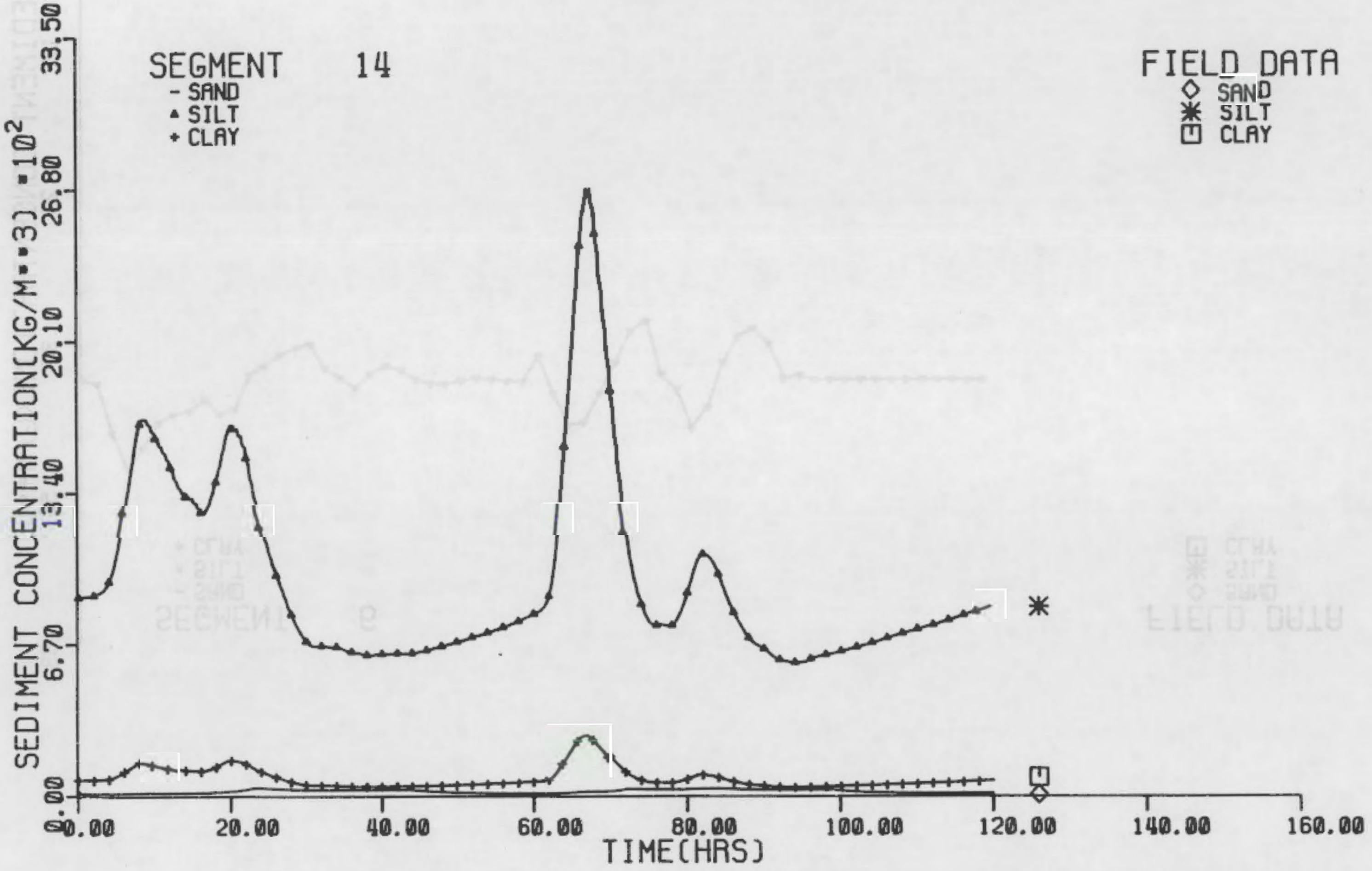

SEGMENT 8
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊞ CLAY
SEDIMENT CONCENTRATION(KG/M**3) *10^3
0.00
4.79
9.58
14.38
19.17
23.97
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

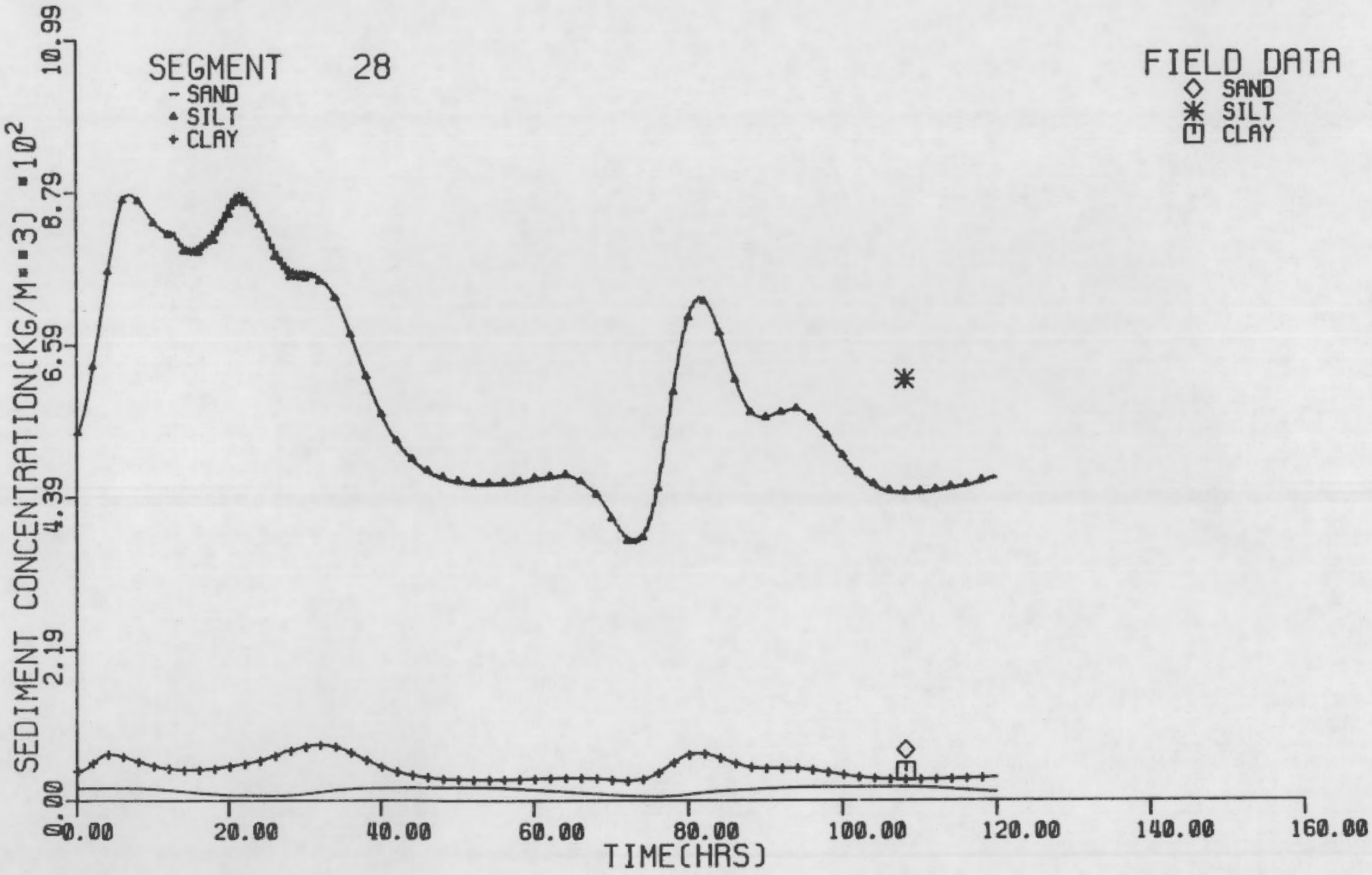

SEGMENT 34
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
SEDIMENT CONCENTRATION(KG/M**3) *10^2
0.00
1.14
2.28
3.42
4.57
5.71
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

A.1.3. SEDIMENT CONCENTRATIONS FOR PHASE 1

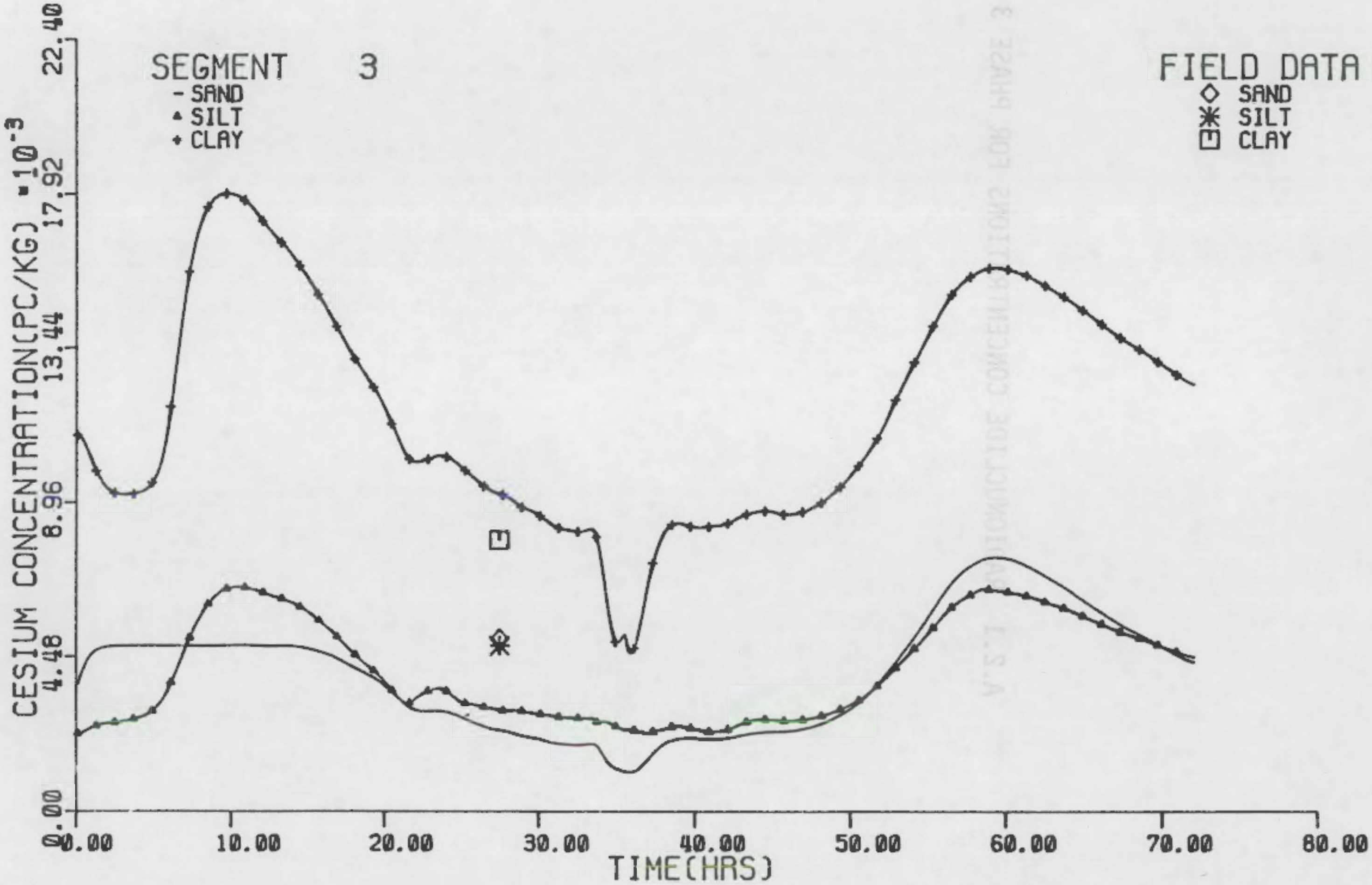

SEGMENT 3
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
SEDIMENT CONCENTRATION(KG/M**3)
0.00
.12
.24
.36
.48
.60
TIME(HRS)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00

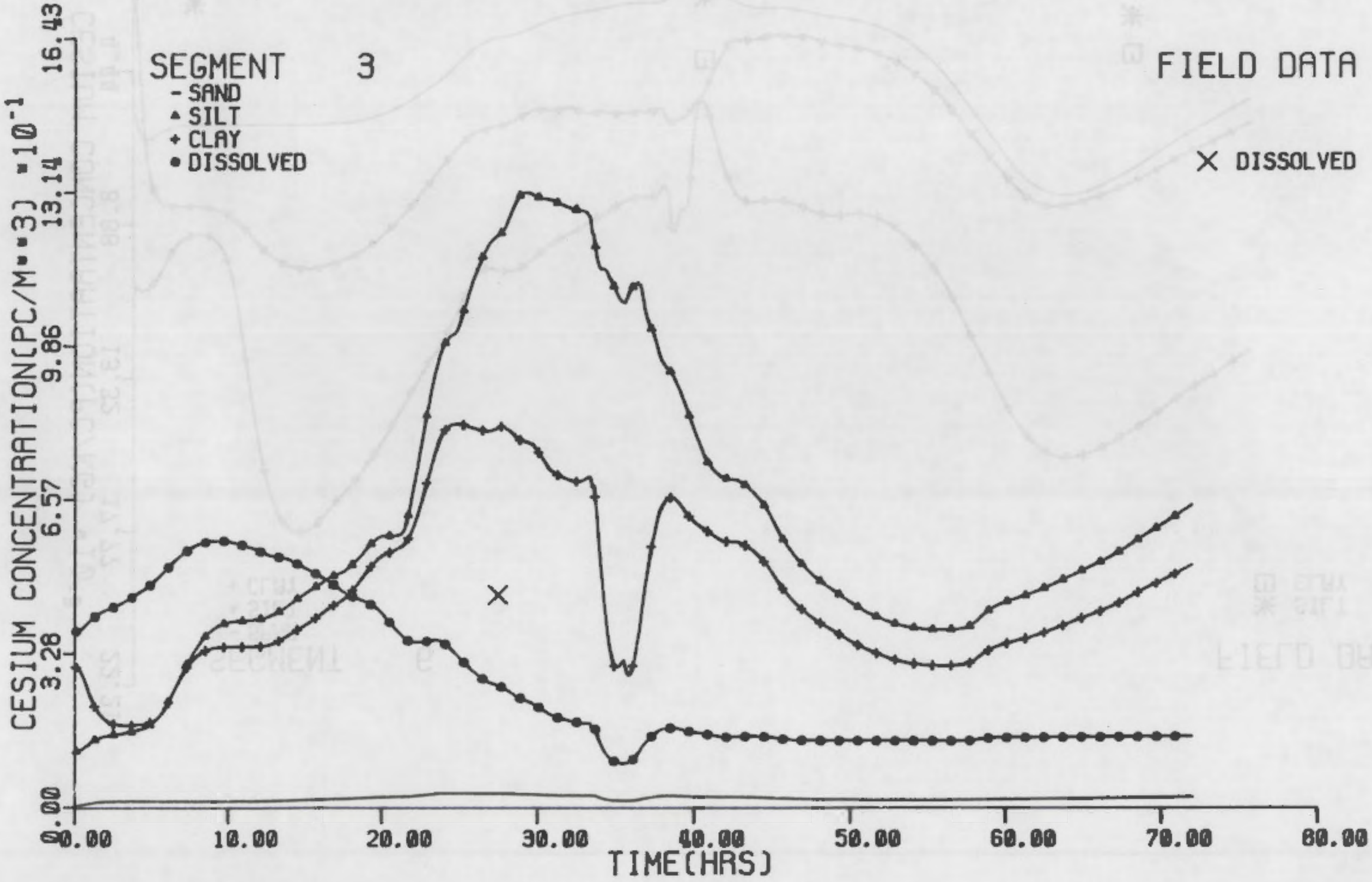

SEGMENT 6
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
SEDIMENT CONCENTRATION(KG/M**3)
.00
.12
.25
.37
.50
.63
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

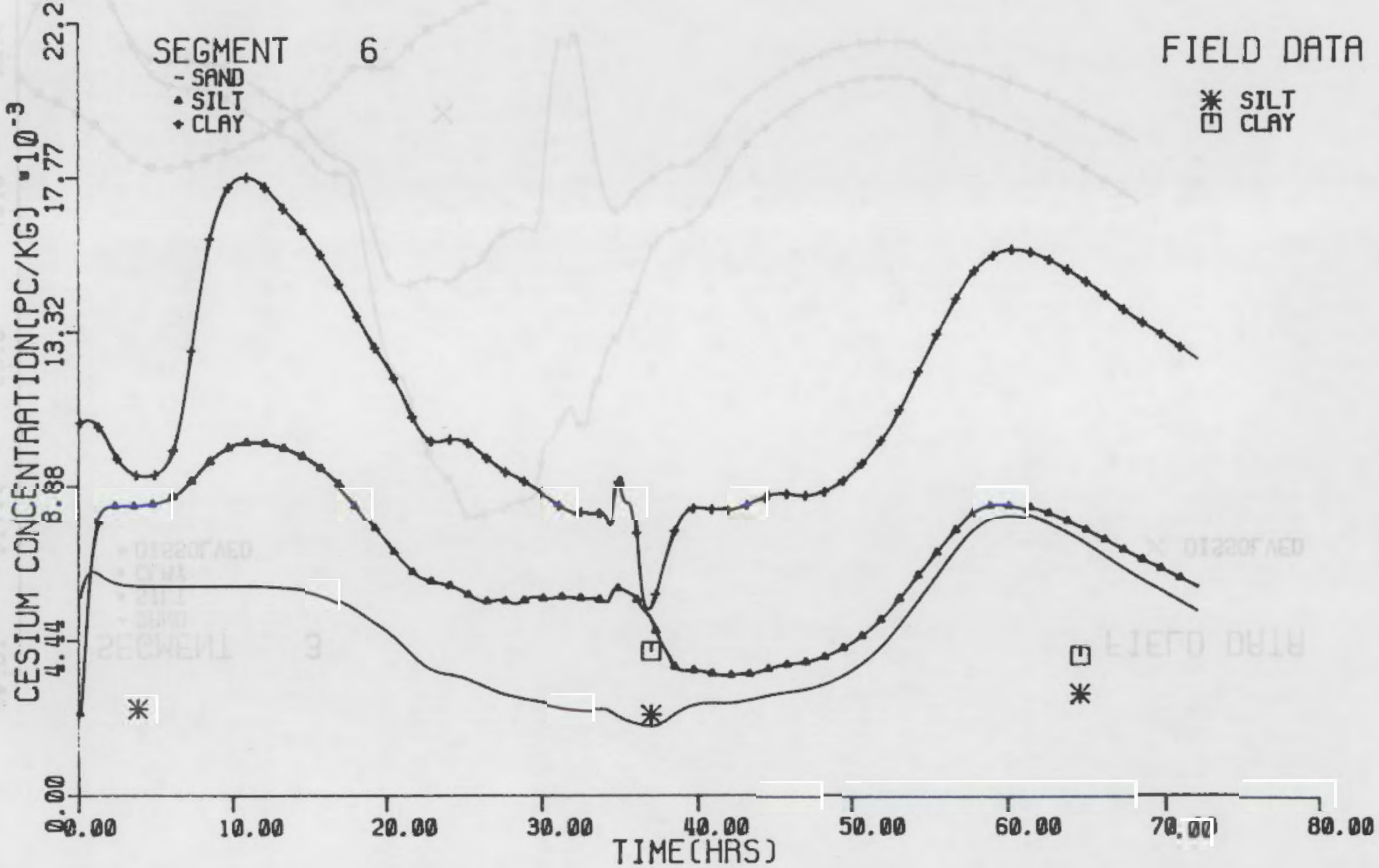

SEGMENT 14
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
SEDIMENT CONCENTRATION(KG/M**3)*10²
0.00
6.70
13.40
20.10
26.80
33.50
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

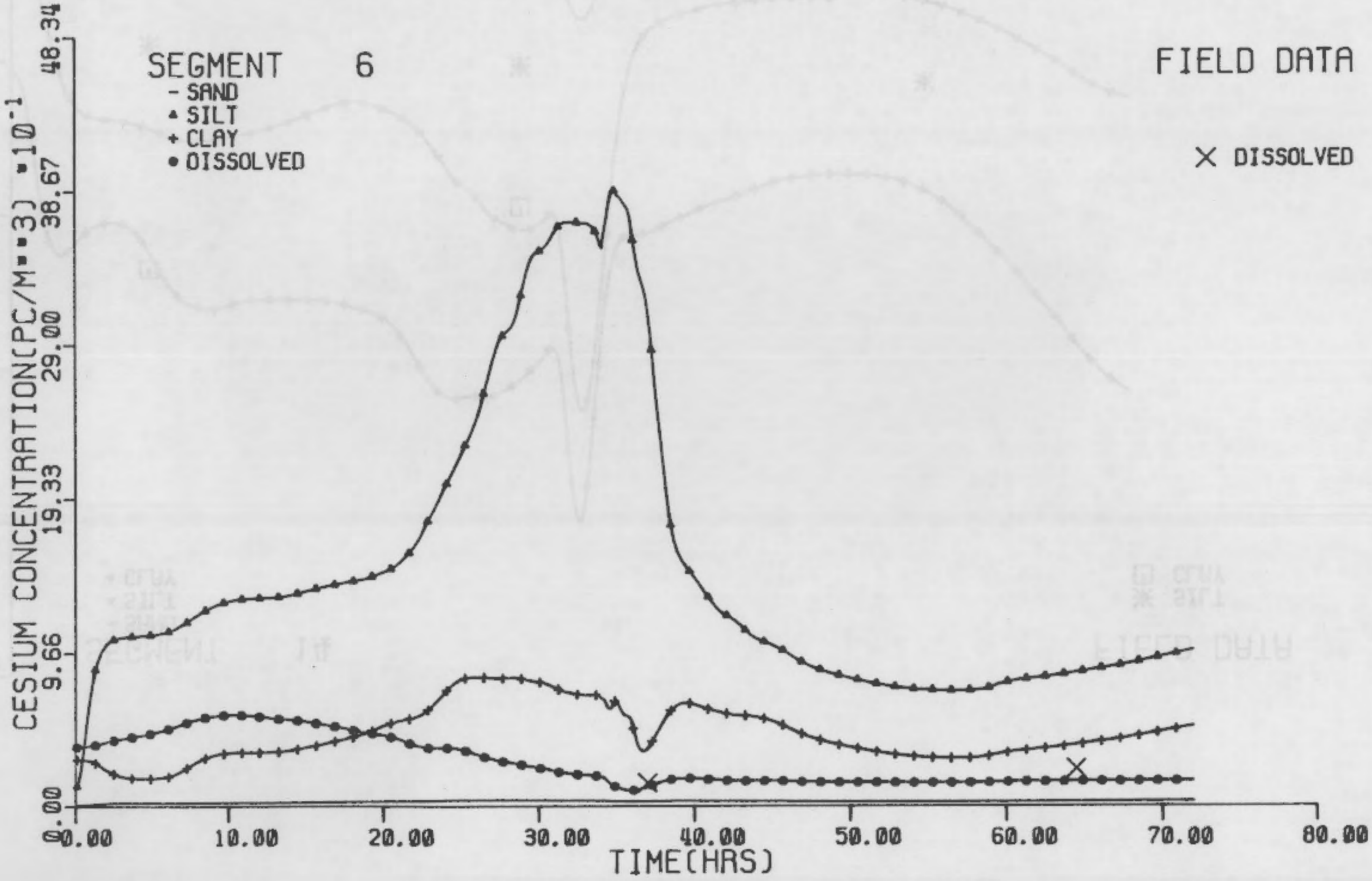

SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
□ CLAY
SEDIMENT CONCENTRATION(KG/M**3) *10²
0.00
2.19
4.39
6.59
8.79
10.99
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

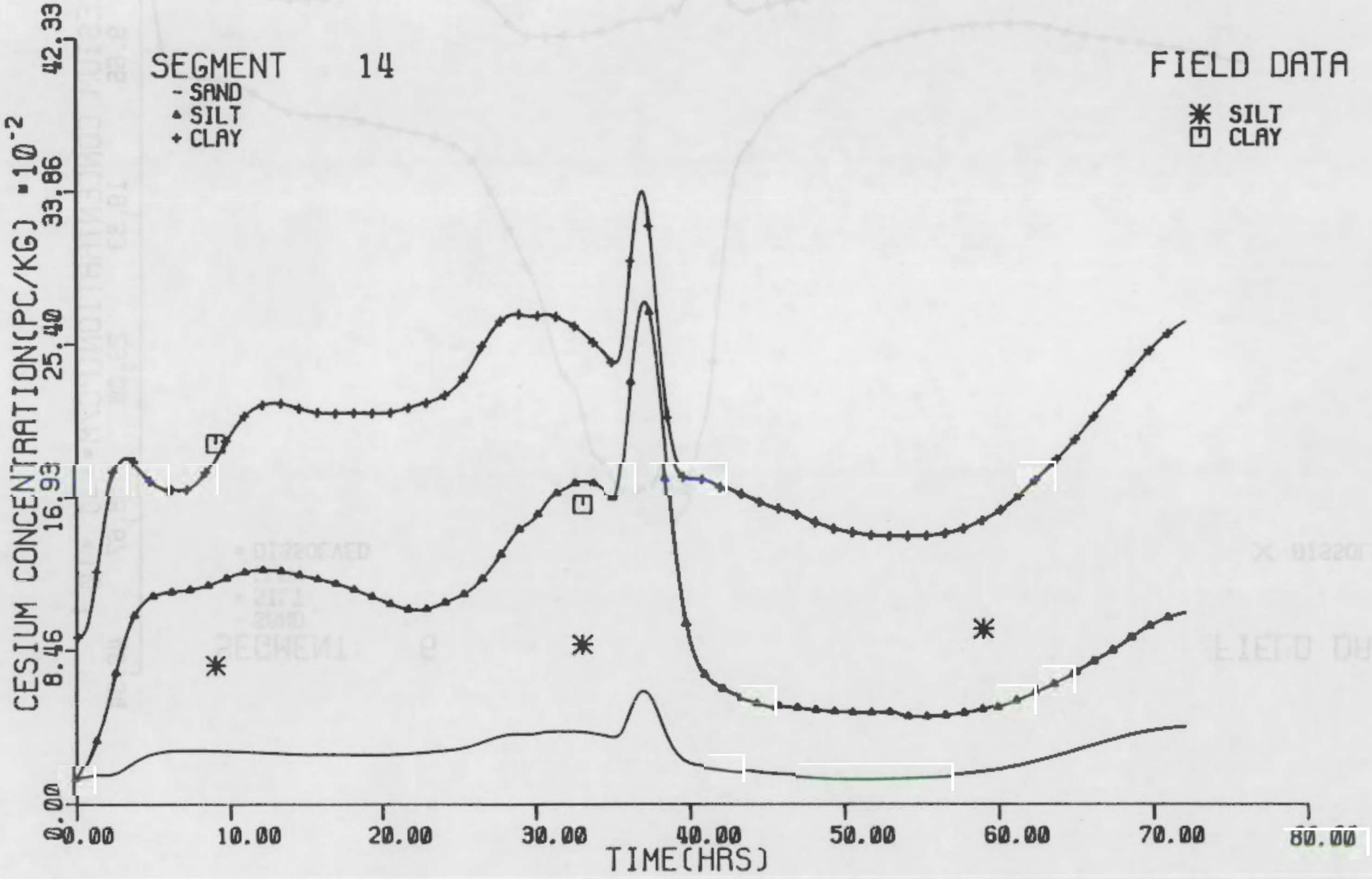
A.2.1 RADIONUCLIDE CONCENTRATIONS FOR PHASE 3

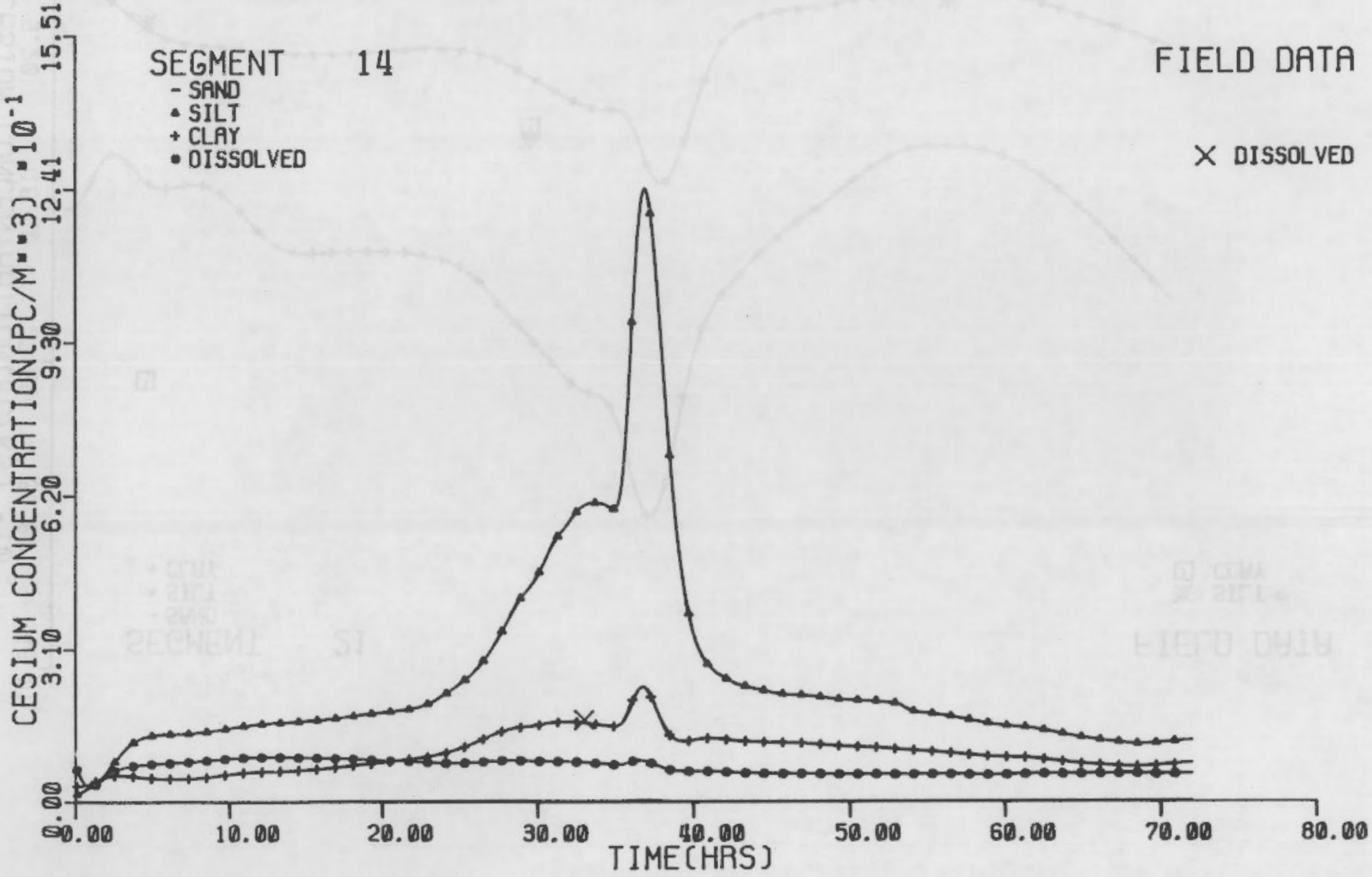

SEGMENT 3
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
☐ CLAY
CESIUM CONCENTRATION(PC/KG) *10⁻³
0.00
4.48
8.96
13.44
17.92
22.40
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

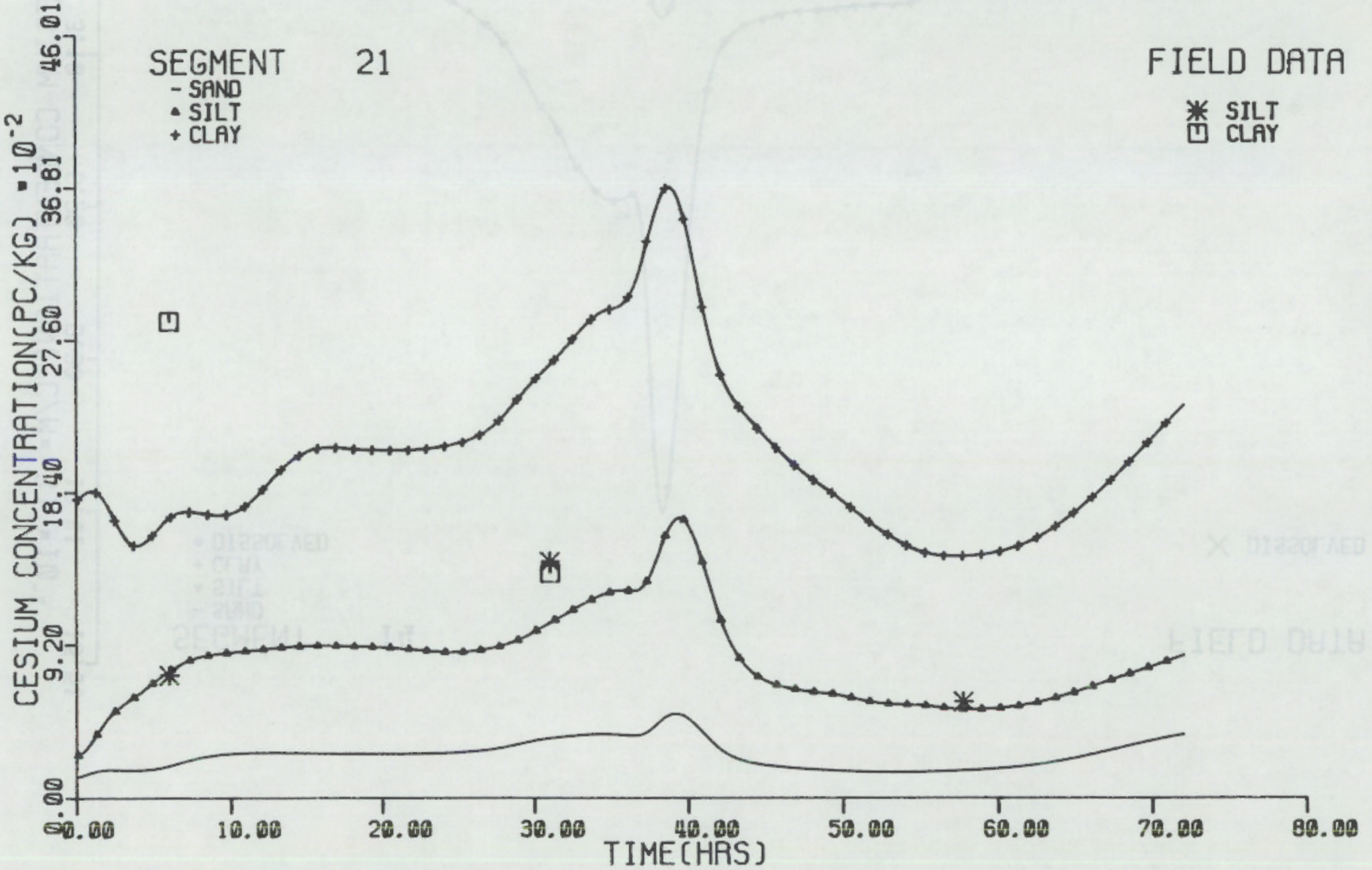

SEGMENT 3
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-1
0.00
3.28
6.57
9.86
13.14
16.43
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

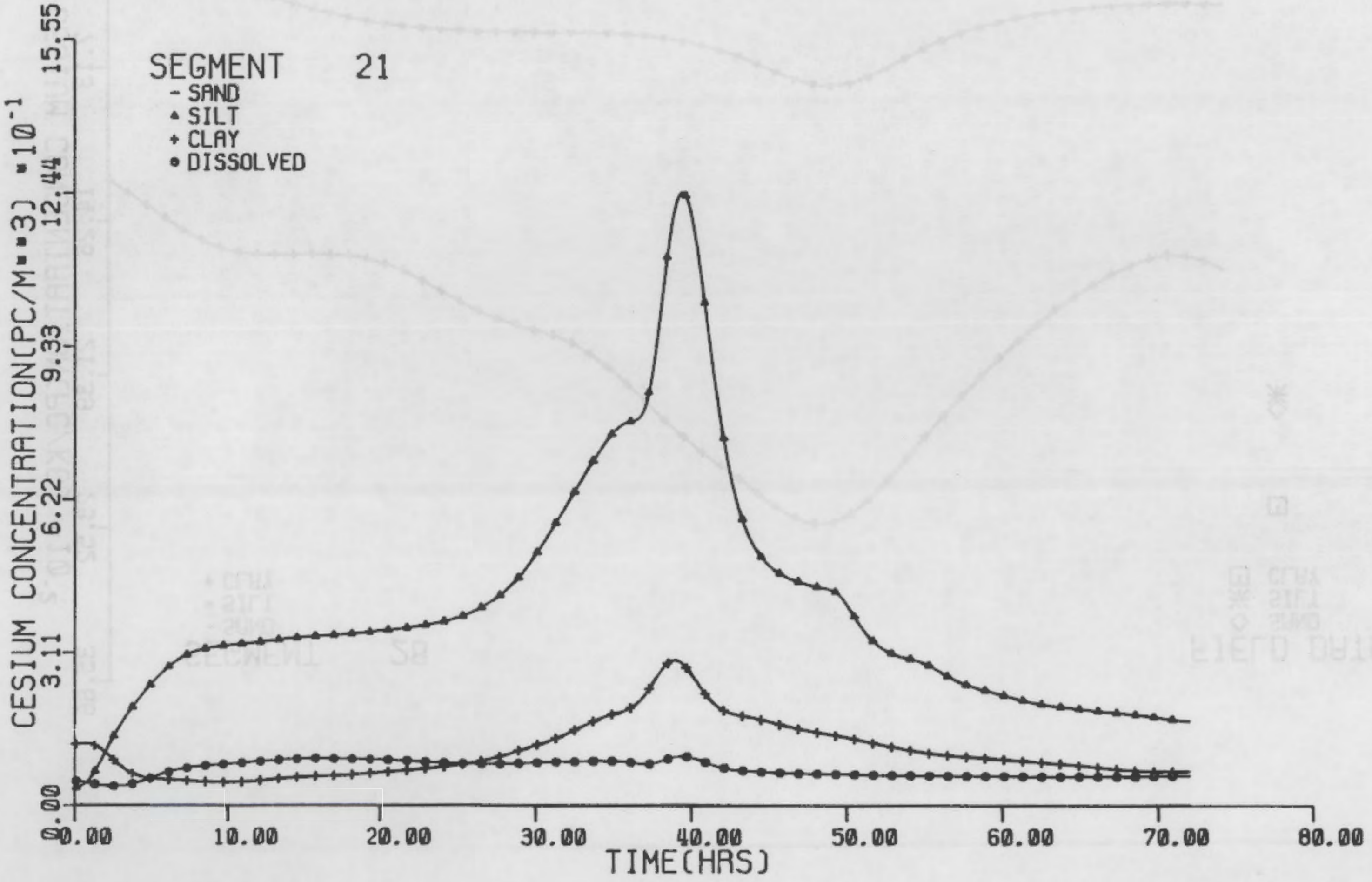

SEGMENT 6
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
4.44
8.88
13.32
17.77
22.21
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

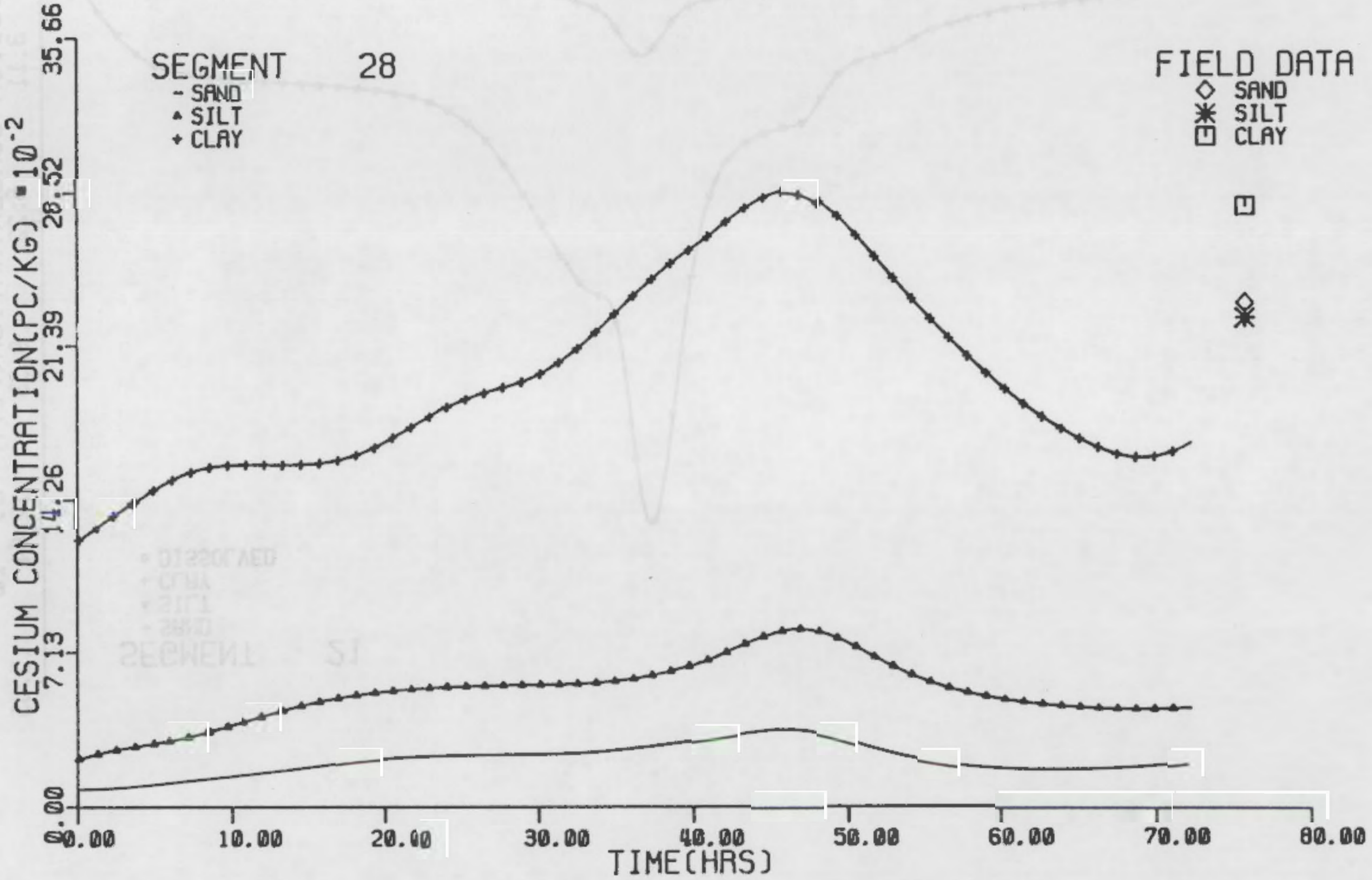

SEGMENT 6
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-1
0.00
9.66
19.33
29.00
38.67
48.34
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

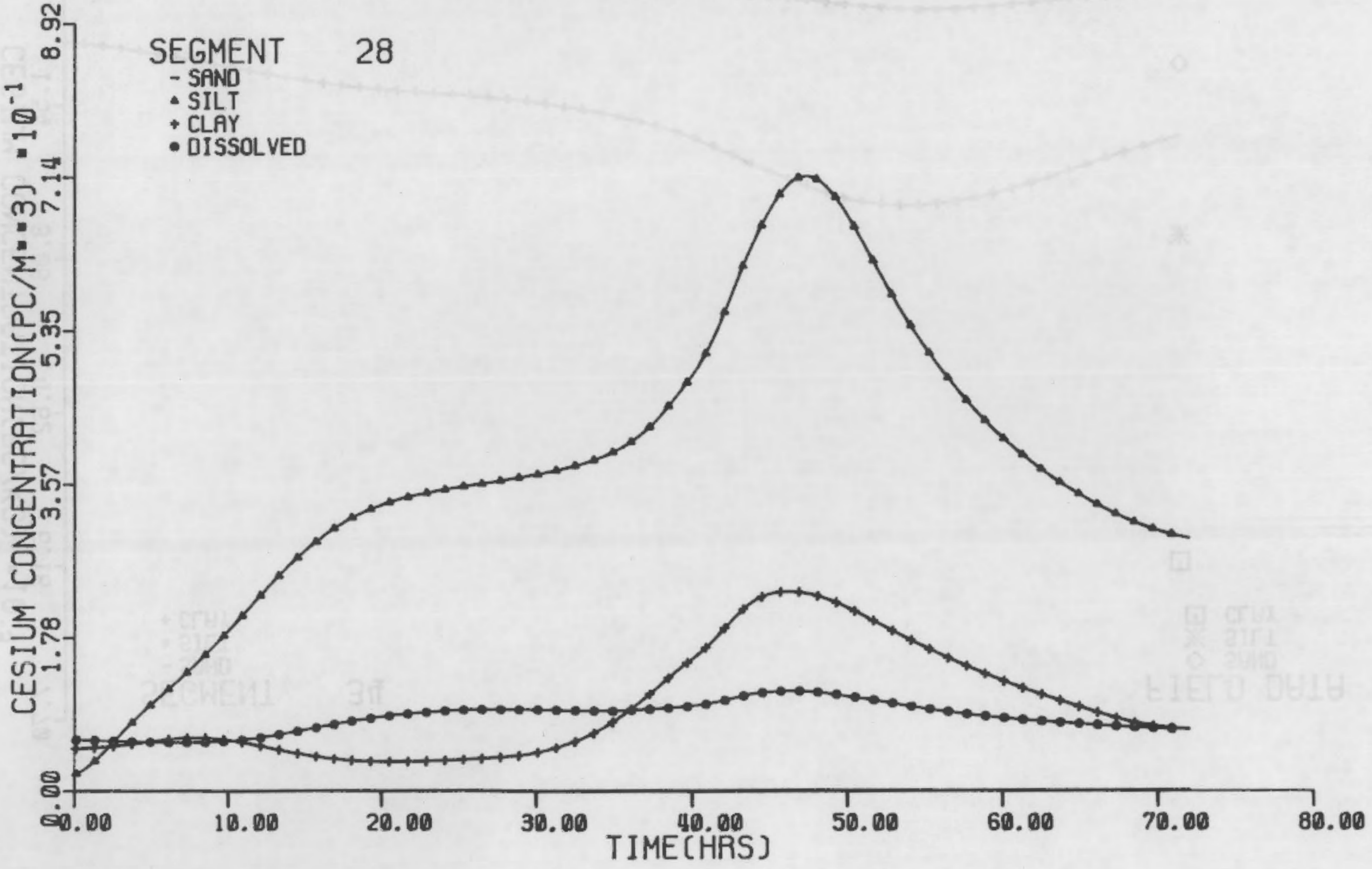

SEGMENT 14
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-2
0.00
8.46
16.93
25.40
33.86
42.33
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

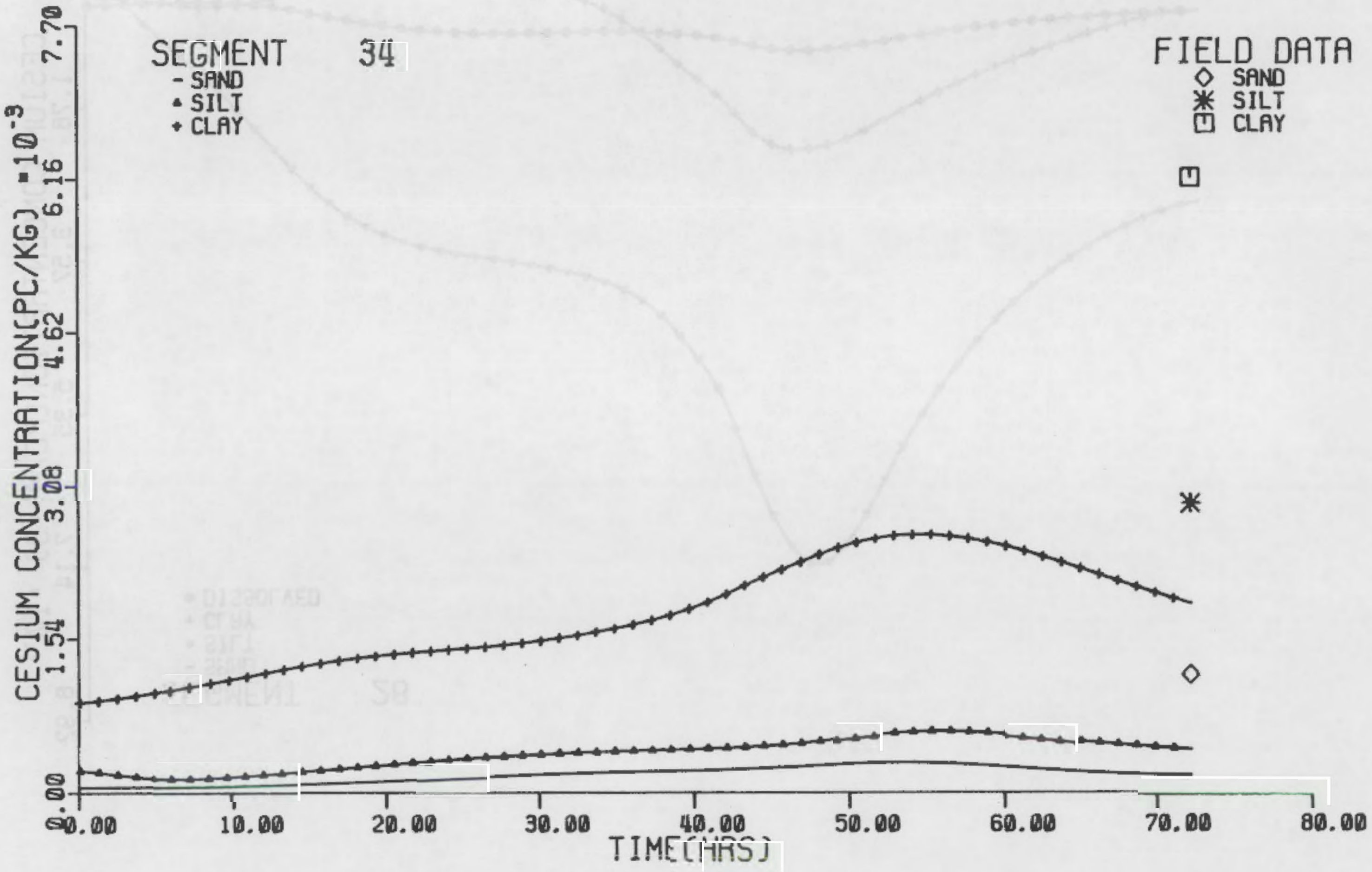

SEGMENT 14
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-1
0.00
3.10
6.20
9.30
12.41
15.51
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

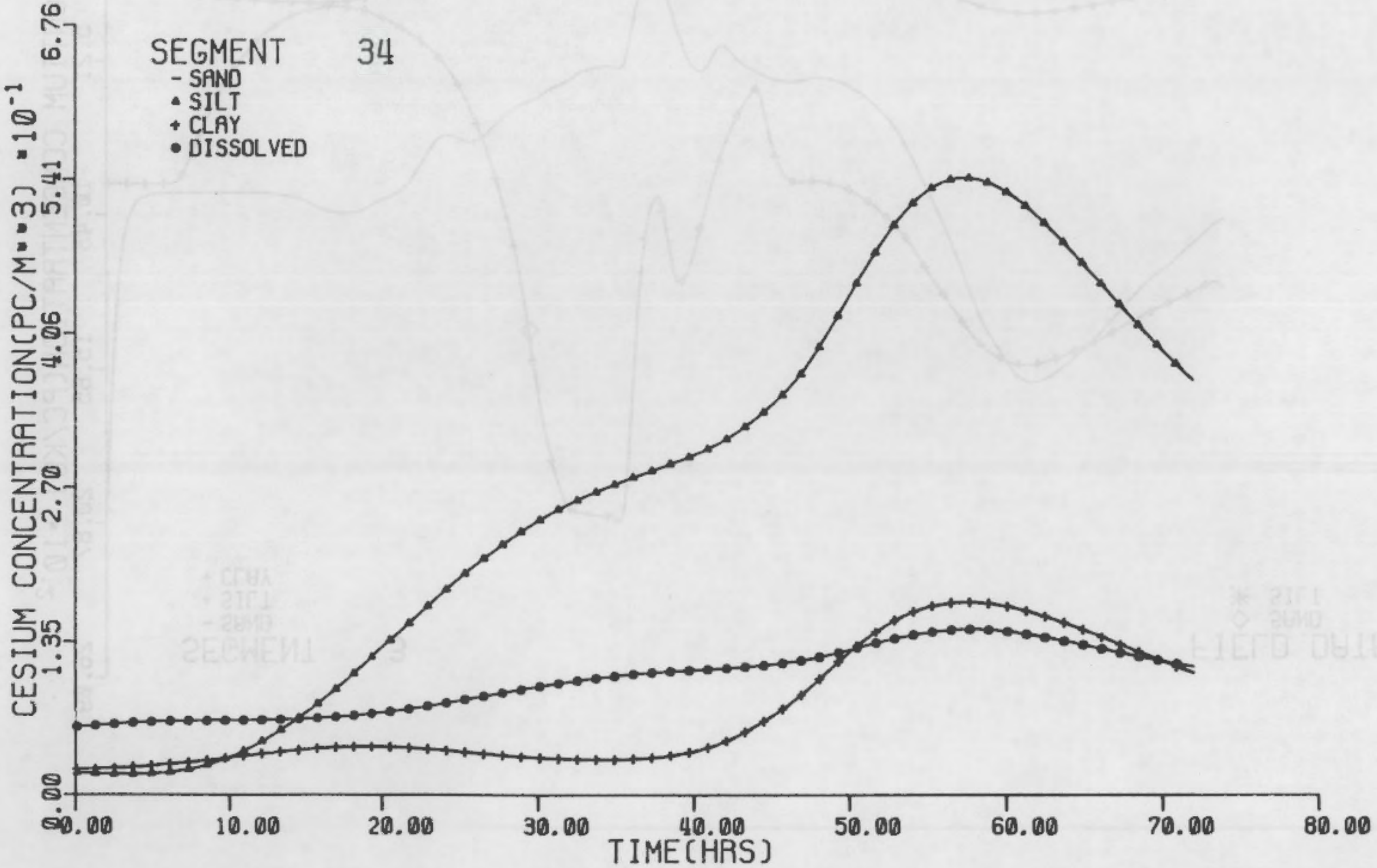

SEGMENT 21
- SAND
▲ SILT
+ CLAY
FIELD DATA
✱ SILT
☐ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-2
0.00
9.20
18.40
27.60
36.81
46.01
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

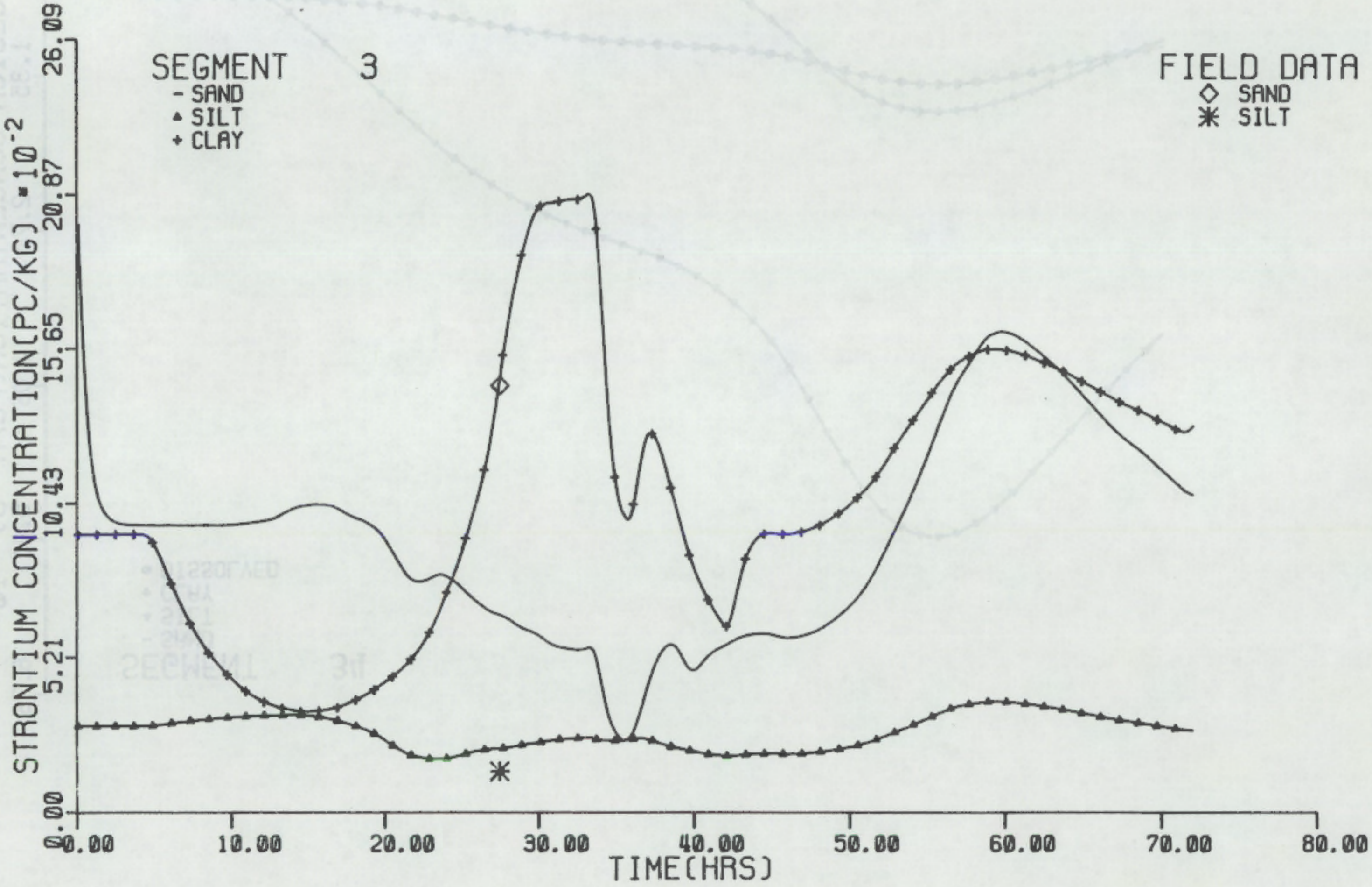

SEGMENT 21
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^{-1}
0.00
3.11
6.22
9.33
12.44
15.55
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

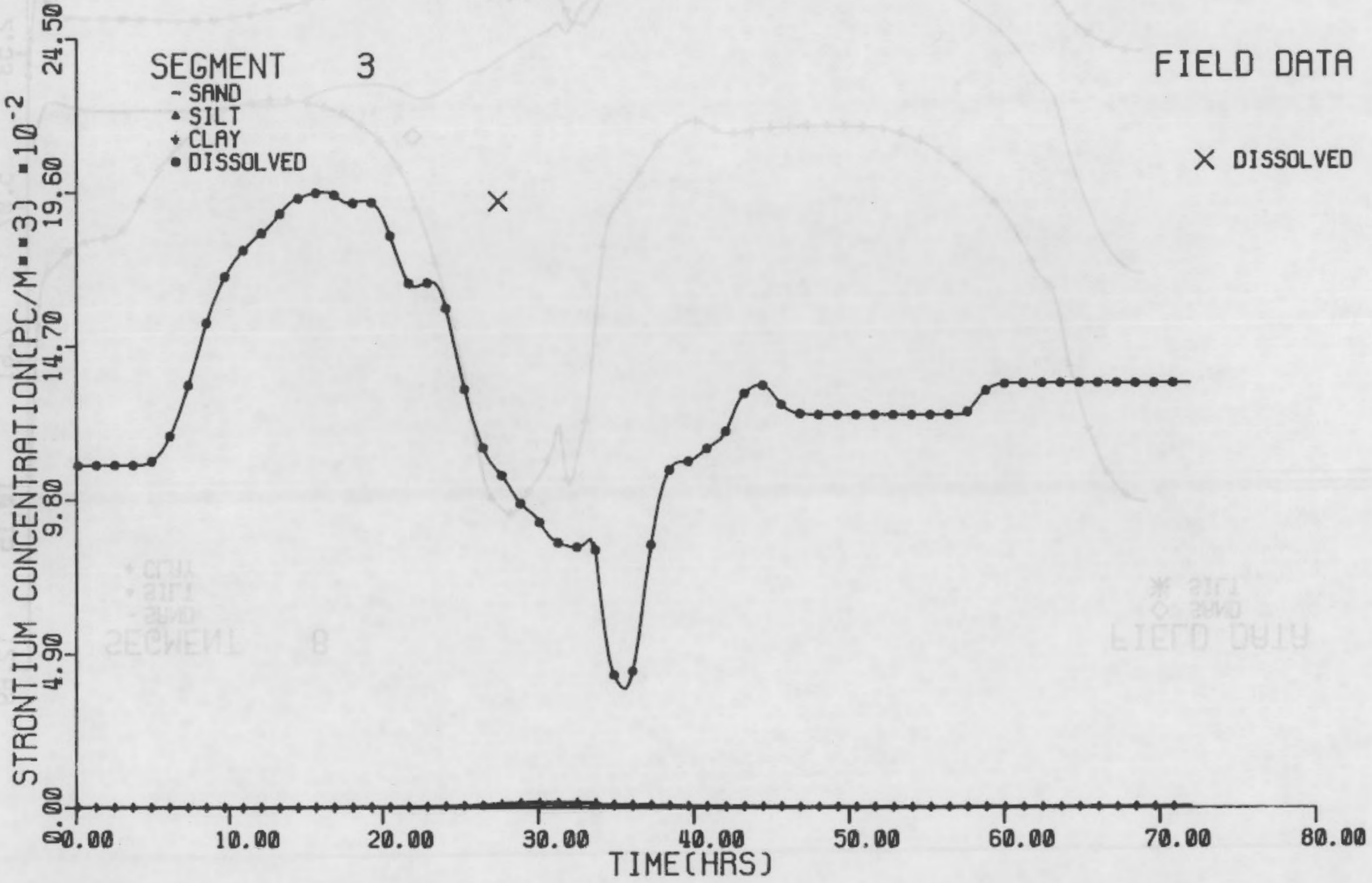

SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-2
35.66
28.52
21.39
14.26
7.13
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

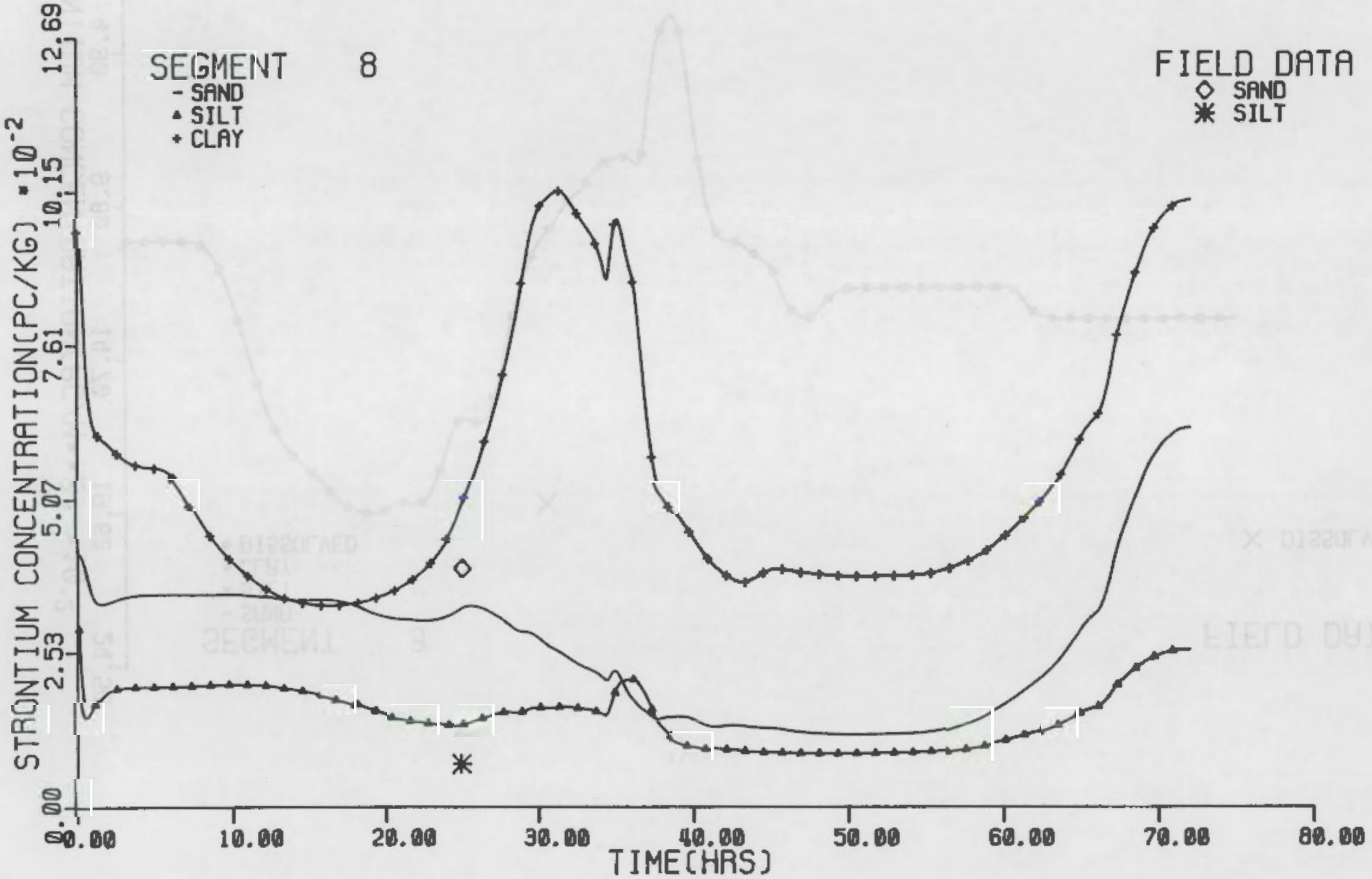

SEGMENT 28
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-1
0.00
1.78
3.57
5.35
7.14
8.92
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

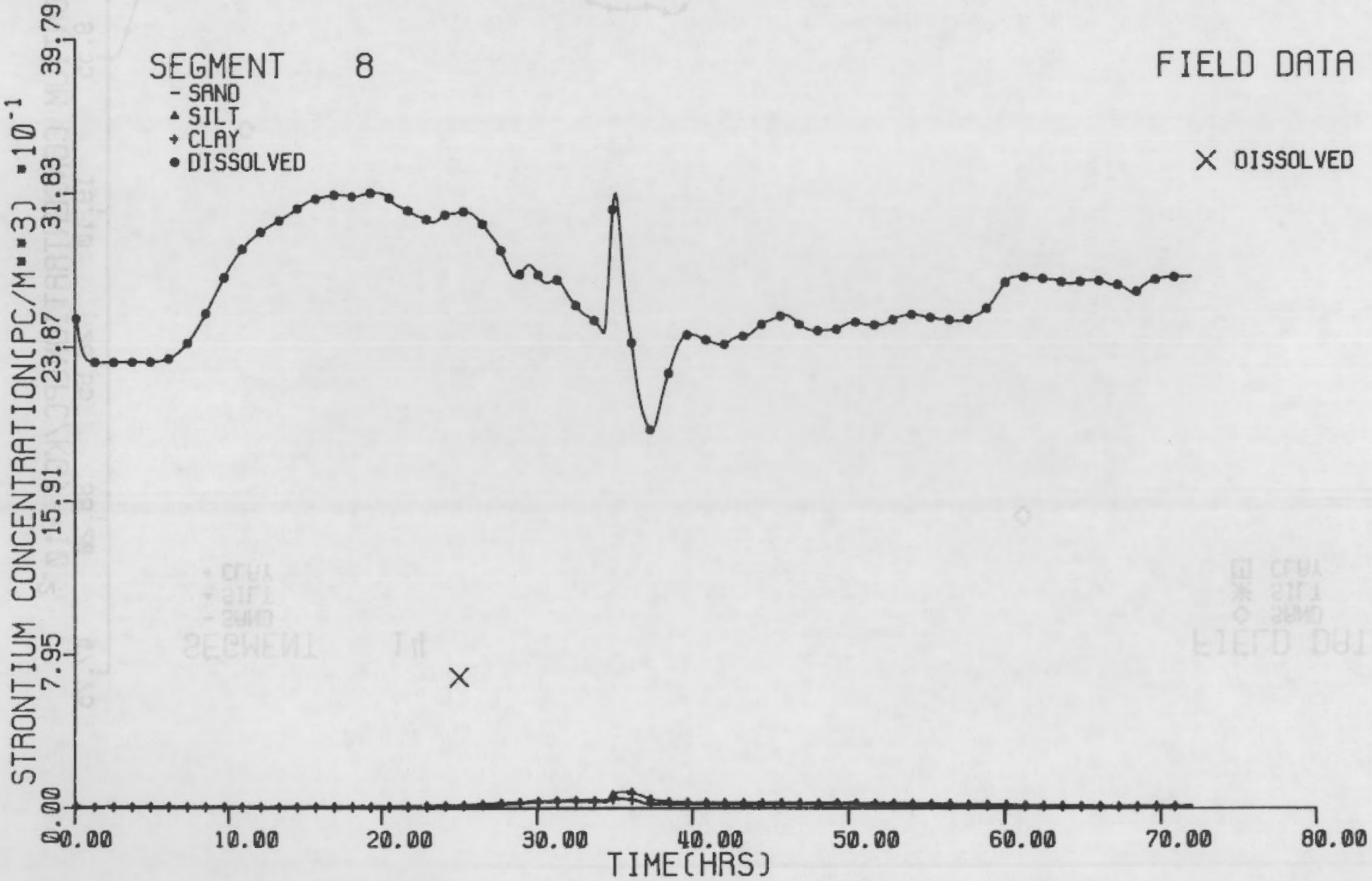

SEGMENT 34
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10⁻³
0.00
1.54
3.08
4.62
6.16
7.70
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

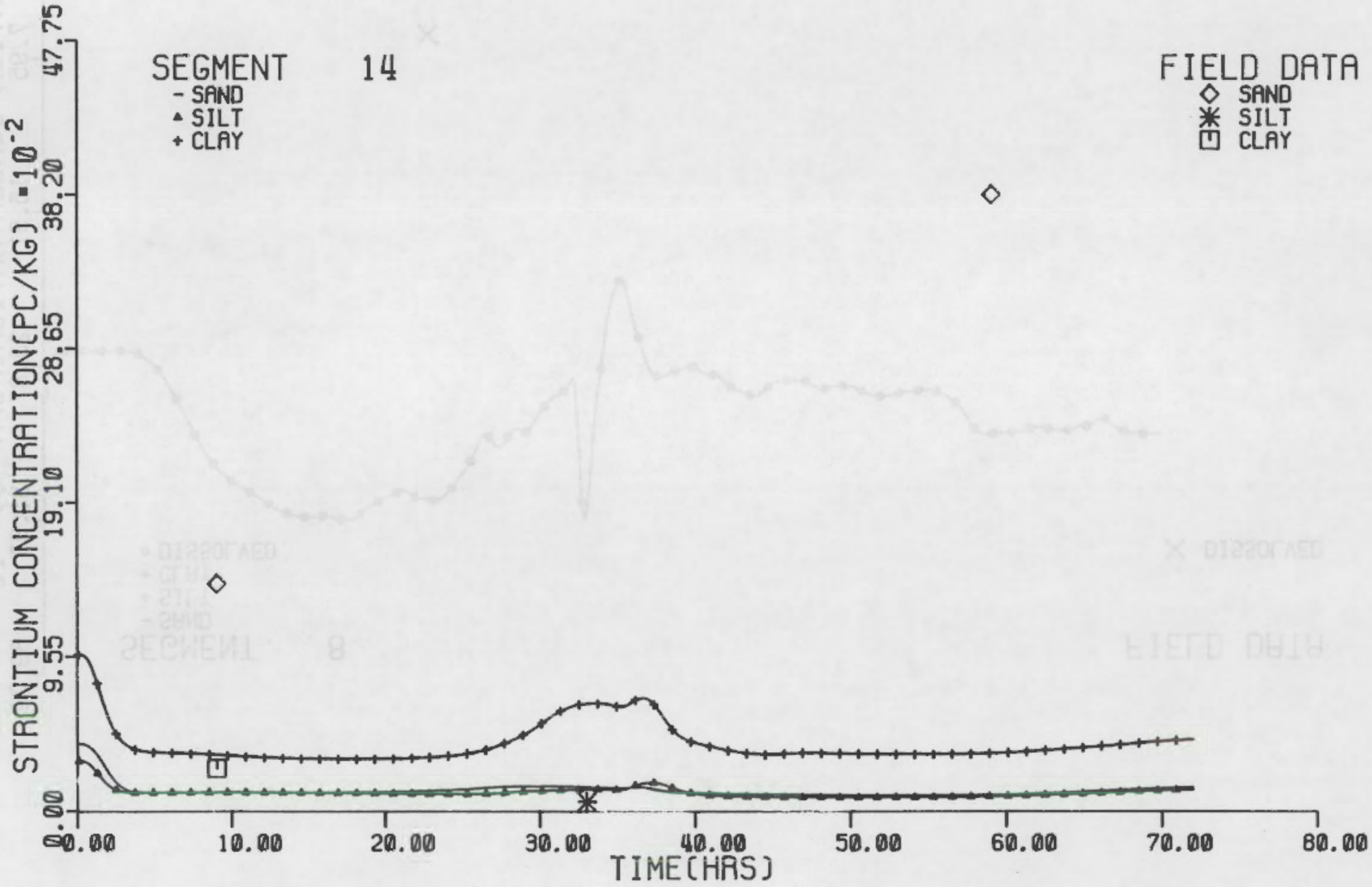

SEGMENT 34
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-1
0.00
1.35
2.70
4.06
5.41
6.76
TIME(HRS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00

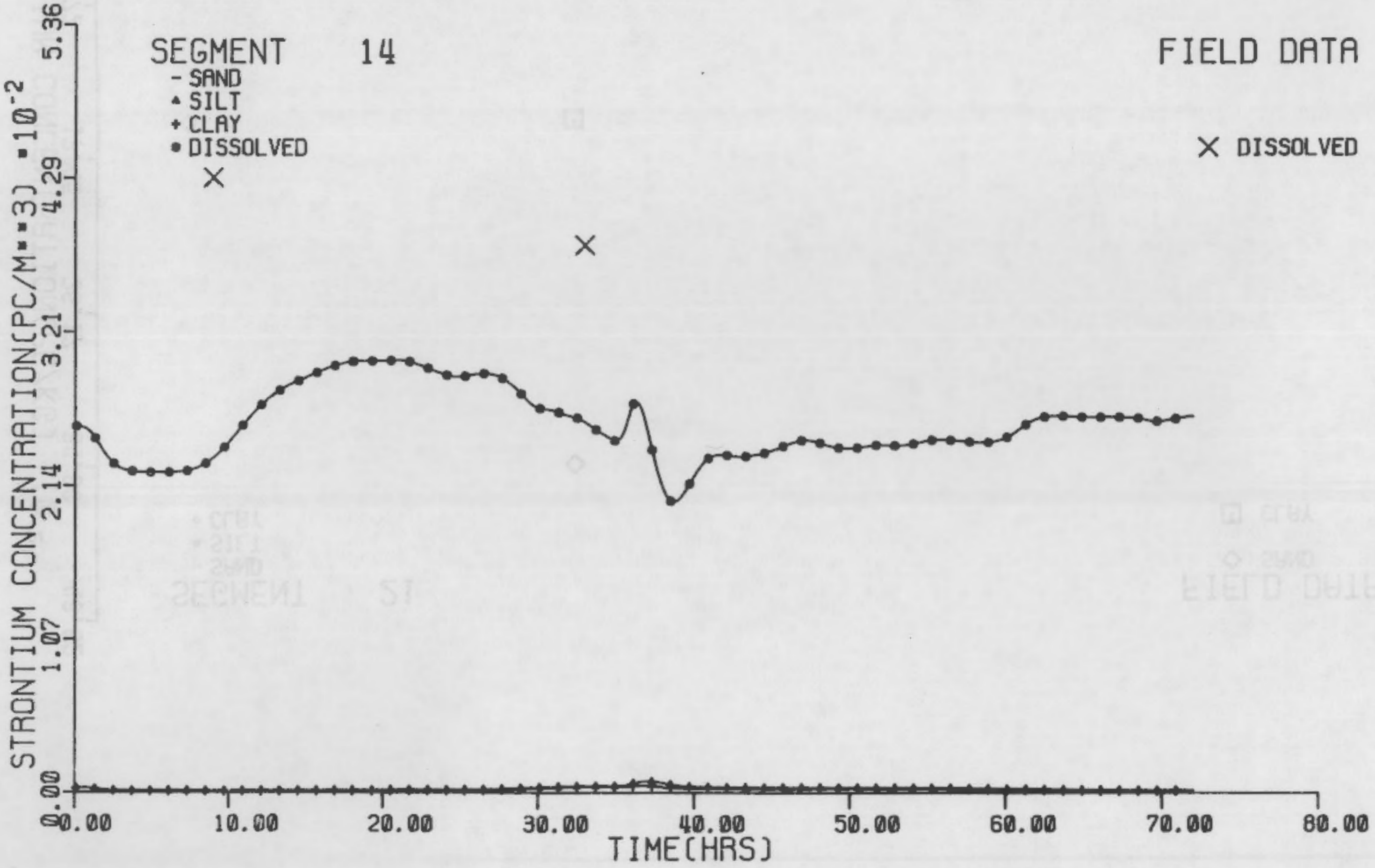

SEGMENT 3
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
STRONTIUM CONCENTRATION(PC/KG) *10^-2
0.00
5.21
10.43
15.65
20.87
26.09
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

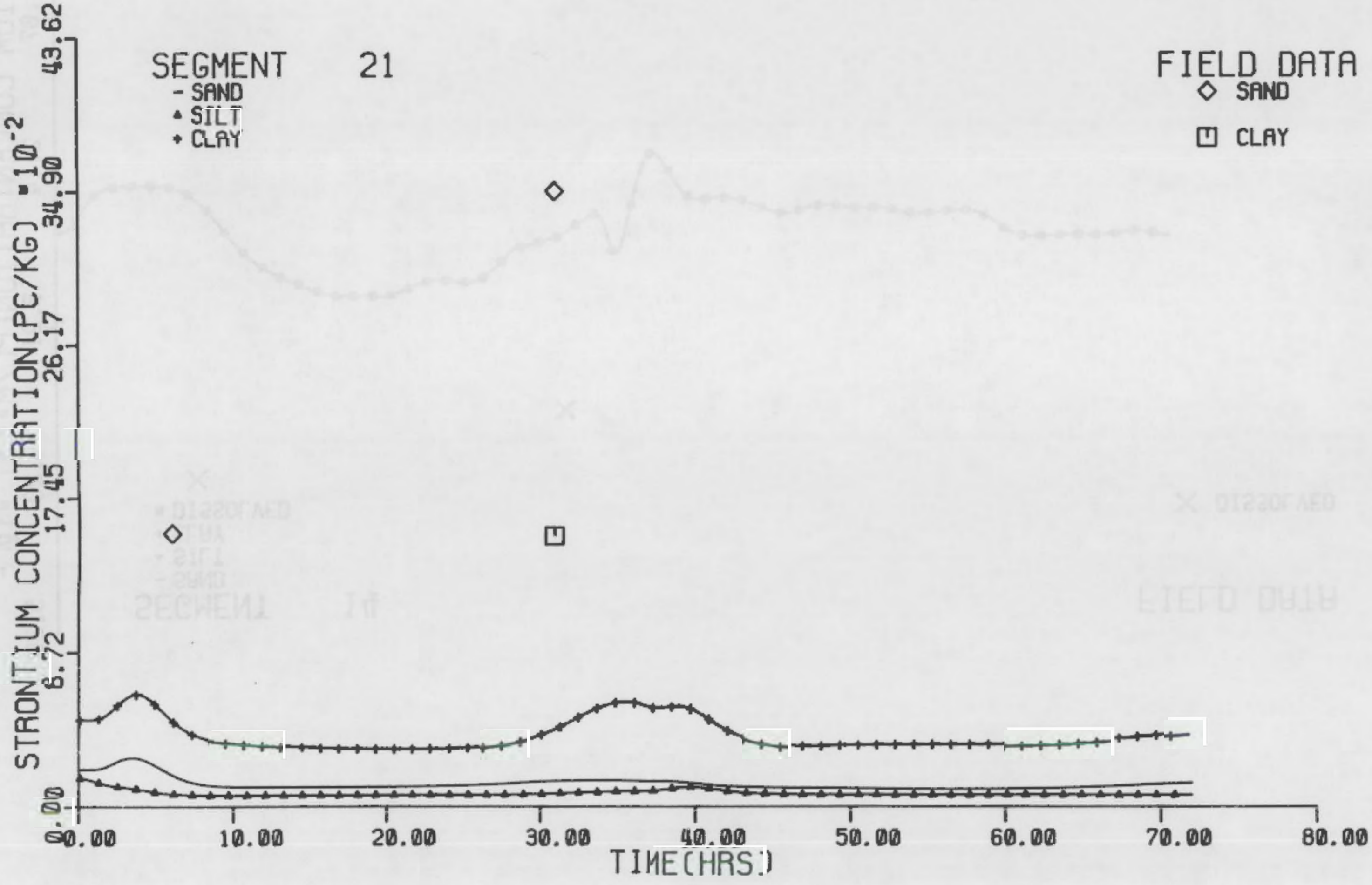

SEGMENT 3
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10^-2
0.00
4.90
9.80
14.70
19.60
24.50
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

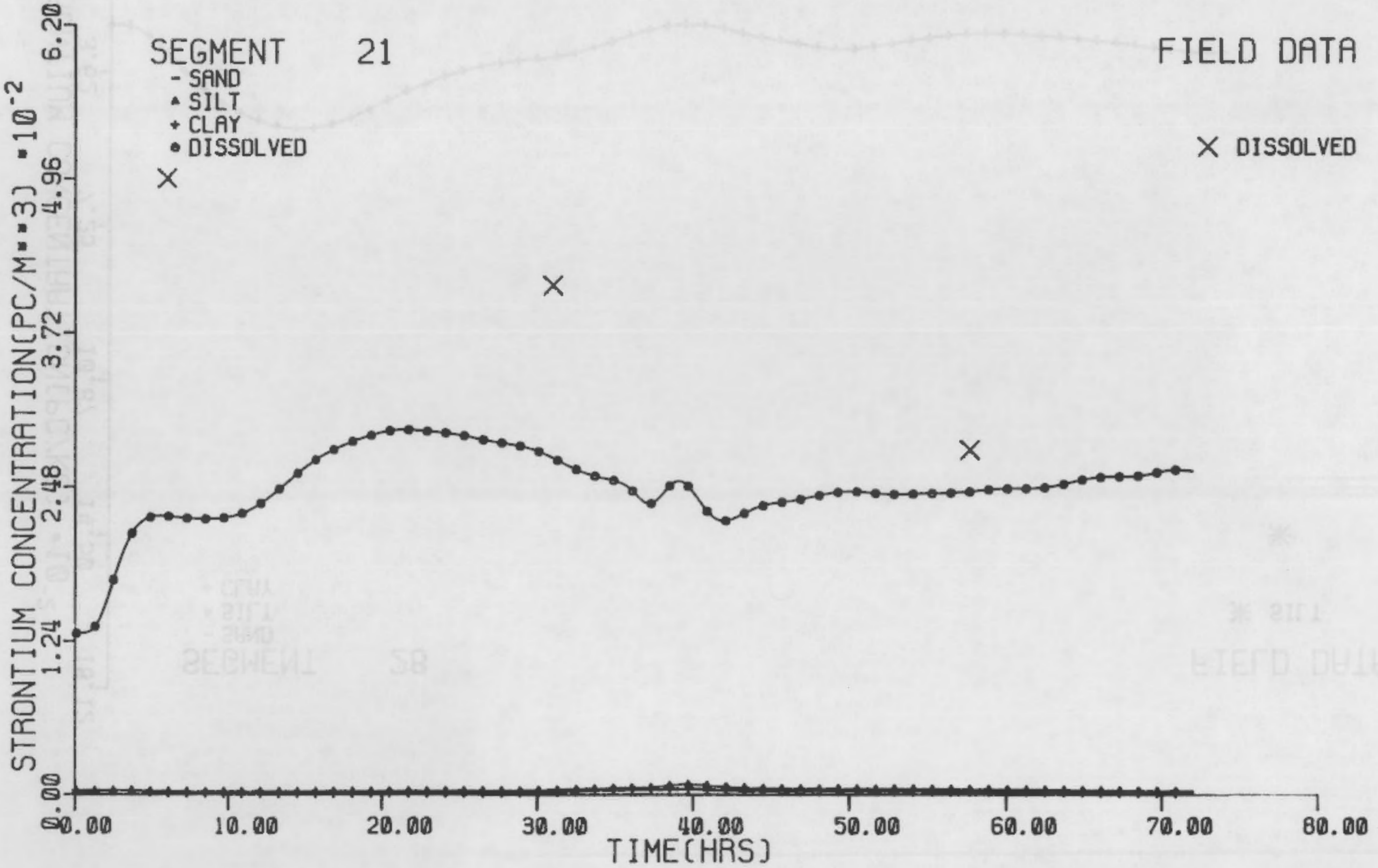

SEGMENT 8
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
STRONTIUM CONCENTRATION(PC/KG) *10^-2
0.00
2.53
5.07
7.61
10.15
12.69
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

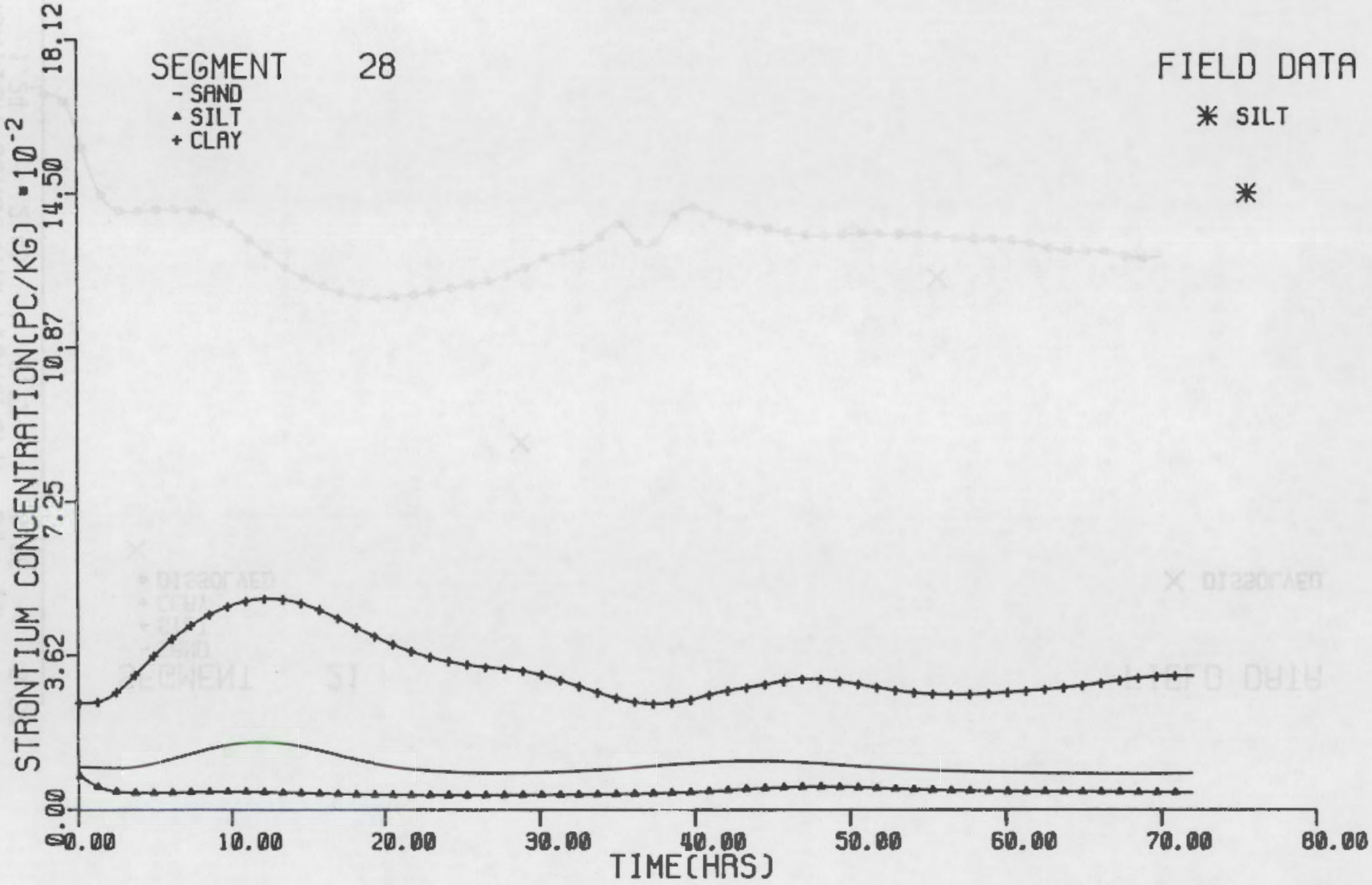

SEGMENT 8
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10^{-1}
0.00
7.95
15.91
23.87
31.83
39.79
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

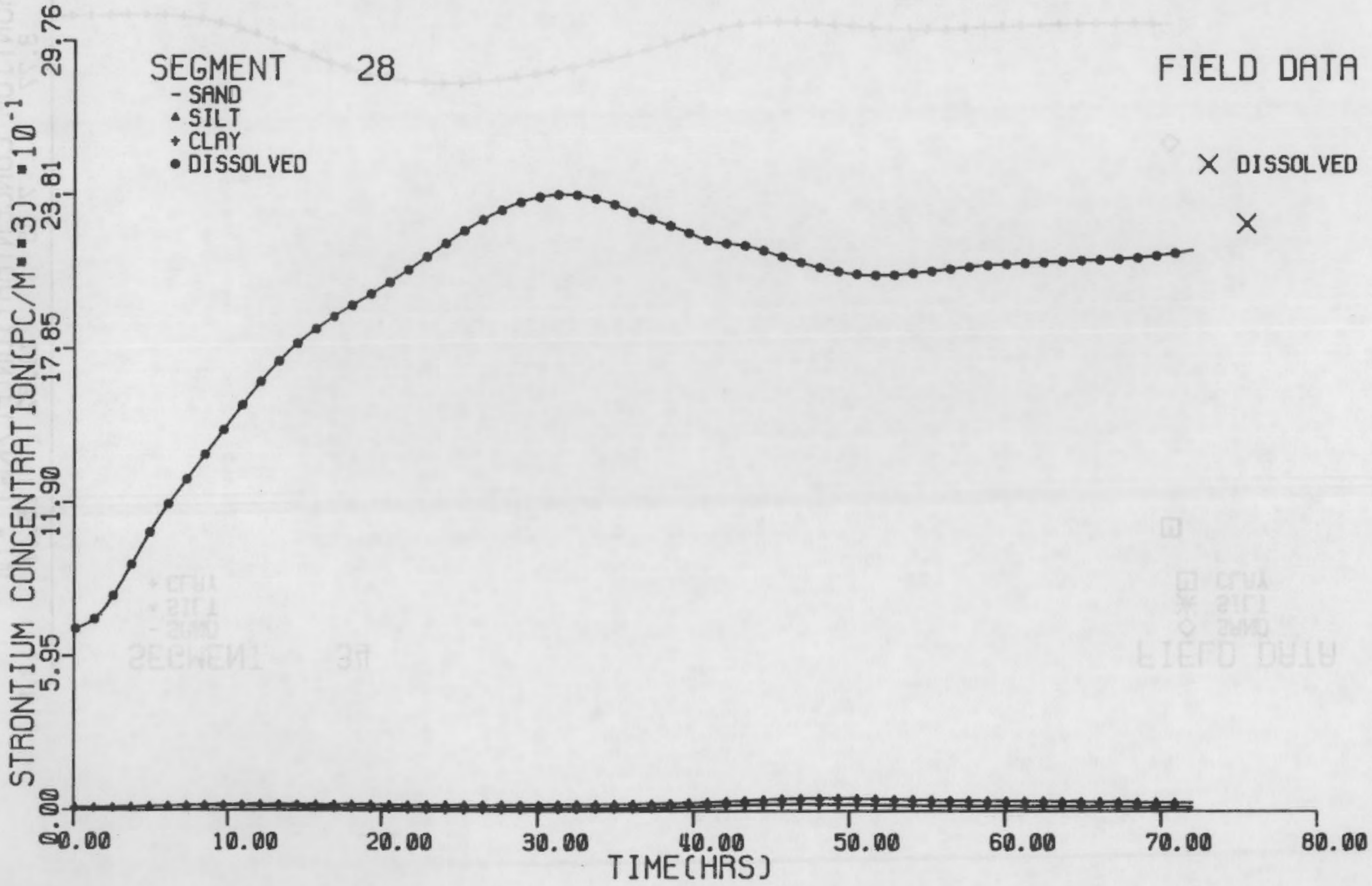

SEGMENT 14
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^-2
0.00
9.55
19.10
28.65
38.20
47.75
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

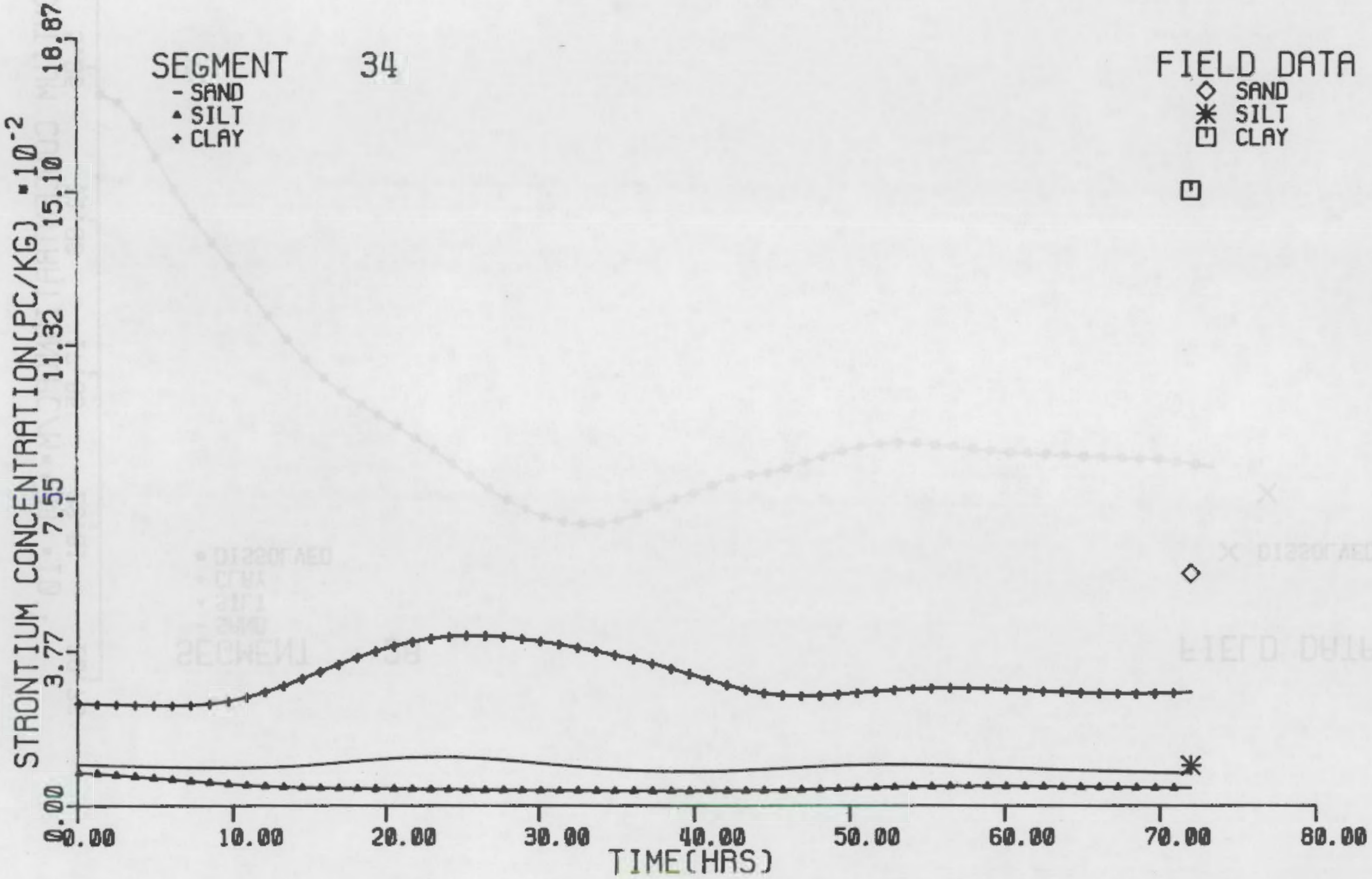

SEGMENT 14
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10^-2
0.00
1.07
2.14
3.21
4.29
5.36
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

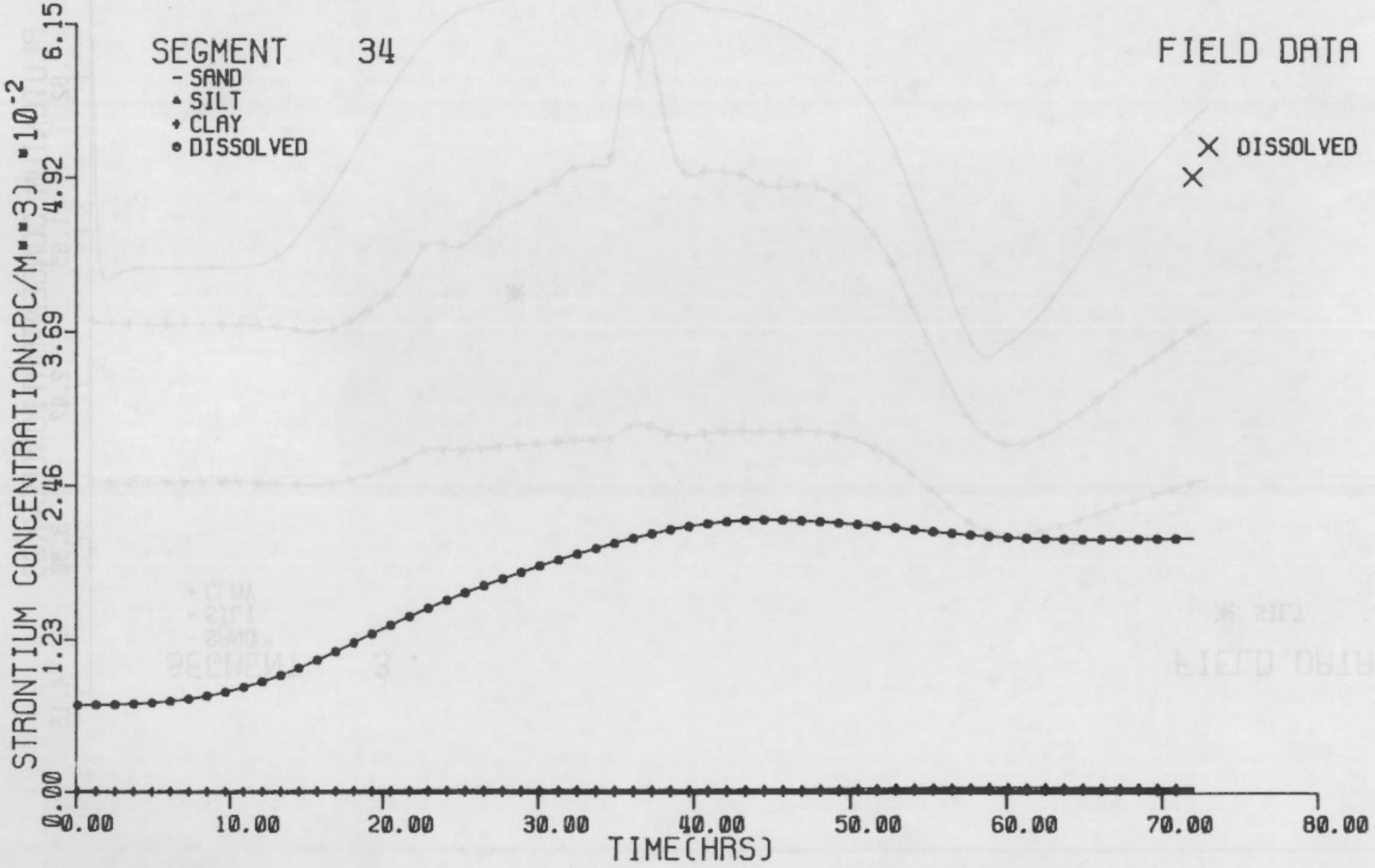

SEGMENT 21
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
□ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^-2
0.00
8.72
17.45
26.17
34.90
43.62
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

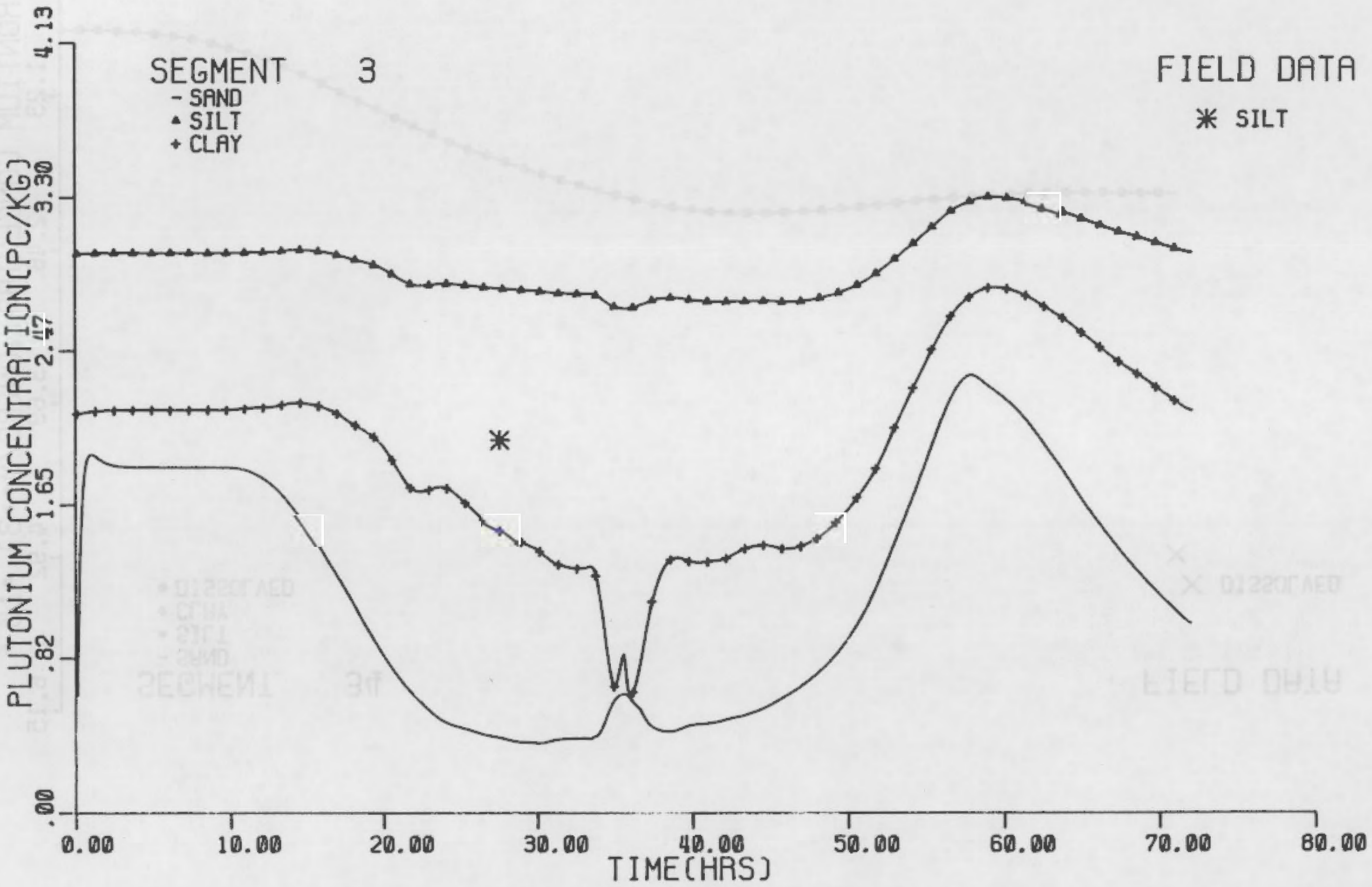

SEGMENT 21
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10^-2
0.00
1.24
2.48
3.72
4.96
6.20
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

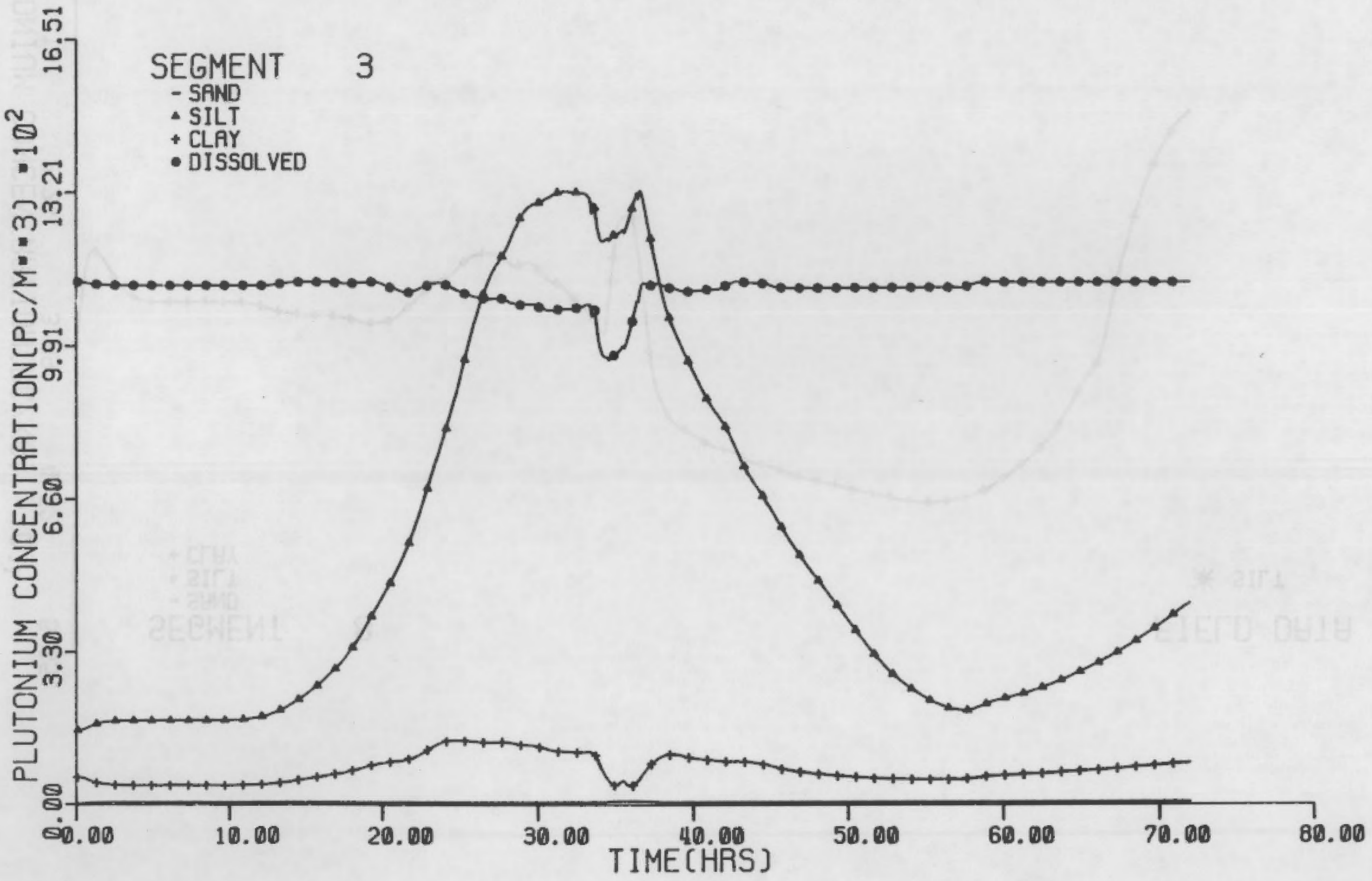

SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
✱ SILT
STRONTIUM CONCENTRATION(PC/KG) *10^{-2}
0.00
3.62
7.25
10.87
14.50
18.12
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)


SEGMENT 28
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10⁻¹
0.00
5.95
11.90
17.85
23.81
29.76
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

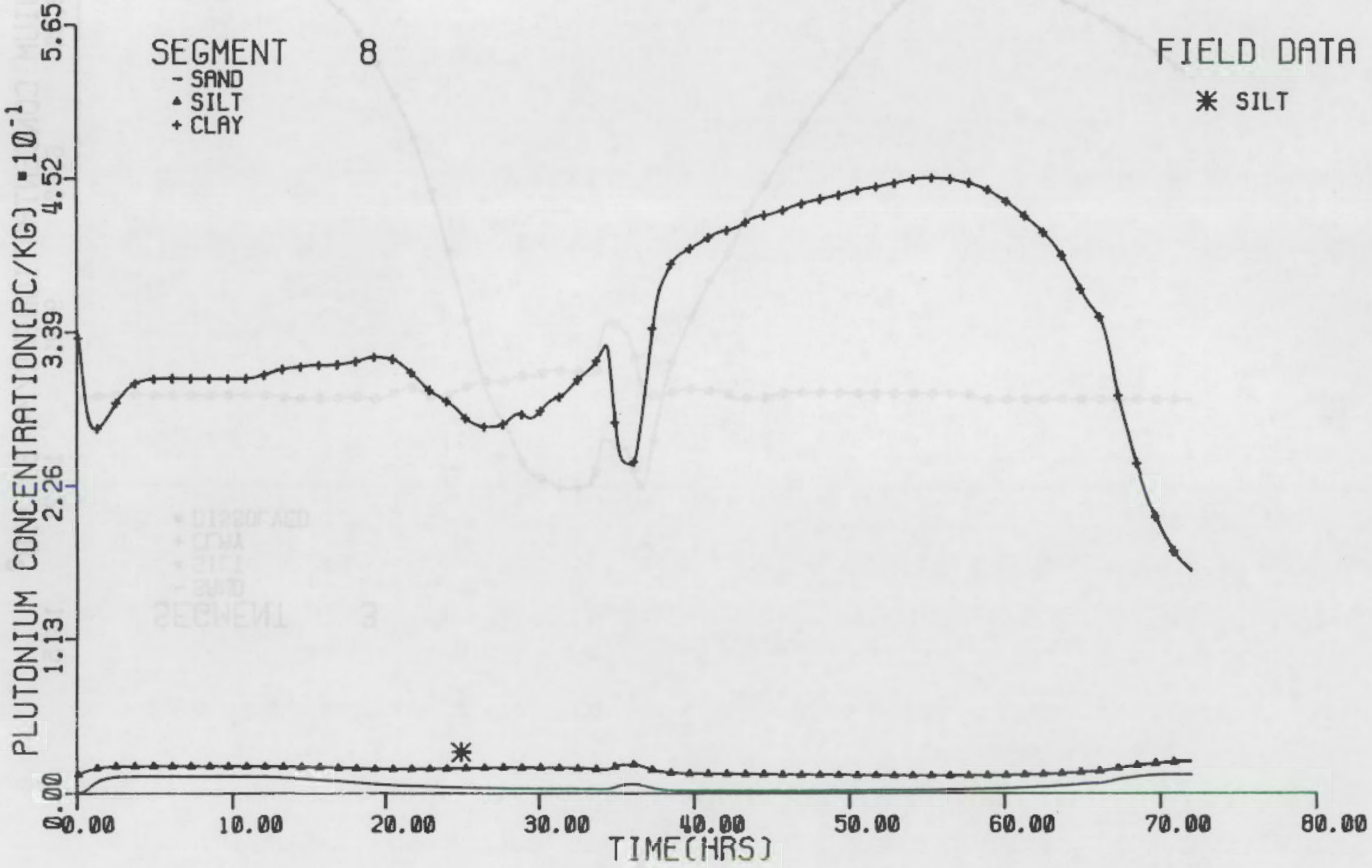

SEGMENT 34
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
□ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^-2
0.00
3.77
7.55
11.32
15.10
18.87
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)


SEGMENT 34
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10^-2
0.00
1.23
2.46
3.69
4.92
6.15
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

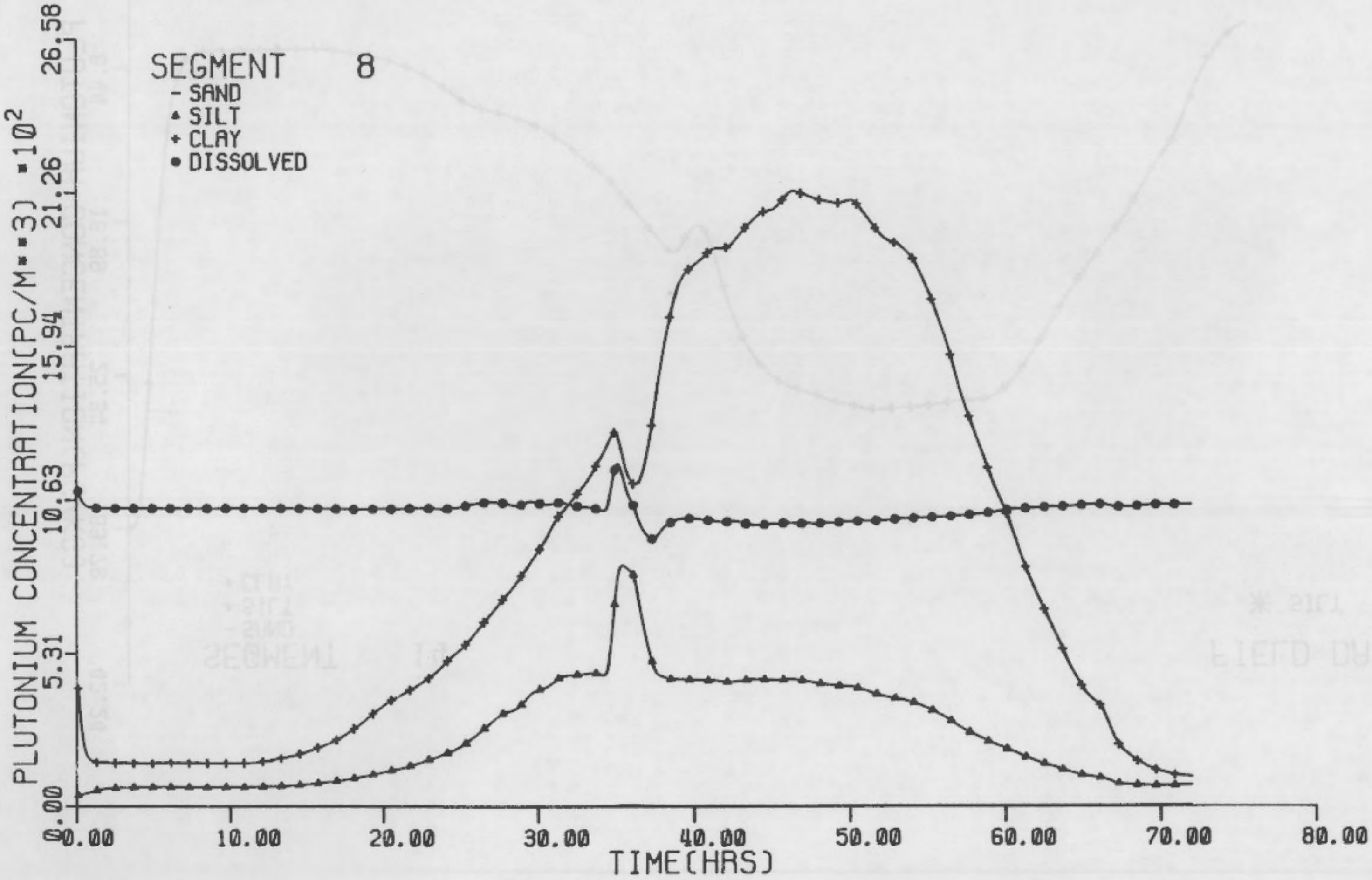

SEGMENT 3
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
PLUTONIUM CONCENTRATION(PC/KG)
.00
.82
1.65
2.47
3.30
4.13
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

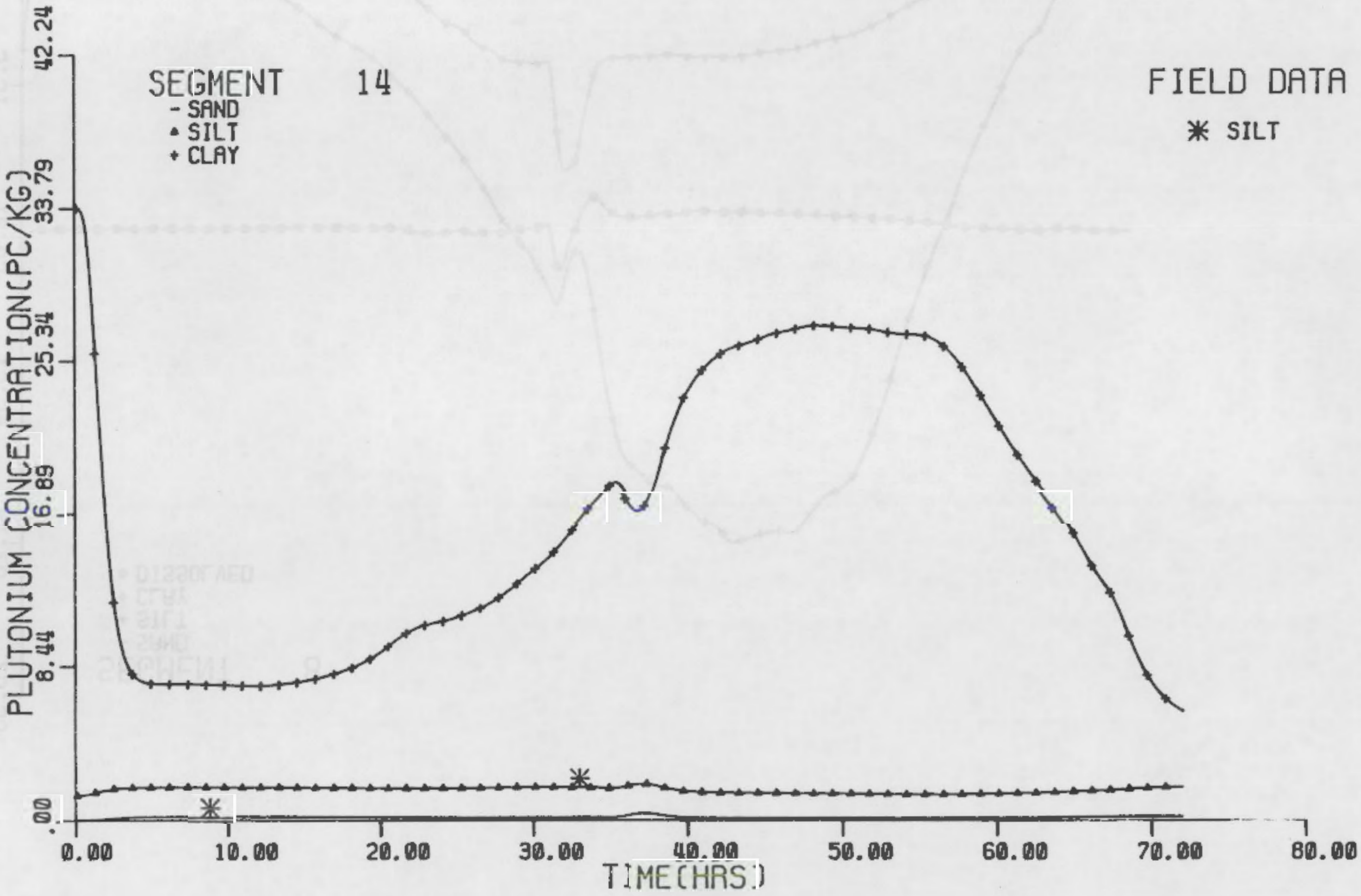


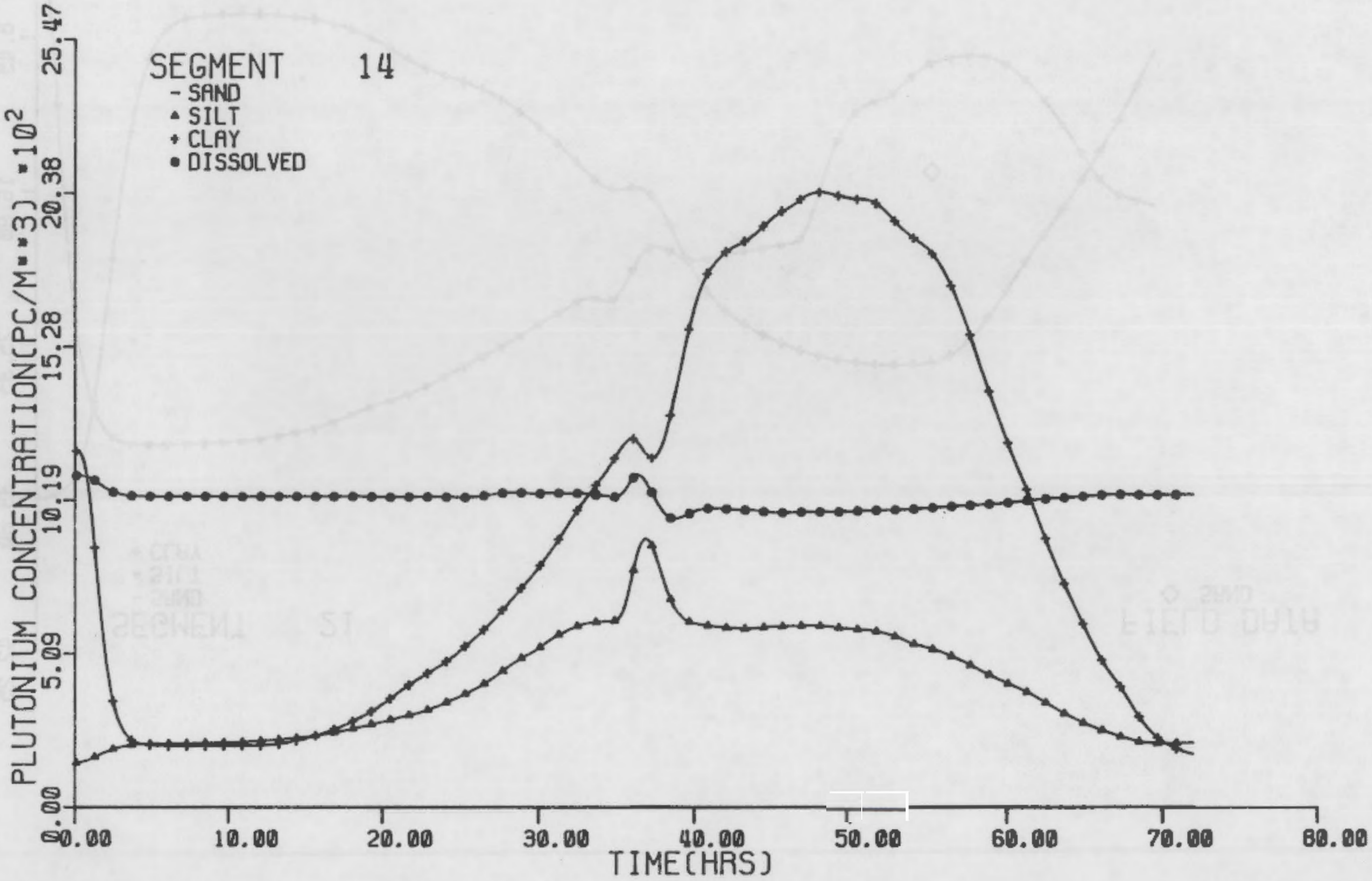
SEGMENT 3
- SAND
▲ SILT
+ CLAY
● DISSOLVED
PLUTONIUM CONCENTRATION(PC/M**3) *10²
0.00
3.30
6.60
9.91
13.21
16.51
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

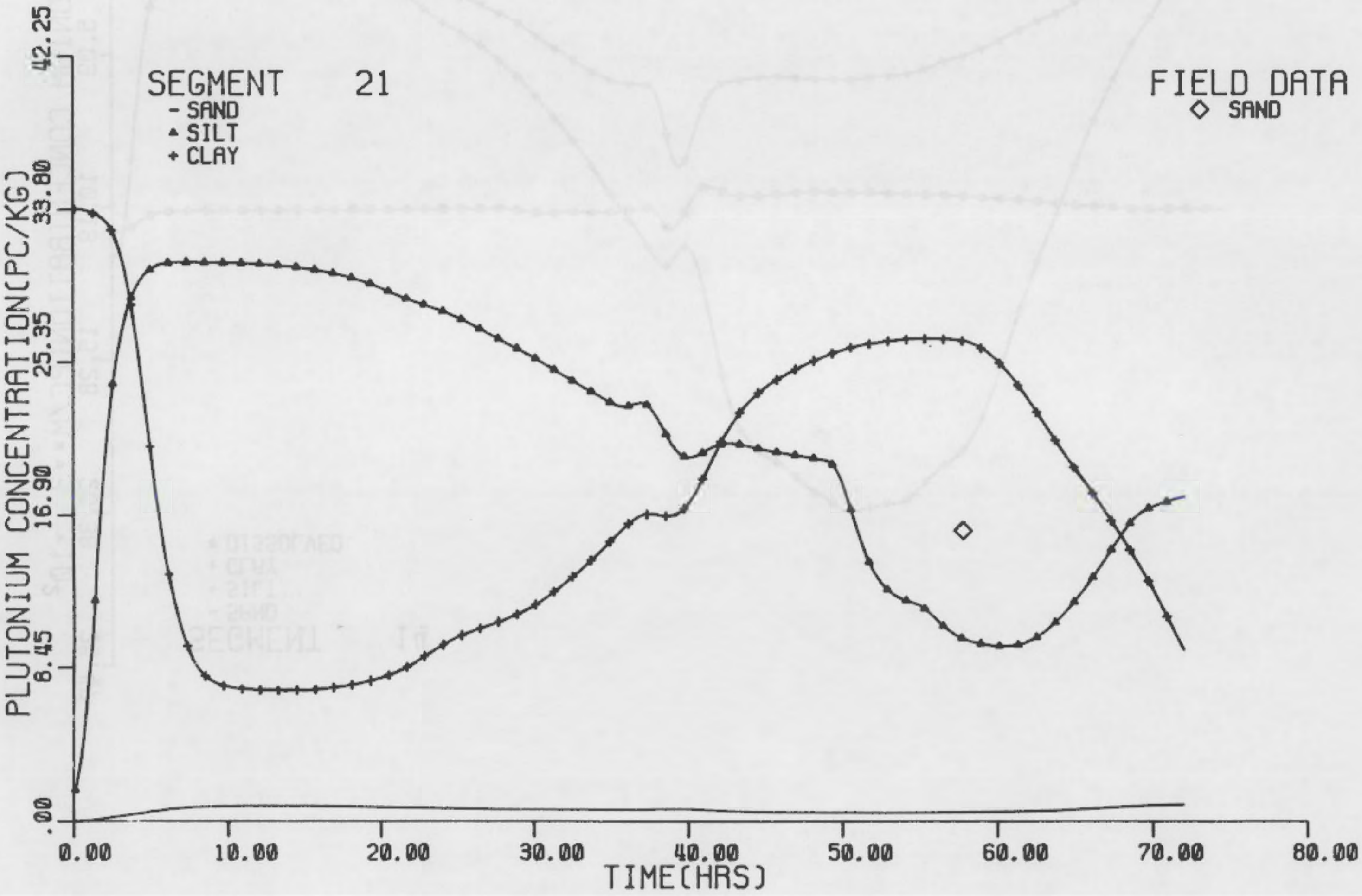


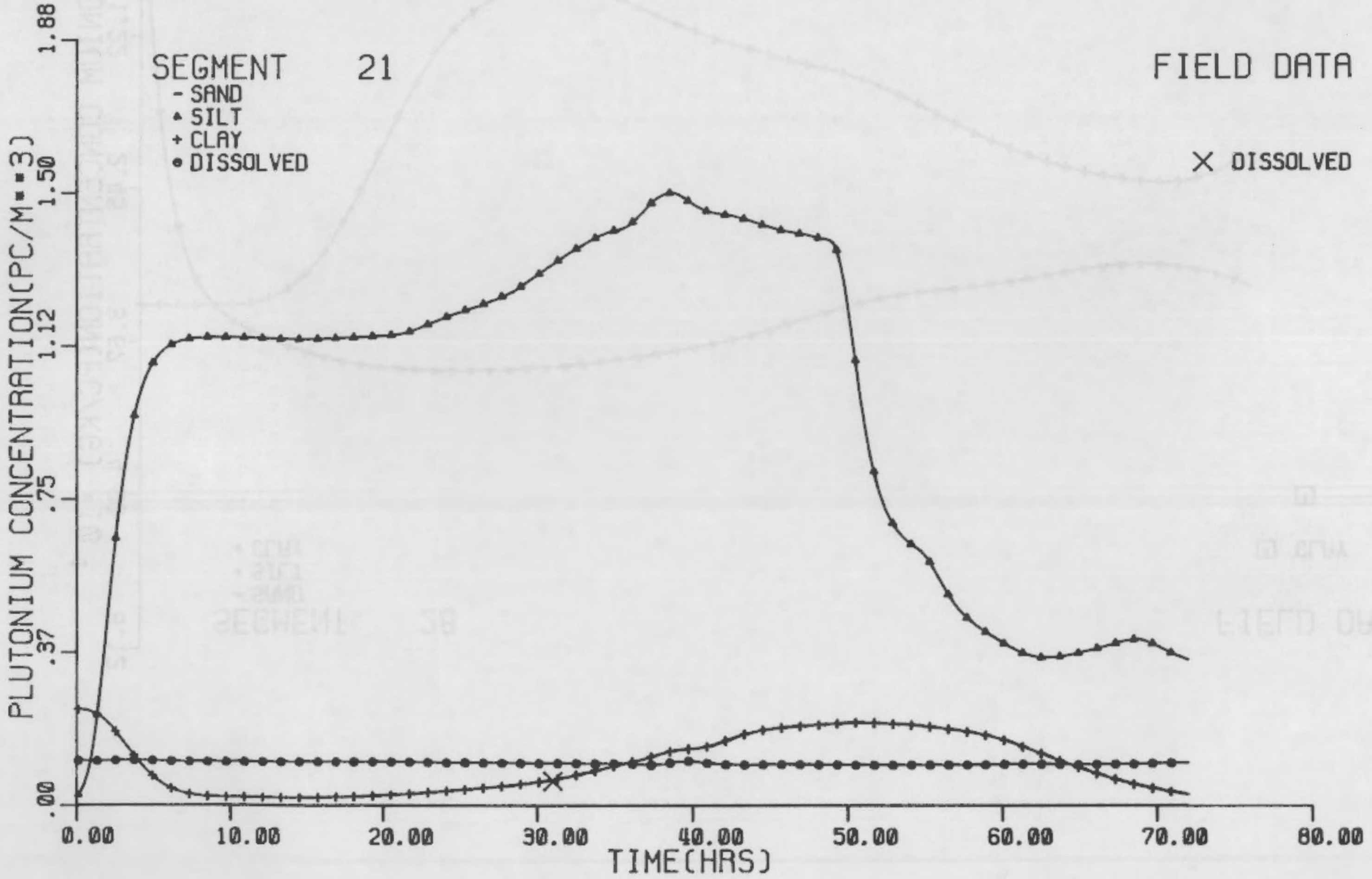
SEGMENT 8
- SAND
▲ SILT
+ CLAY
FIELD DATA
✱ SILT
PLUTONIUM CONCENTRATION(PC/KG) *10^-1
0.00
1.13
2.26
3.39
4.52
5.65
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

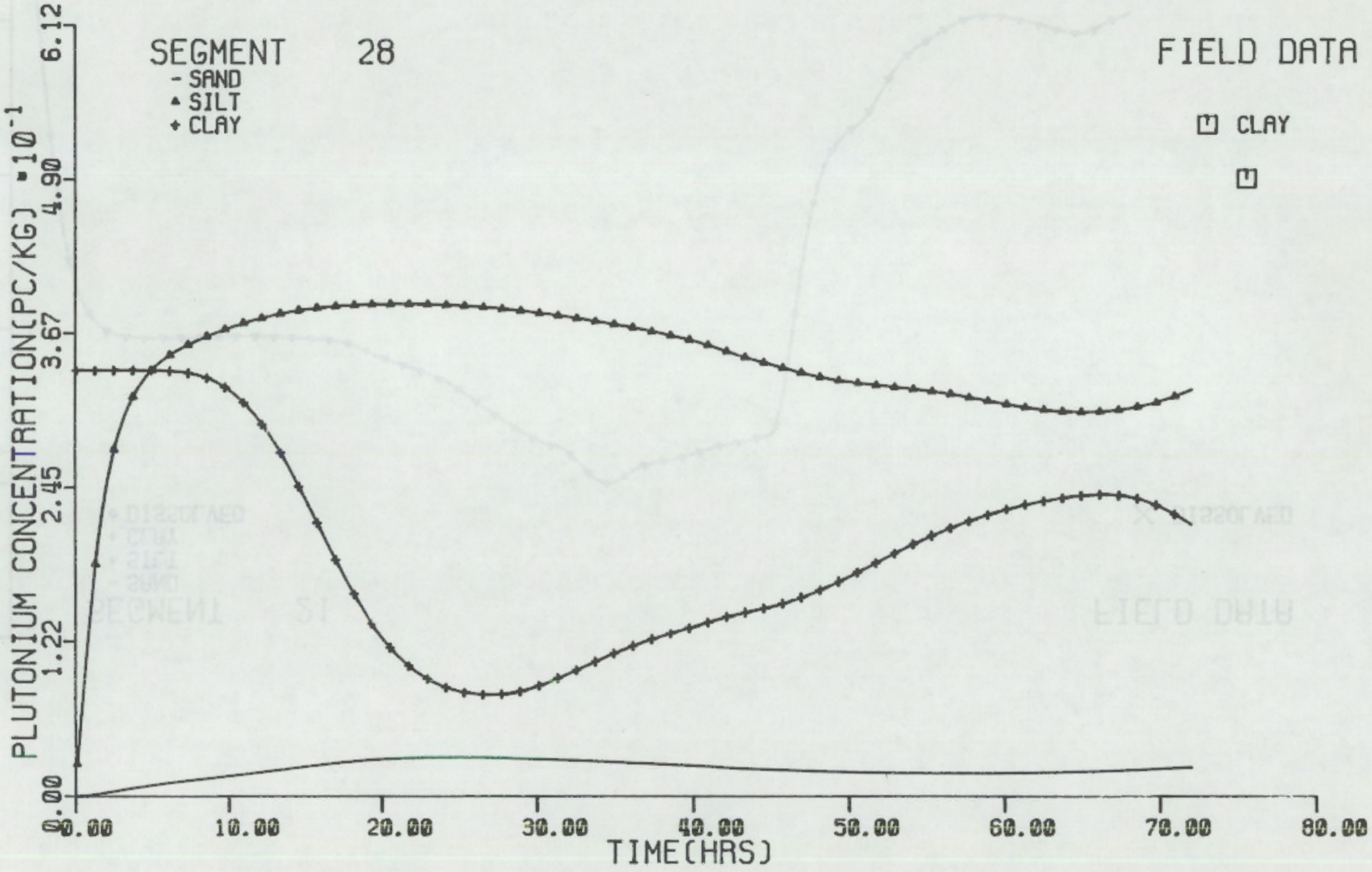

SEGMENT 8
- SAND
▲ SILT
+ CLAY
● DISSOLVED
PLUTONIUM CONCENTRATION(PC/M**3) *10^2
0.00
5.31
10.63
15.94
21.26
26.58
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

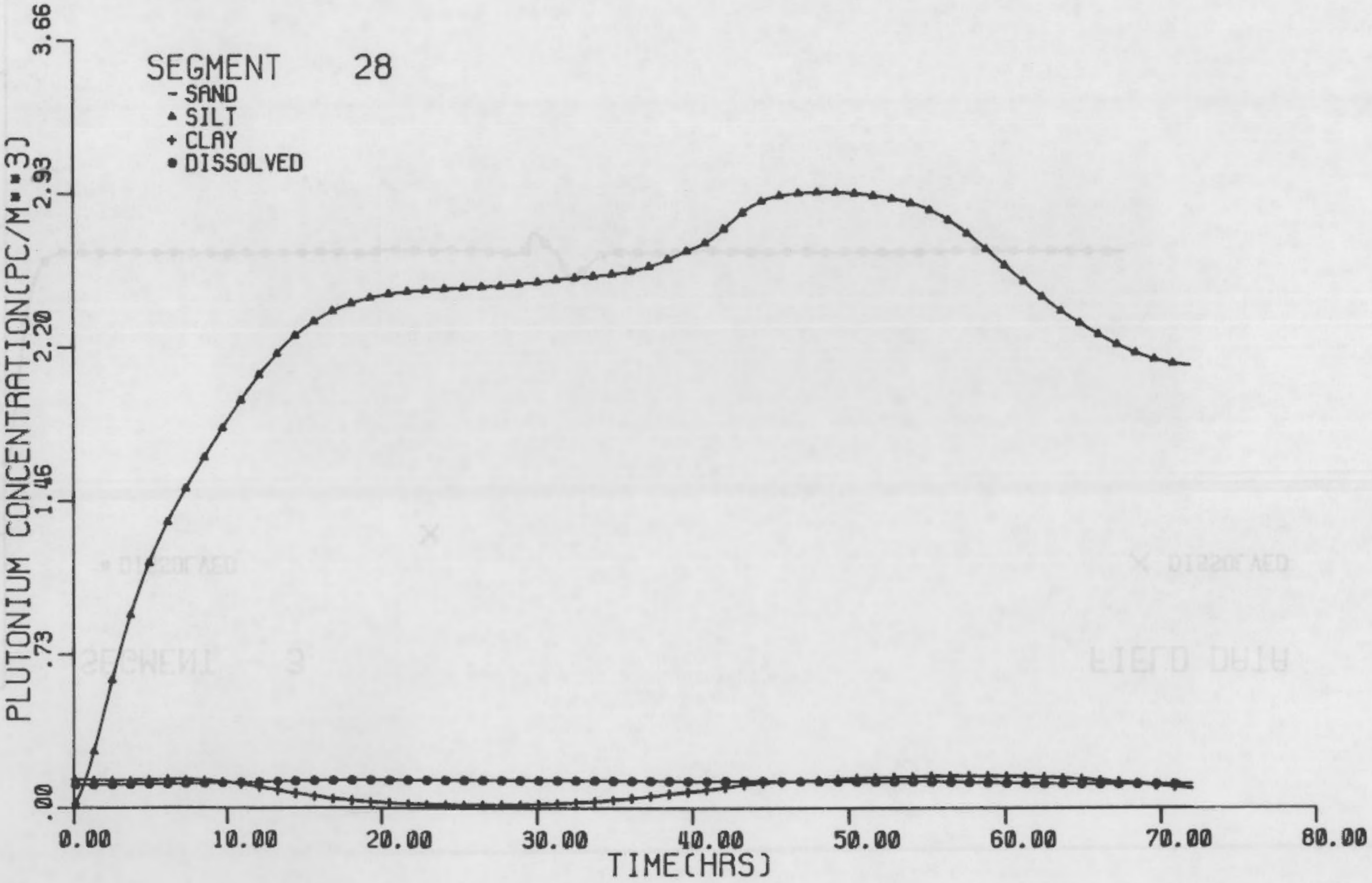

SEGMENT 14
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
PLUTONIUM CONCENTRATION(PC/KG)
42.24
33.79
25.34
16.89
8.44
.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

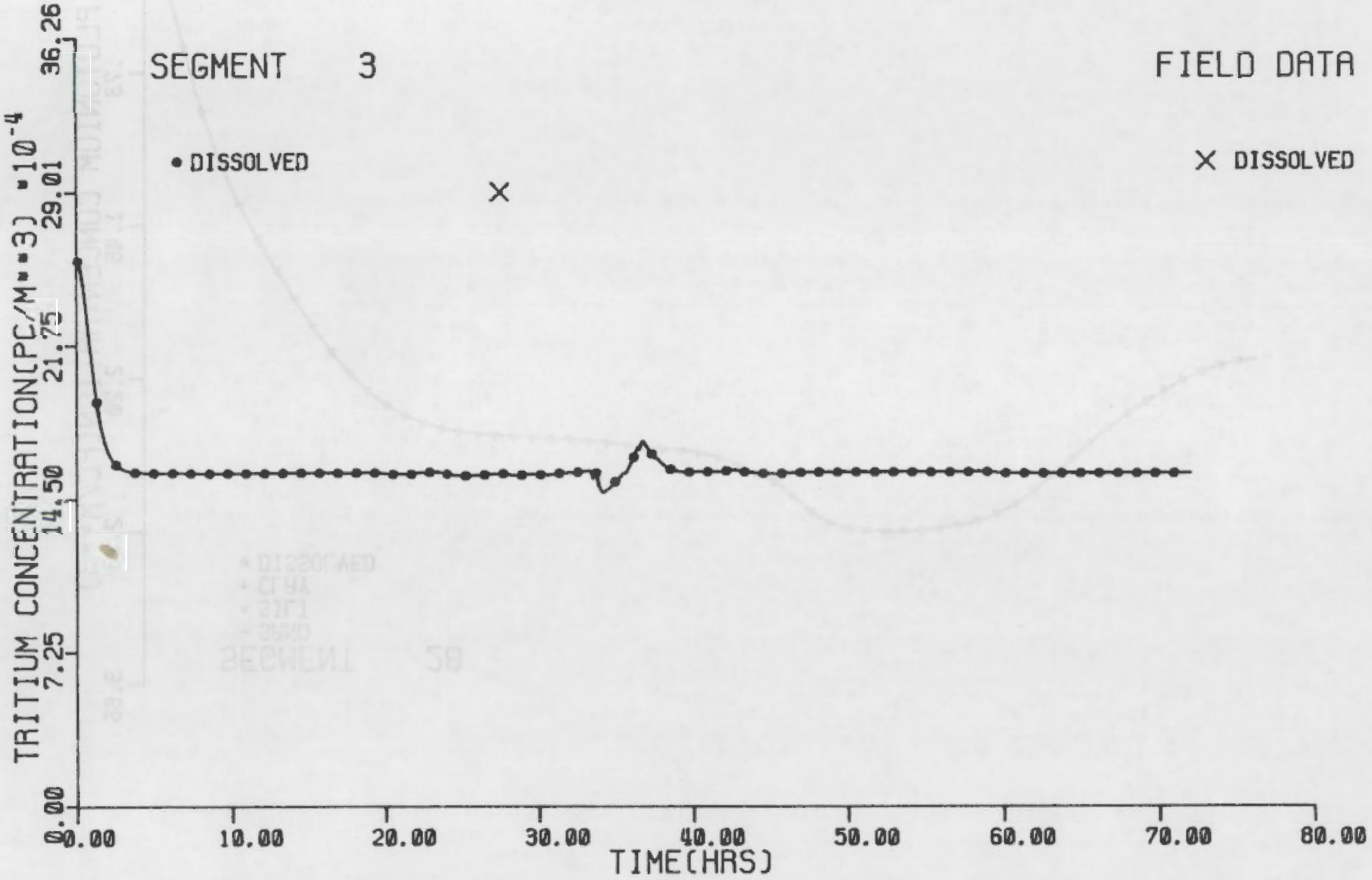

SEGMENT 14
- SAND
▲ SILT
+ CLAY
● DISSOLVED
PLUTONIUM CONCENTRATION(PC/M**3) *10²
0.00
5.09
10.19
15.28
20.38
25.47
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

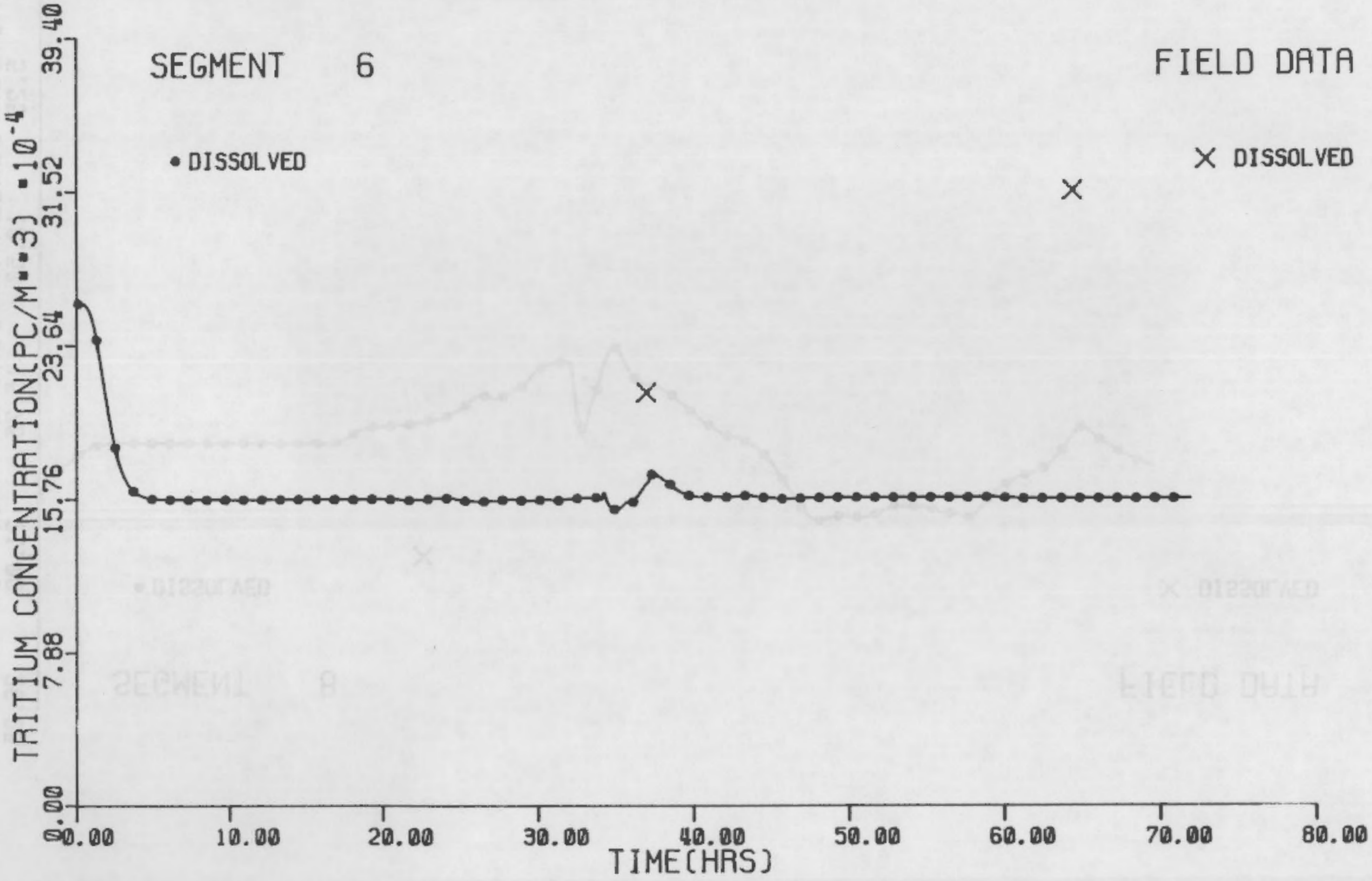

SEGMENT 21
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
PLUTONIUM CONCENTRATION(PC/KG)
42.25
33.80
25.35
16.90
8.45
.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

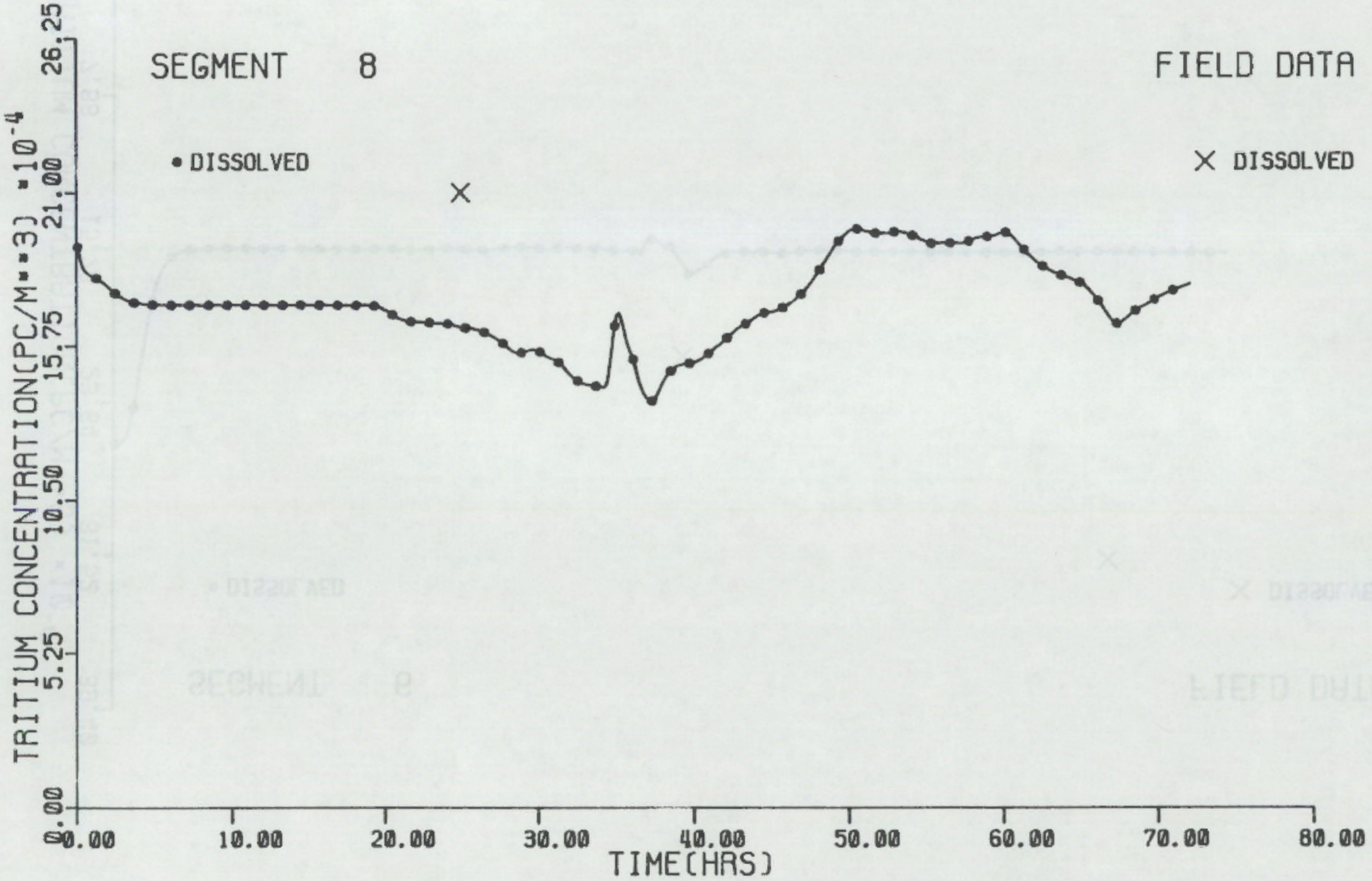

SEGMENT 21
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
PLUTONIUM CONCENTRATION(PC/M**3)
1.88
1.50
1.12
.75
.37
.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

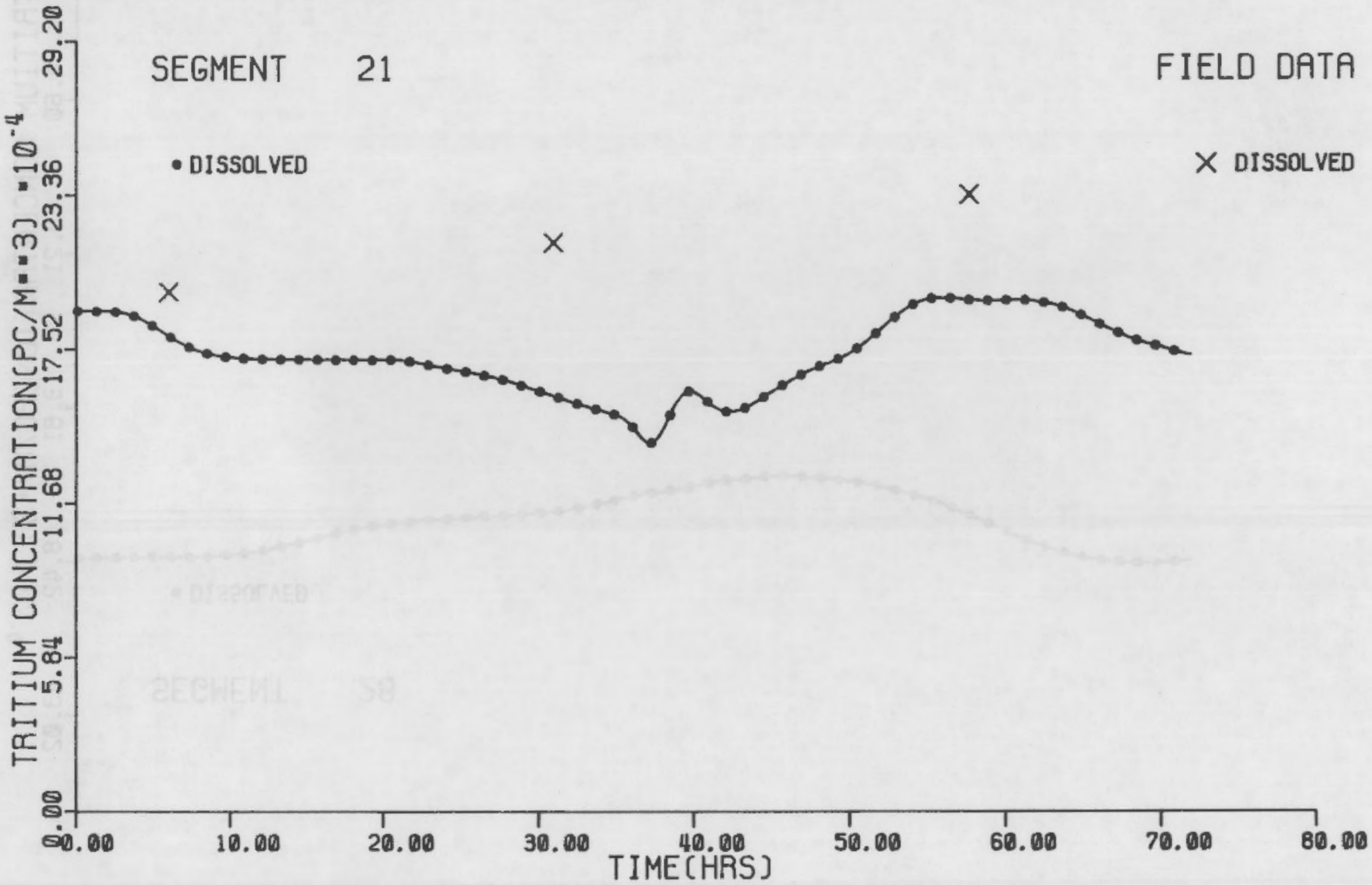

SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
⊡ CLAY
PLUTONIUM CONCENTRATION(PC/KG) *10⁻¹
0.00
1.22
2.45
3.67
4.90
6.12
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

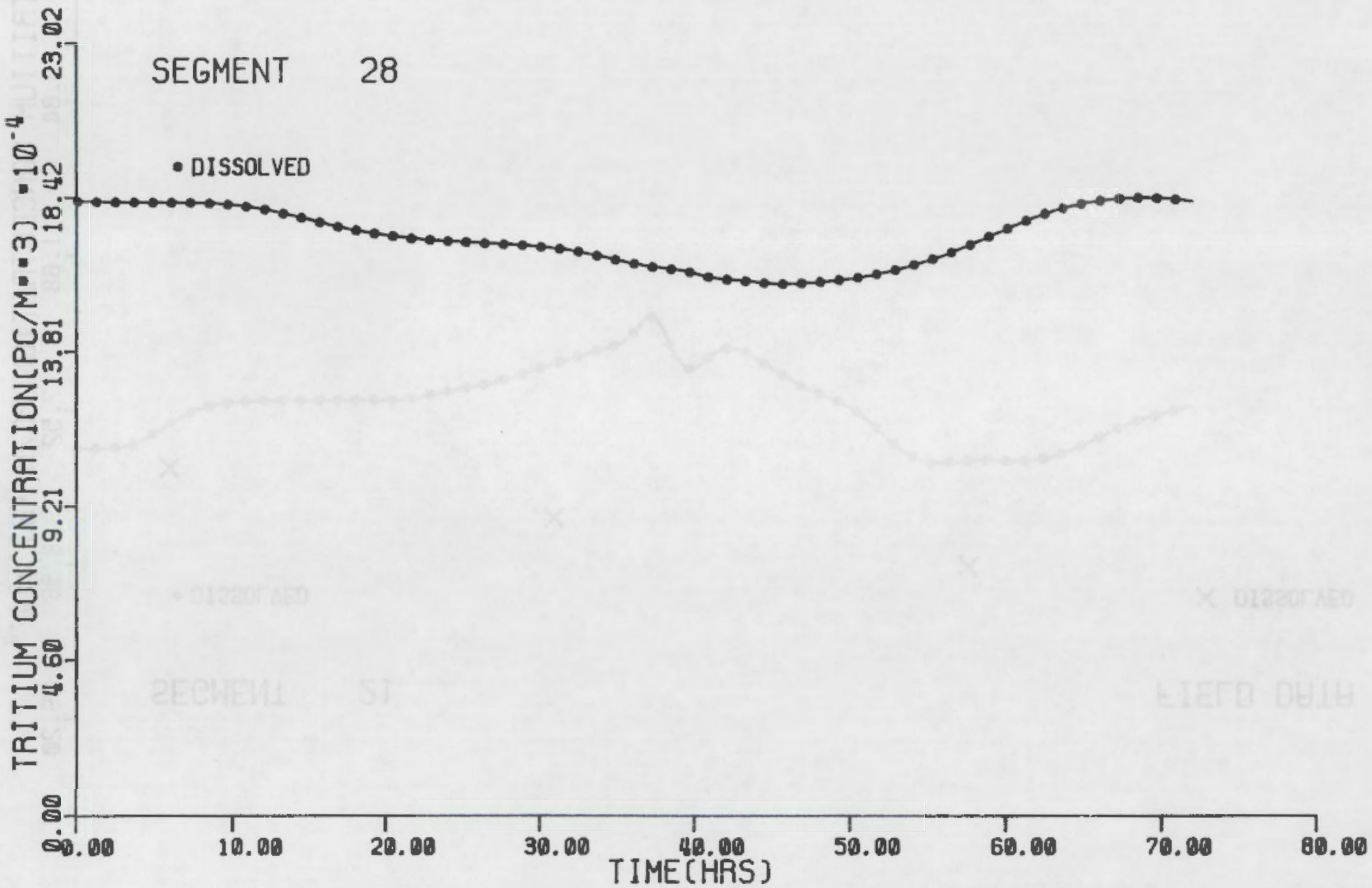

SEGMENT 28
- SAND
▲ SILT
+ CLAY
● DISSOLVED
PLUTONIUM CONCENTRATION(PC/M**3)
3.66
2.93
2.20
1.46
.73
.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

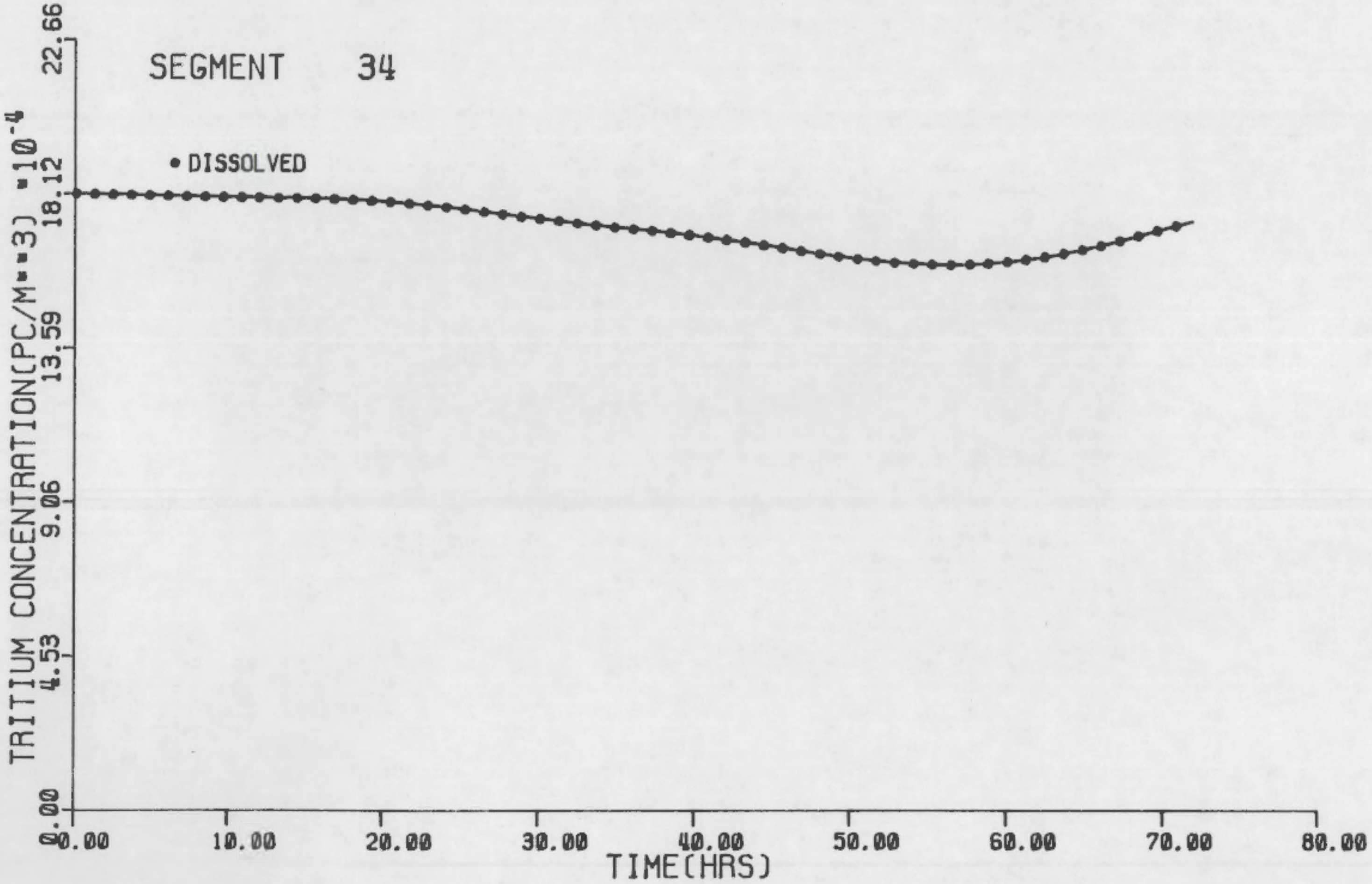

SEGMENT 3
FIELD DATA
● DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-4
36.26
29.01
21.75
14.50
7.25
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)


SEGMENT 6
FIELD DATA
• DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-4
0.00
7.88
15.76
23.64
31.52
39.40
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

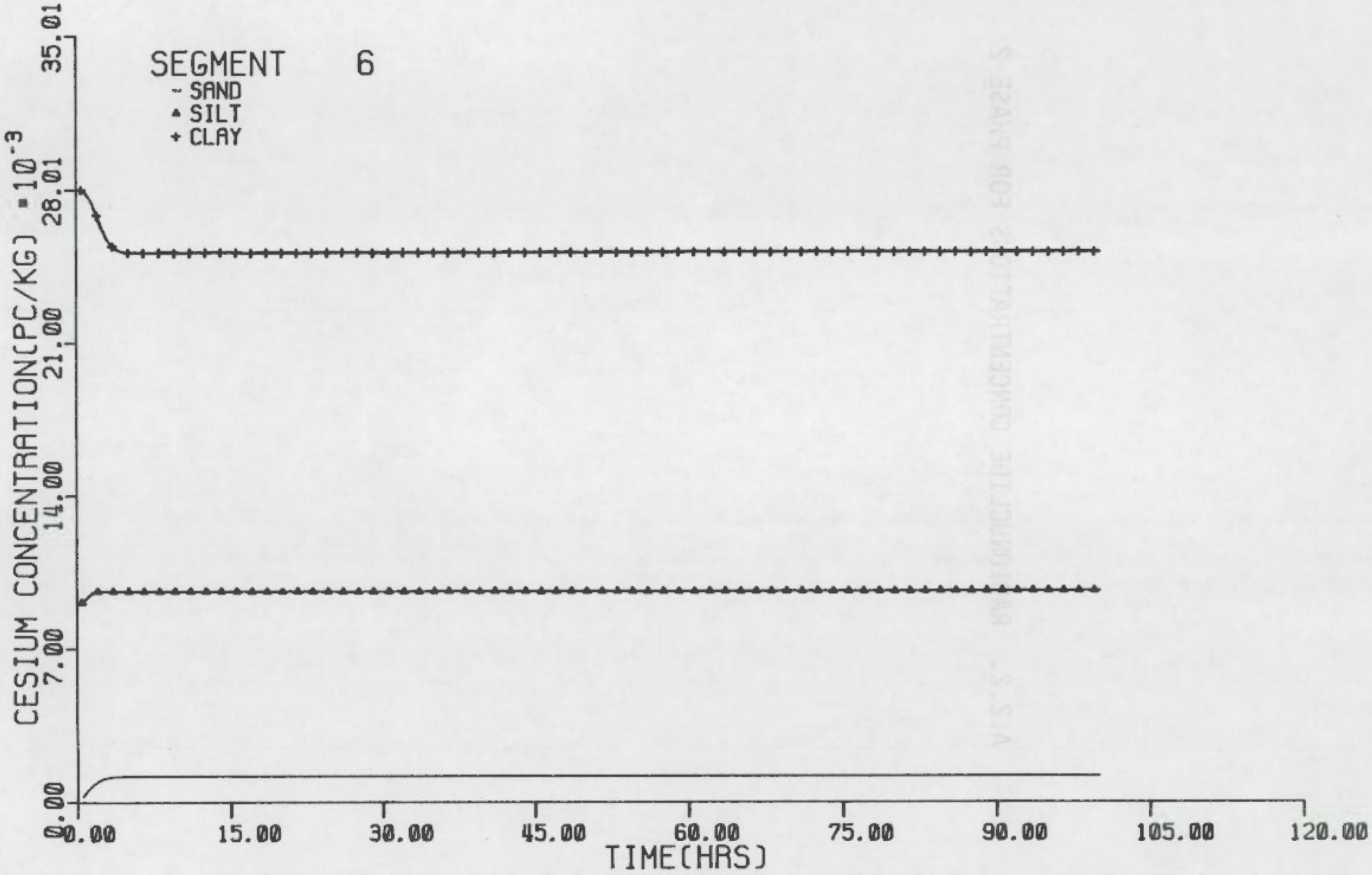

SEGMENT 8
FIELD DATA
• DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-4
0.00
5.25
10.50
15.75
21.00
26.25
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

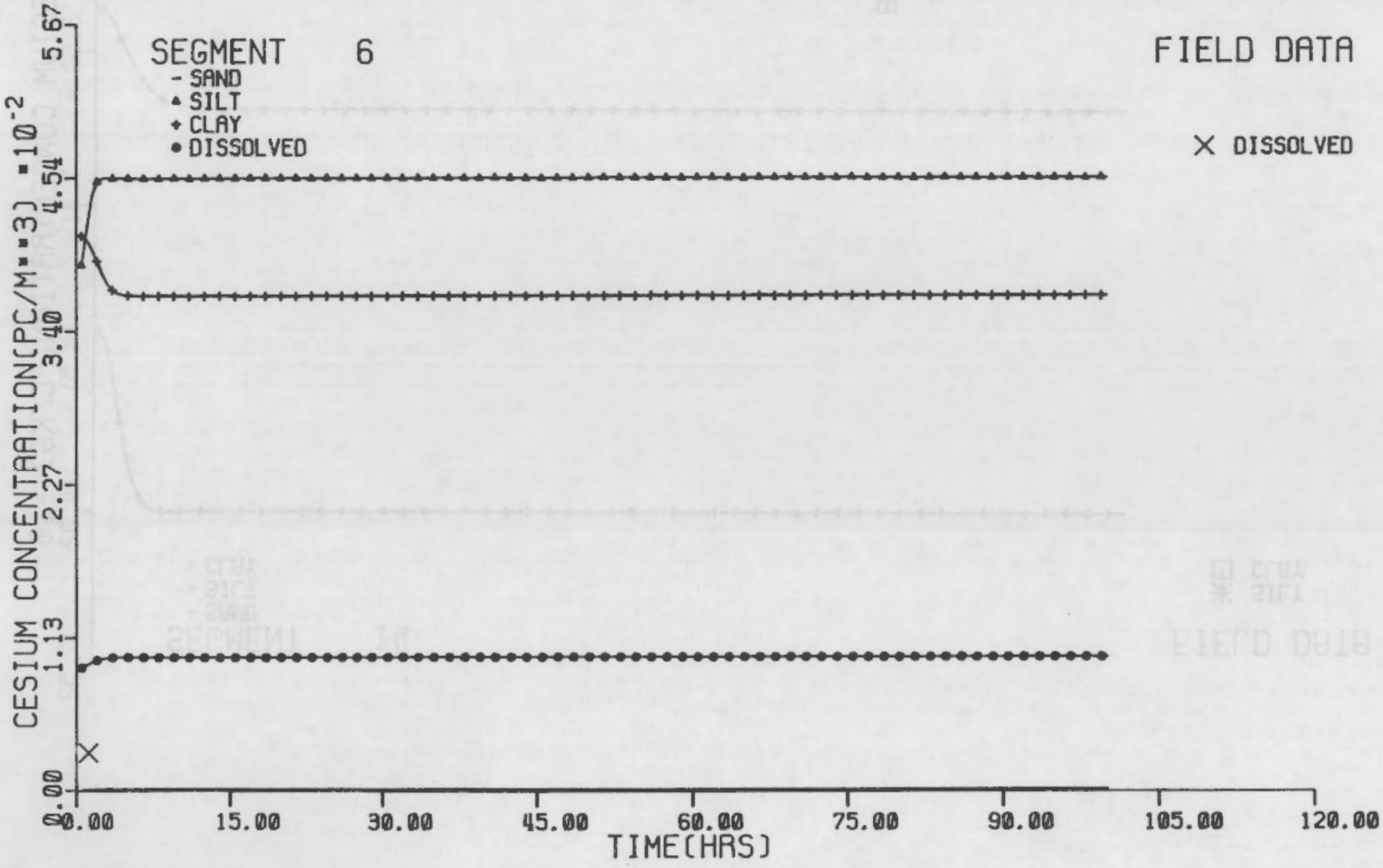

SEGMENT 21
FIELD DATA
• DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10⁴
0.00
5.84
11.68
17.52
23.36
29.20
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

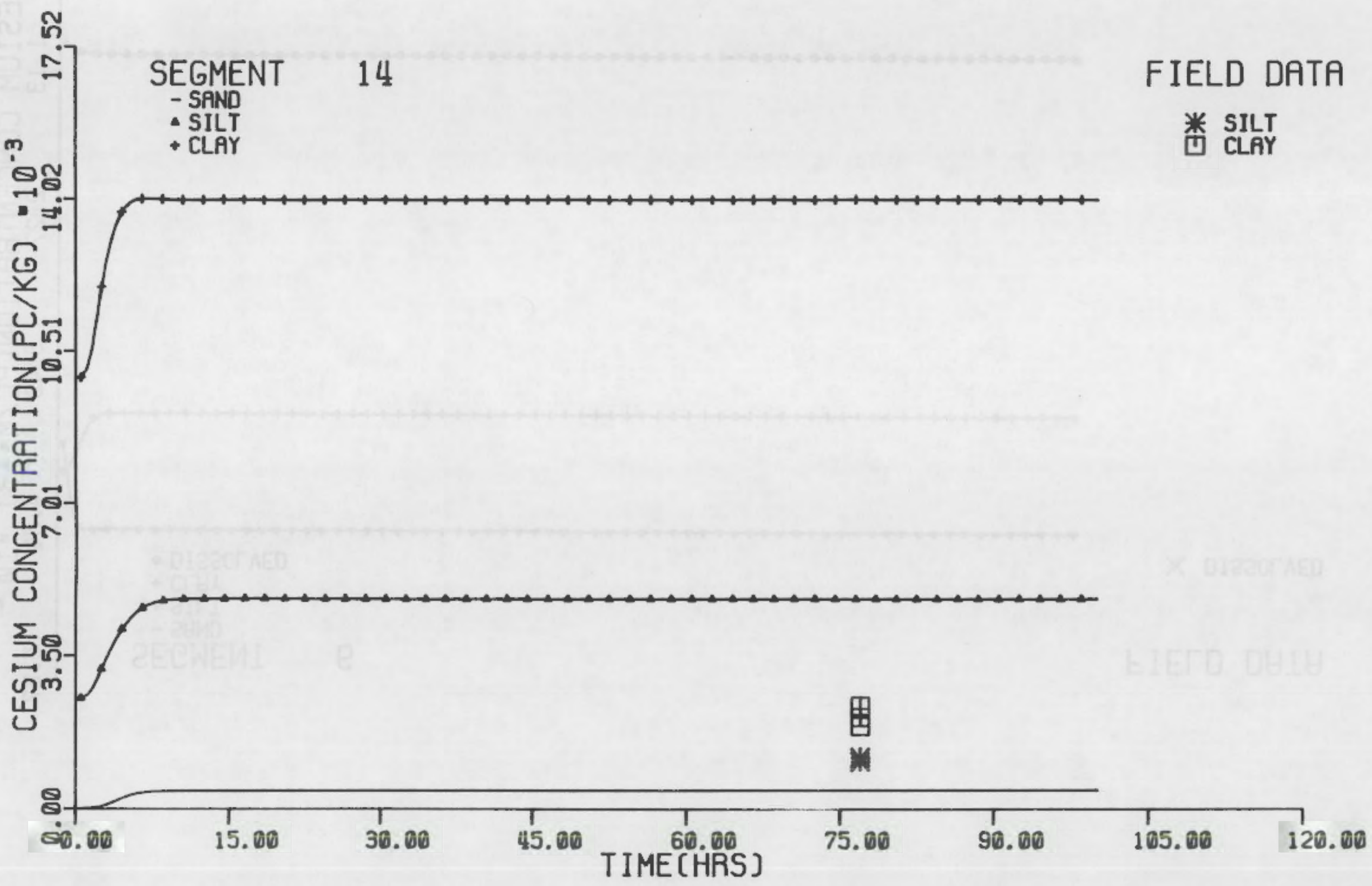

SEGMENT 28
• DISSOLVED
TRITIUM CONCENTRATION(PC/M**3)*10^4
0.00
4.60
9.21
13.81
18.42
23.02
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

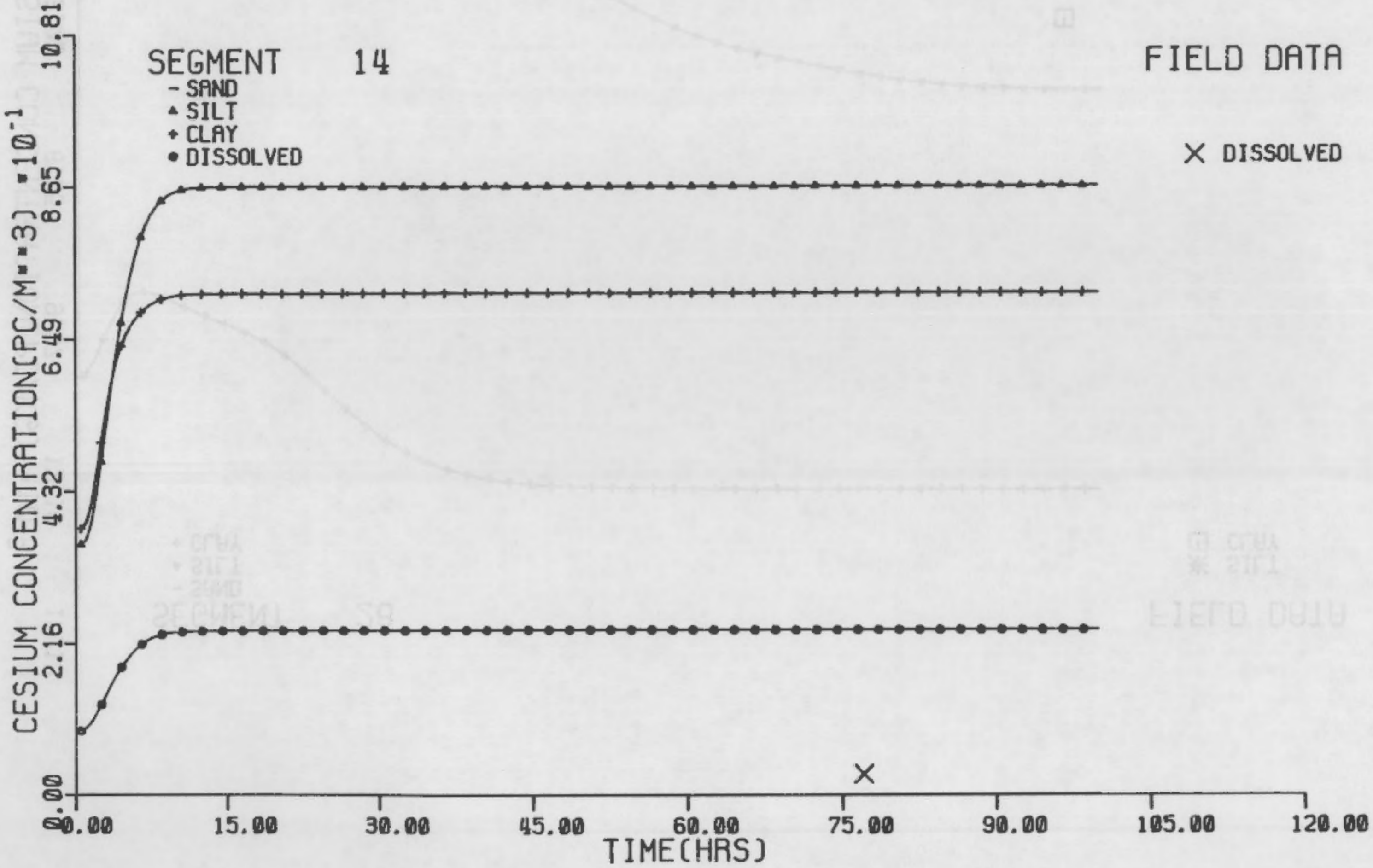

SEGMENT 34
● DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-4
0.00
4.53
9.06
13.59
18.12
22.66
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME(HRS)

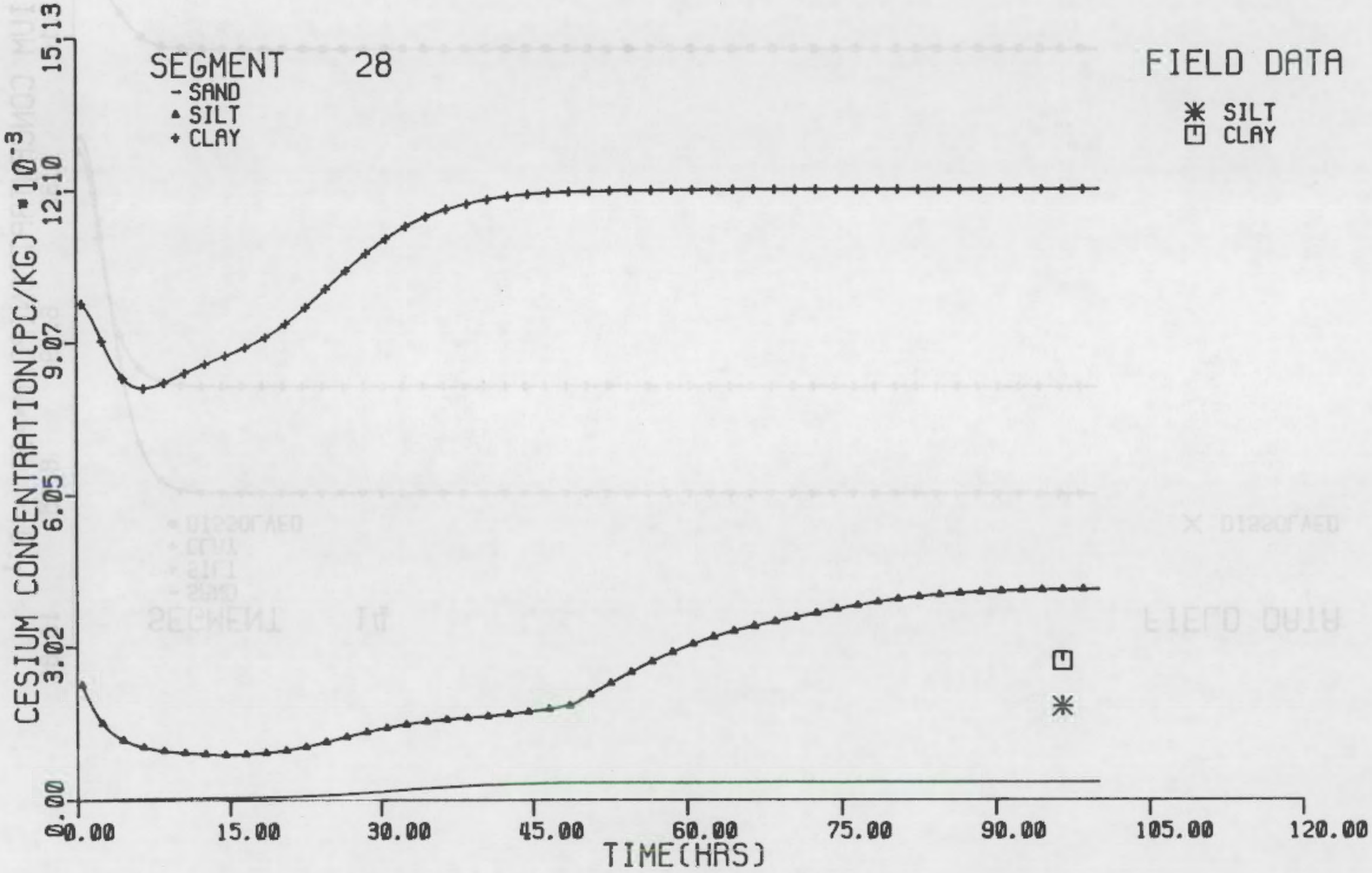
A.2.2. RADIONUCLIDE CONCENTRATIONS FOR PHASE 2

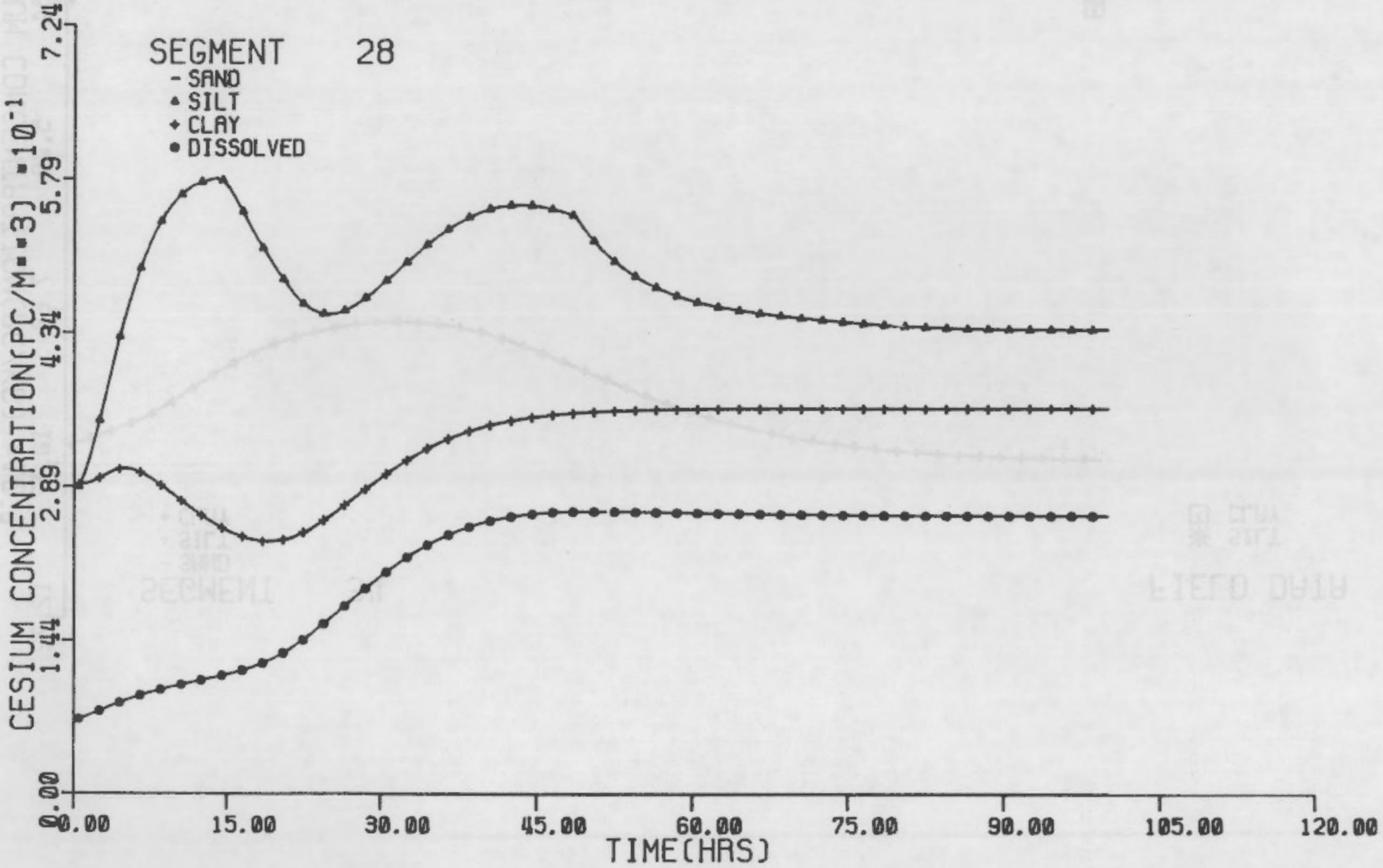

SEGMENT 6
- SAND
▲ SILT
+ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
7.00
14.00
21.00
28.01
35.01
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

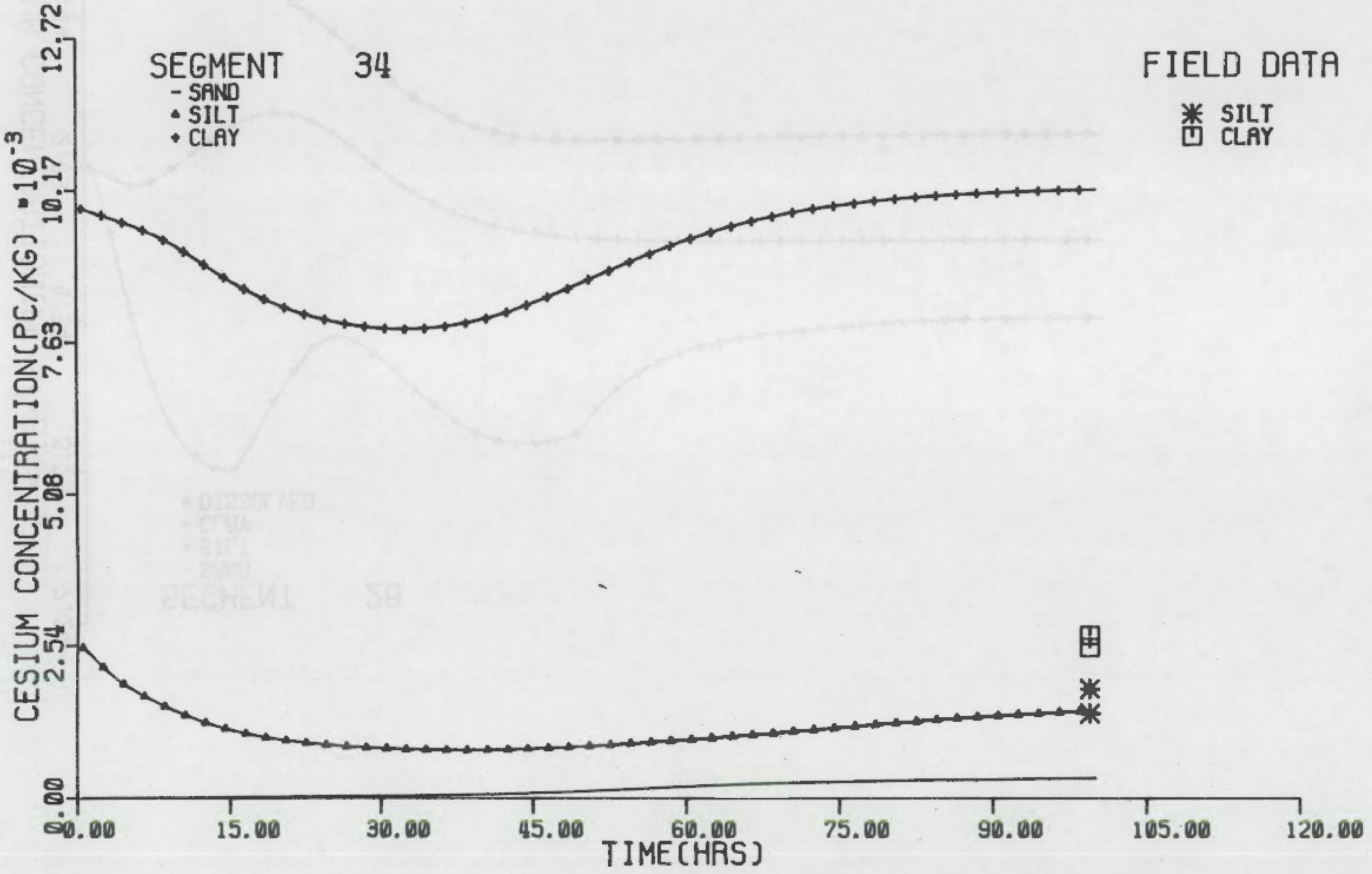

SEGMENT 6
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-2
0.00
1.13
2.27
3.40
4.54
5.67
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

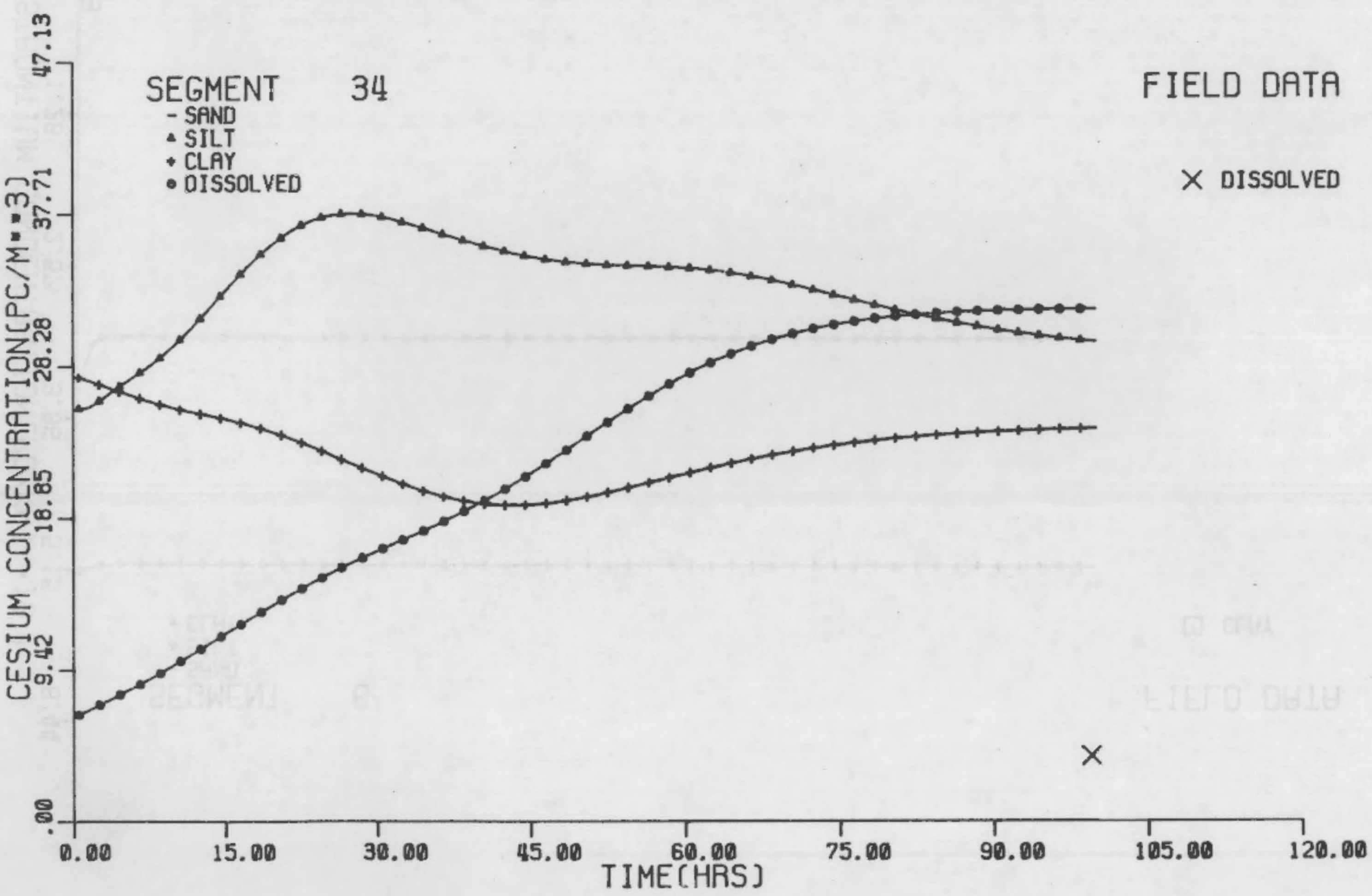

SEGMENT 14
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
3.50
7.01
10.51
14.02
17.52
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

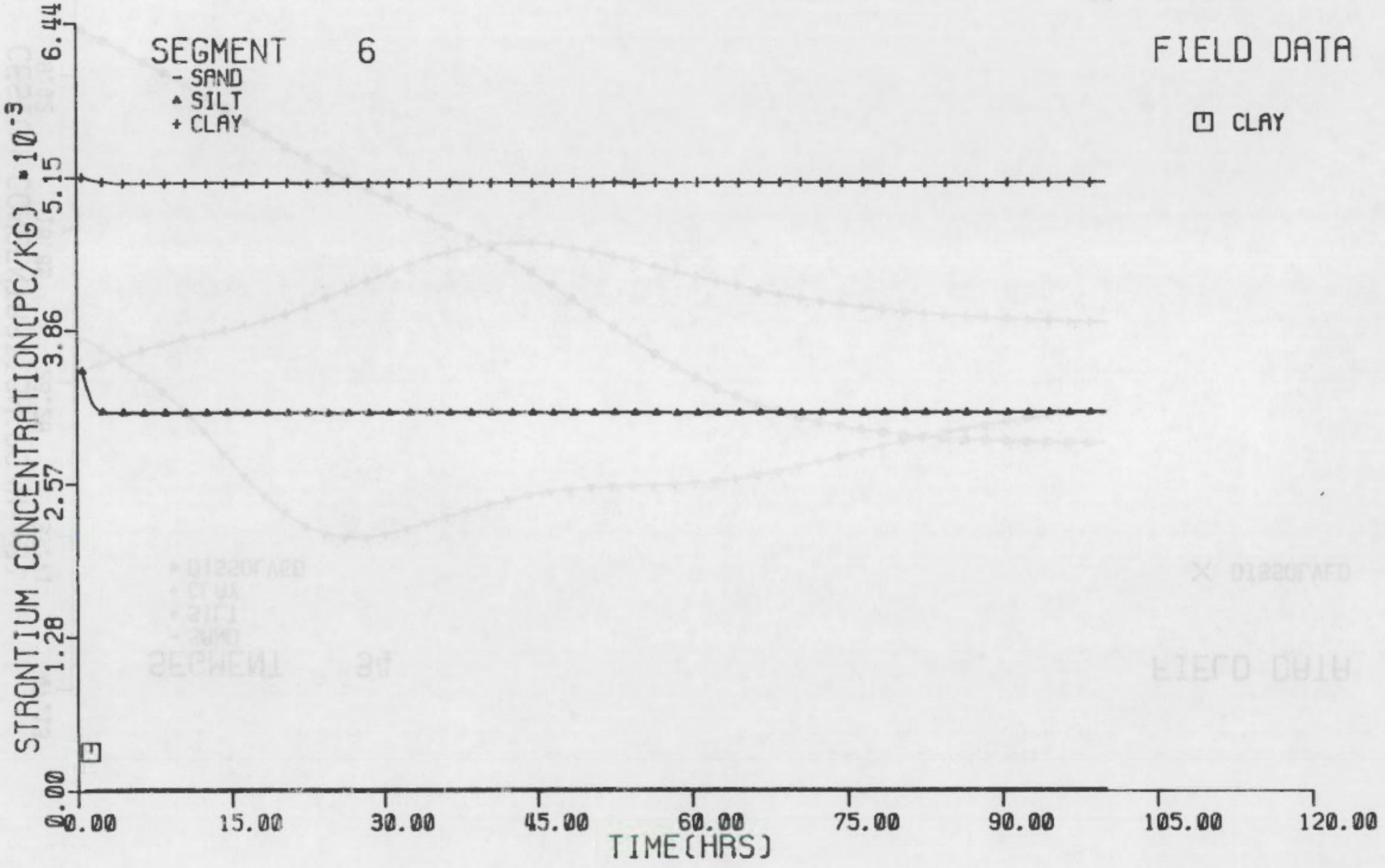

SEGMENT 14
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
CESIUM CONCENTRATION(PC/M**3)*10⁻¹
0.00
2.16
4.32
6.49
8.65
10.81
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

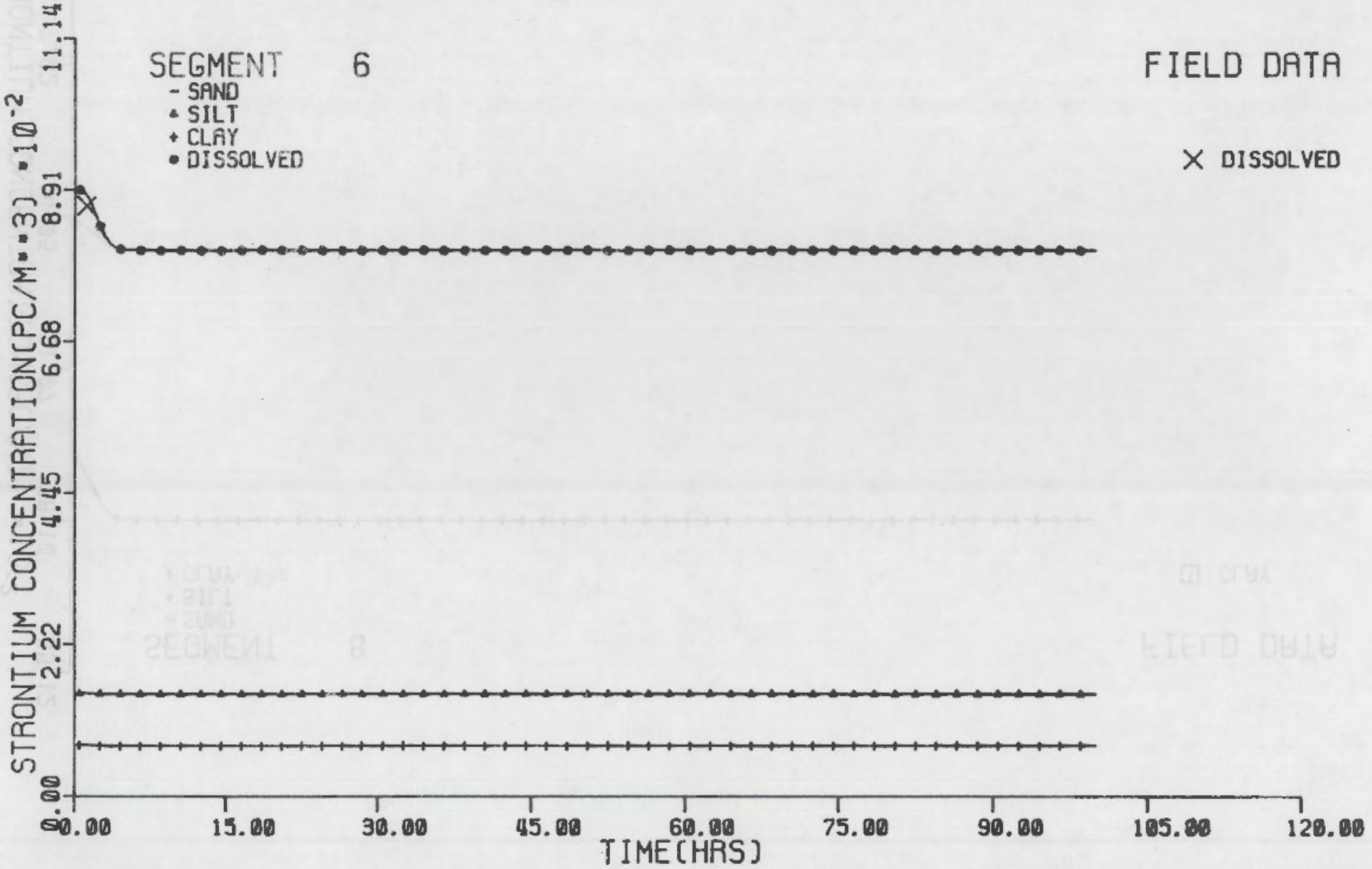

SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
□ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
3.02
6.05
9.07
12.10
15.13
TIME(HRS)
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00

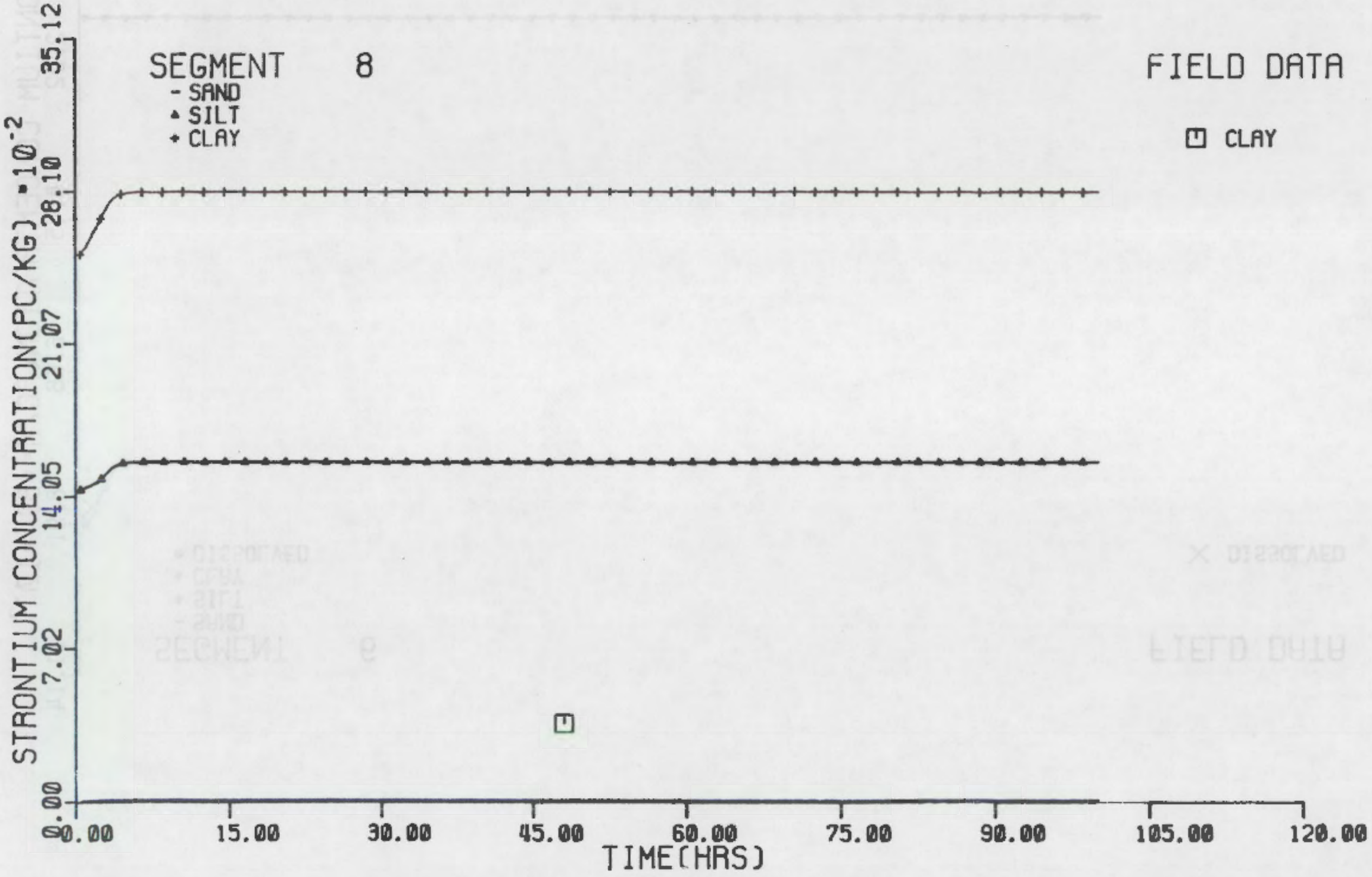

SEGMENT 28
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^{-1}
0.00
1.44
2.89
4.34
5.79
7.24
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

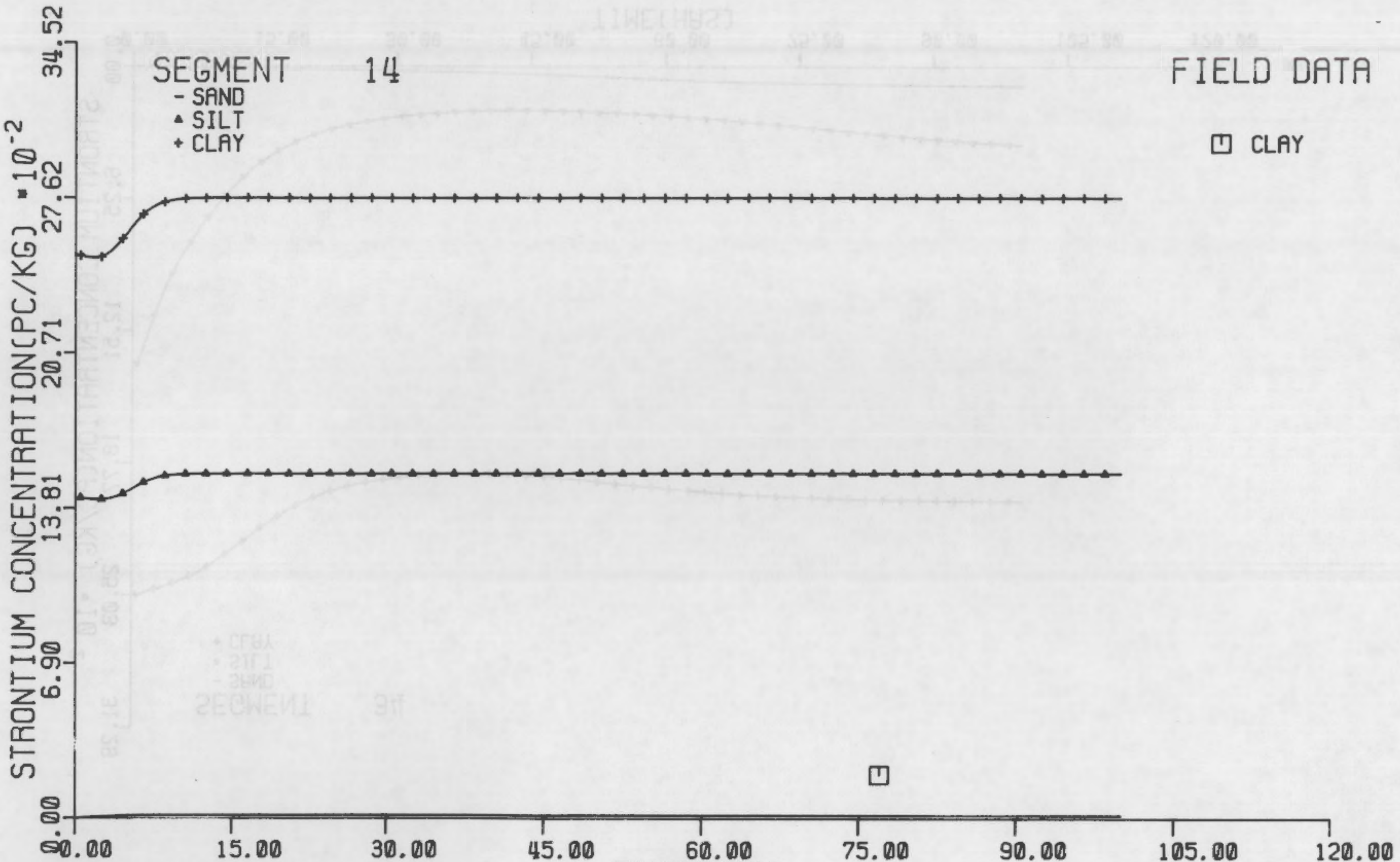

SEGMENT 34
- SAND
▲ SILT
◆ CLAY
FIELD DATA
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^{-3}
0.00
2.54
5.08
7.63
10.17
12.72
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

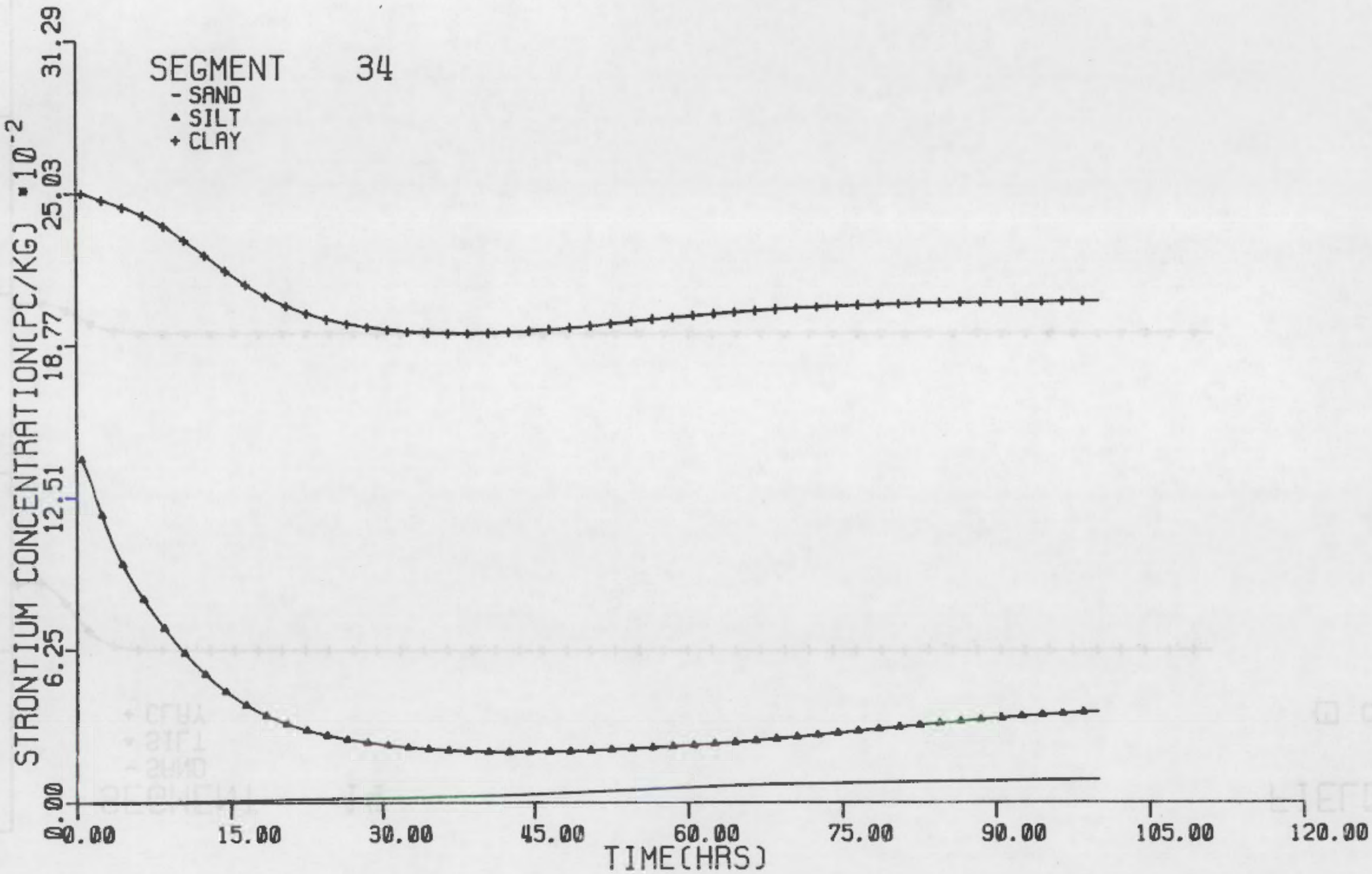

SEGMENT 34
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
CESIUM CONCENTRATION(PC/M**3)
.00
9.42
18.85
28.28
37.71
47.13
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

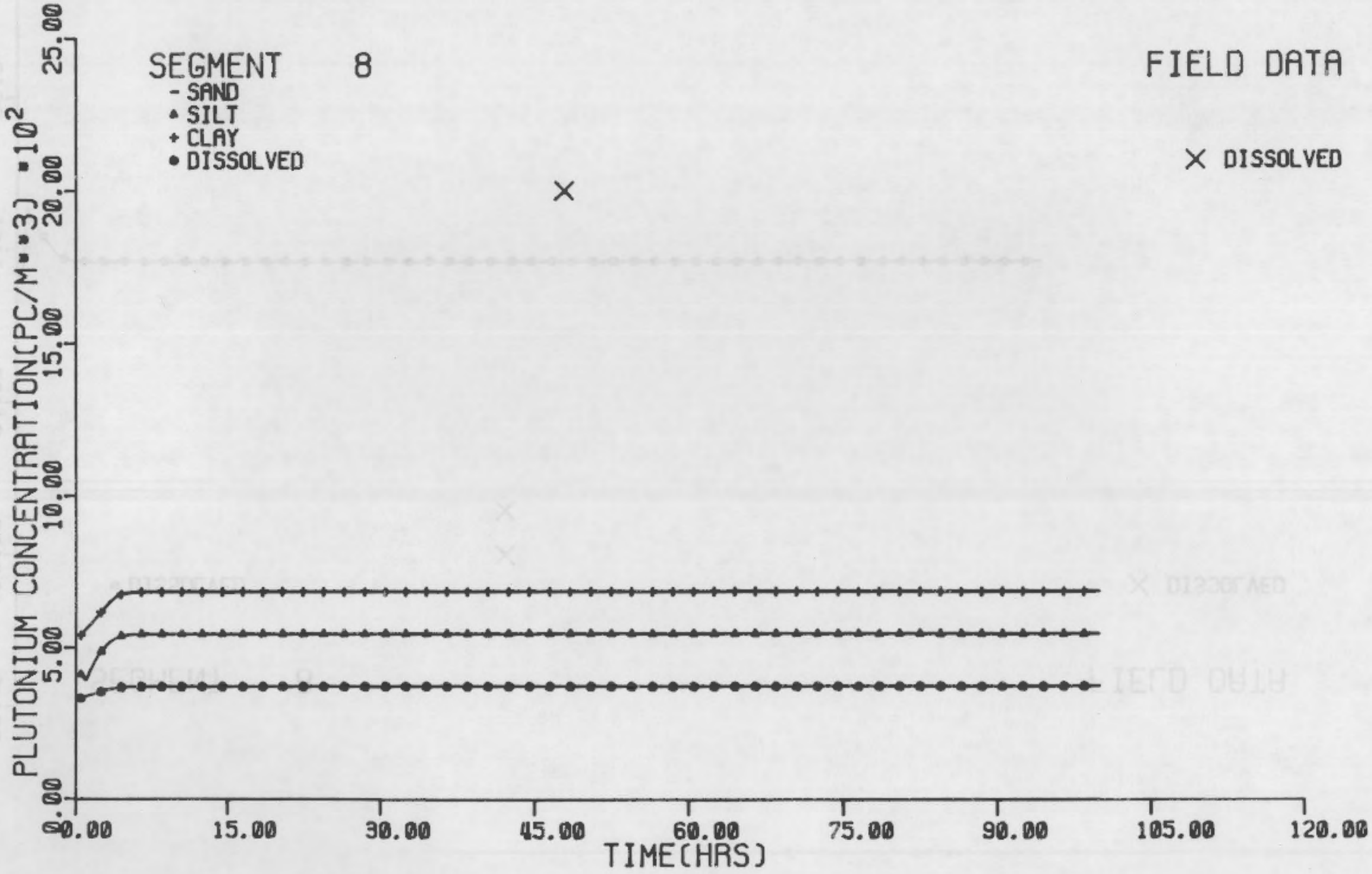

SEGMENT 6
- SAND
▲ SILT
+ CLAY
FIELD DATA
⊡ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^{-3}
0.00
1.28
2.57
3.86
5.15
6.44
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

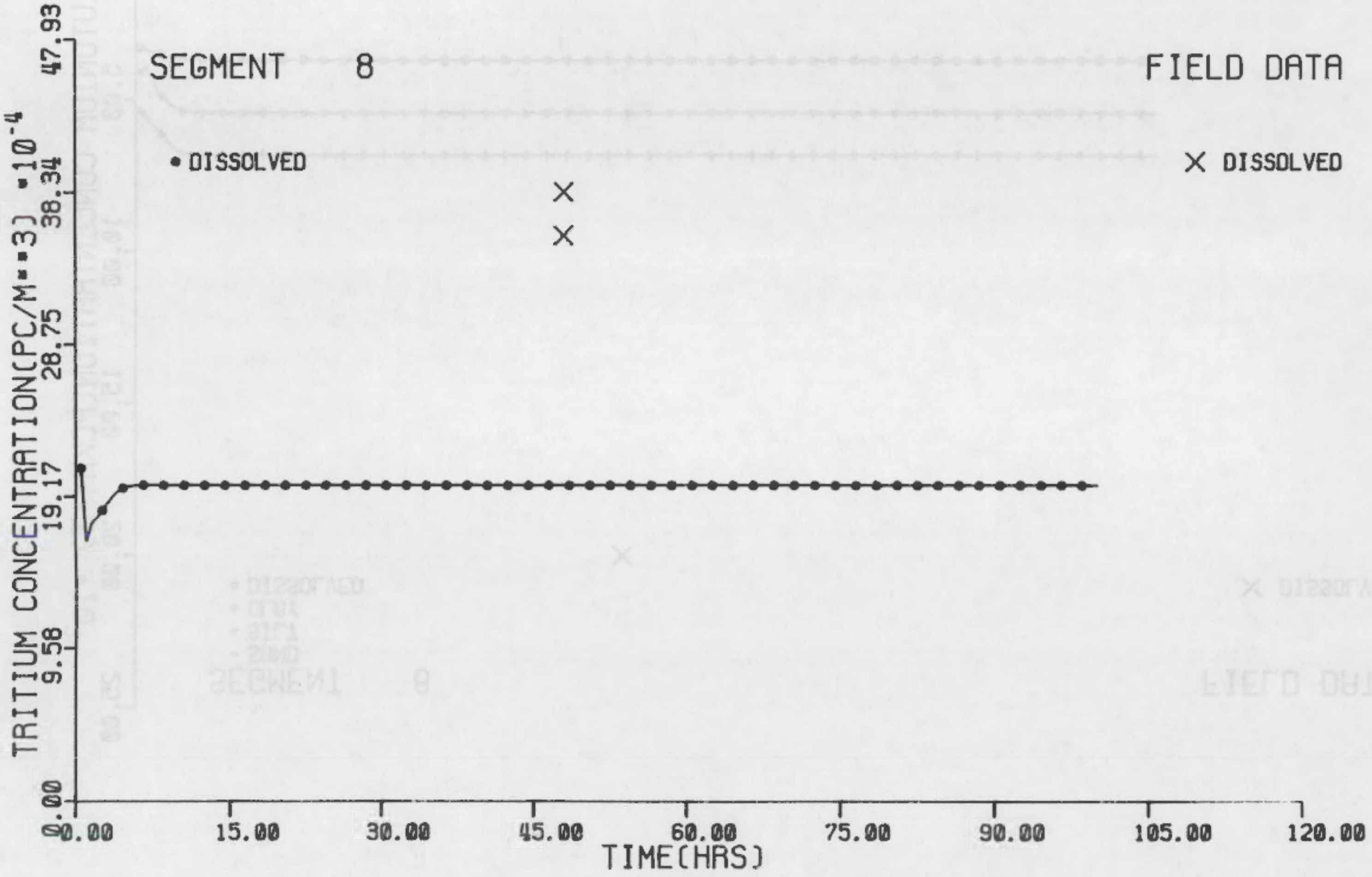

SEGMENT 6
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
STRONTIUM CONCENTRATION(PC/M**3) *10^-2
0.00
2.22
4.45
6.68
8.91
11.14
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

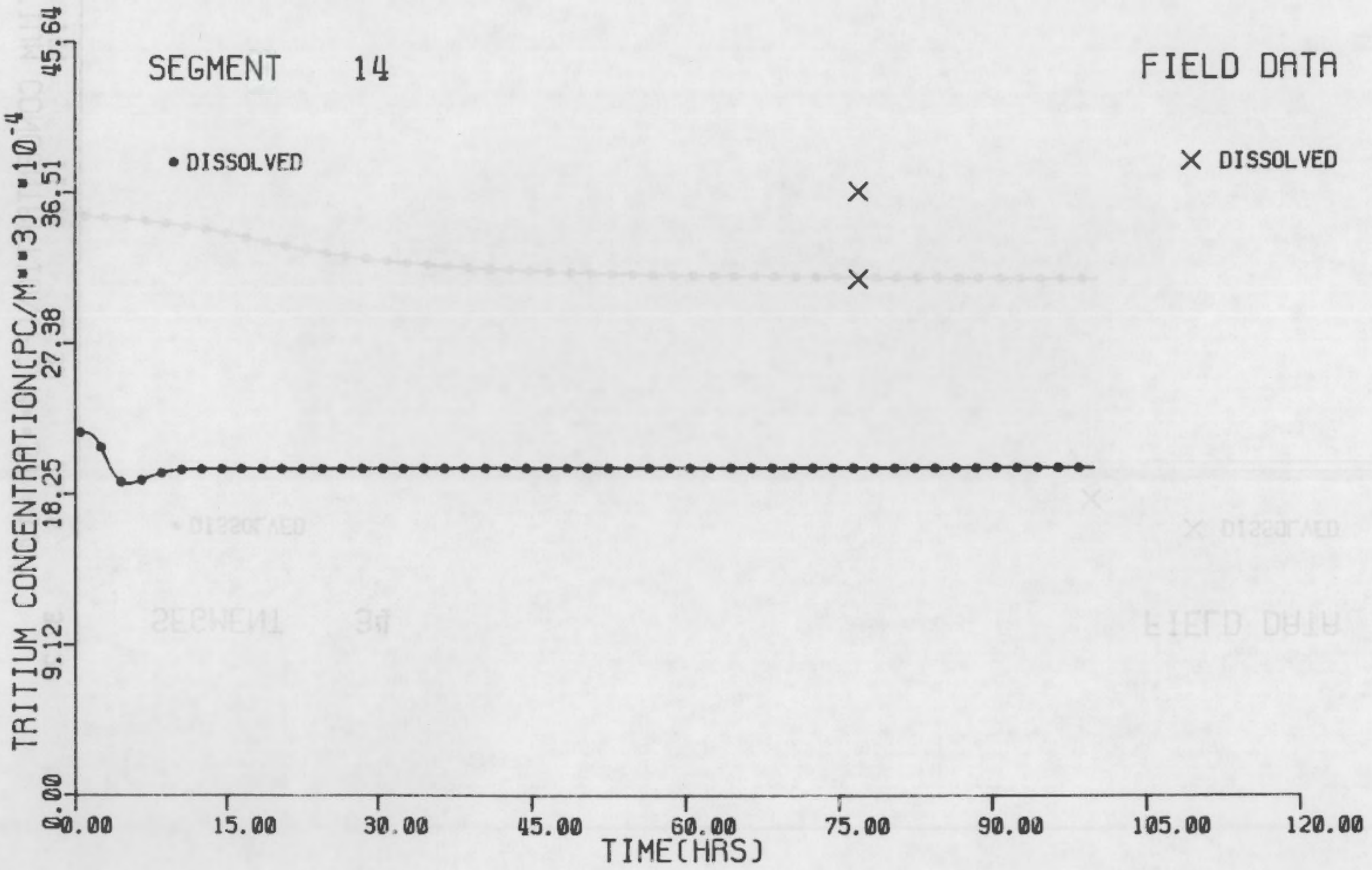

SEGMENT 8
- SAND
▲ SILT
+ CLAY
FIELD DATA
⊡ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^-2
35.12
28.10
21.07
14.05
7.02
0.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

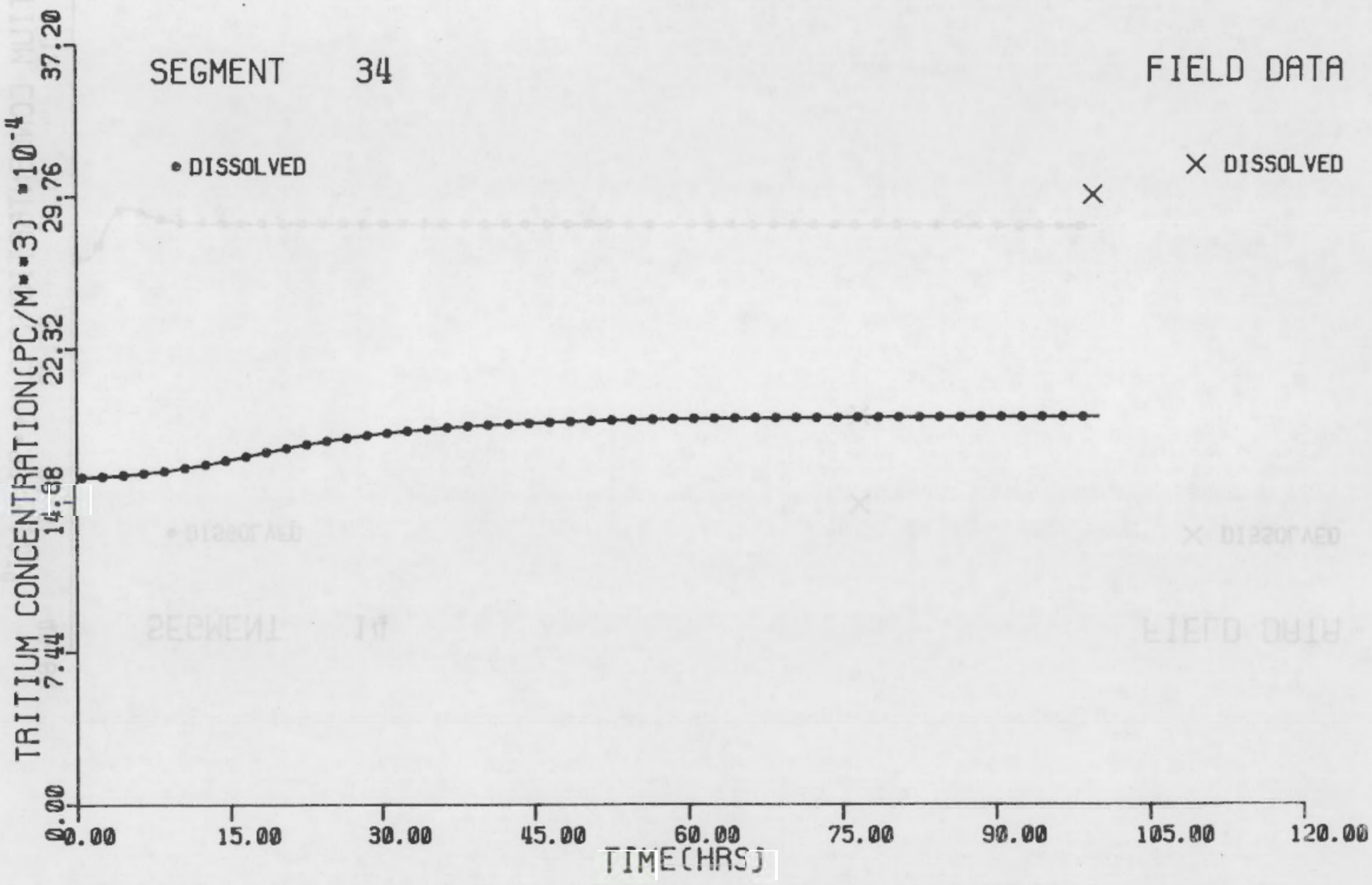

SEGMENT 14
- SAND
▲ SILT
+ CLAY
FIELD DATA
⊡ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^-2
34.52
27.62
20.71
13.81
6.90
0.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)


SEGMENT 34
- SAND
▲ SILT
+ CLAY
STRONTIUM CONCENTRATION(PC/KG) *10^-2
31.29
25.03
18.77
12.51
6.25
0.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

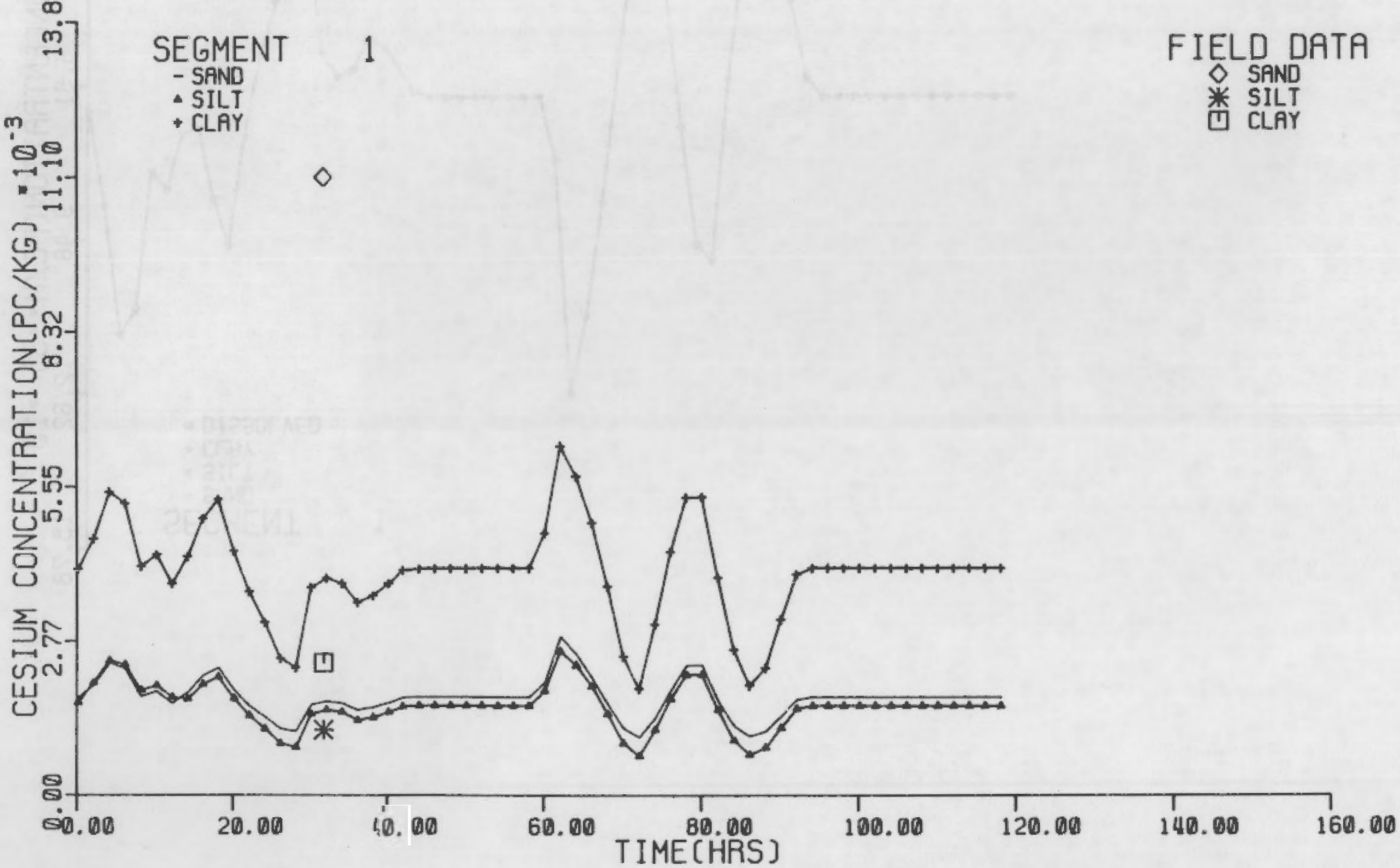

SEGMENT 8
- SAND
▲ SILT
+ CLAY
● DISSOLVED
FIELD DATA
× DISSOLVED
PLUTONIUM CONCENTRATION(PC/M**3) *10^2
0.00
5.00
10.00
15.00
20.00
25.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

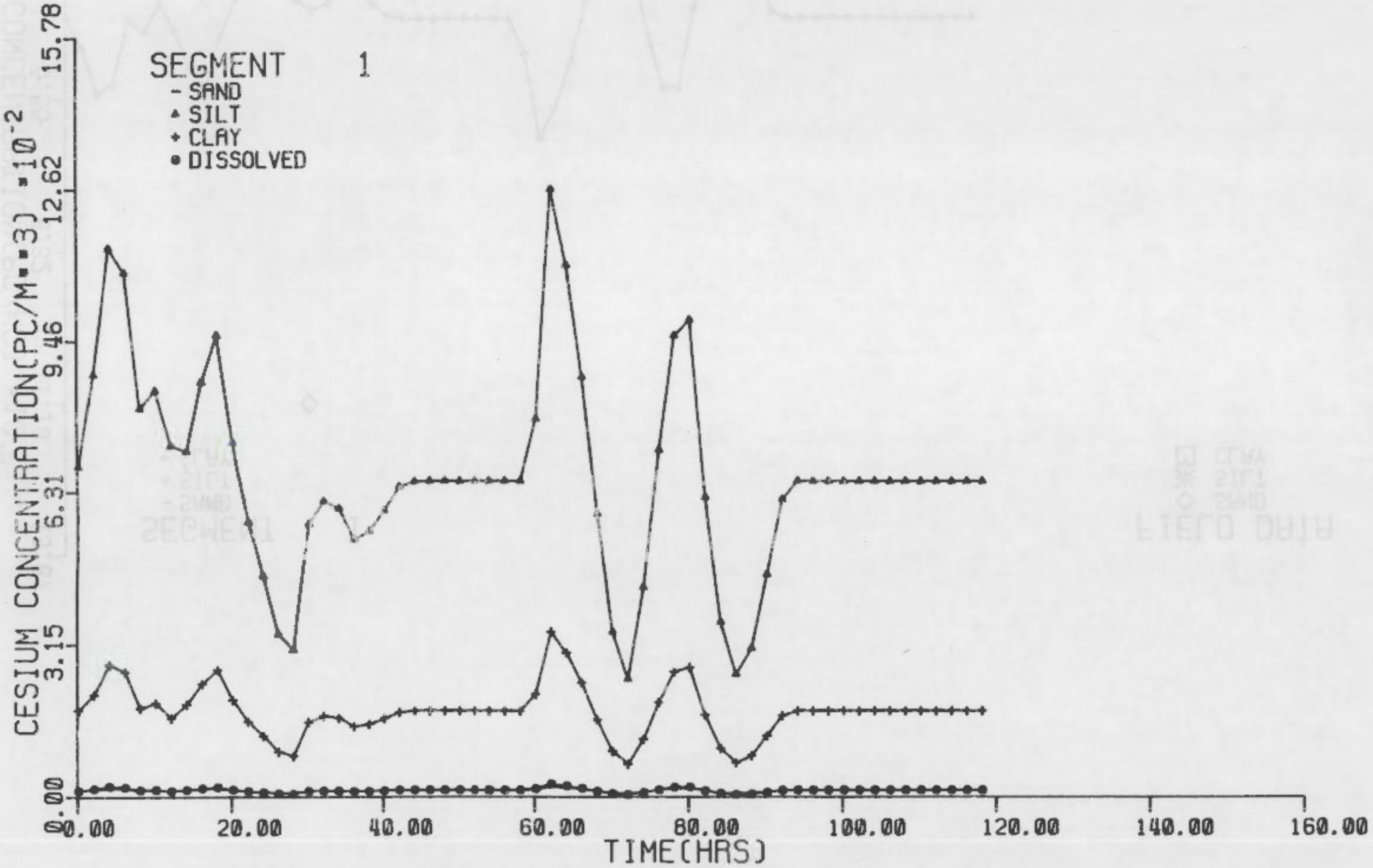

SEGMENT 8
FIELD DATA
• DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-4
0.00
9.58
19.17
28.75
38.34
47.93
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

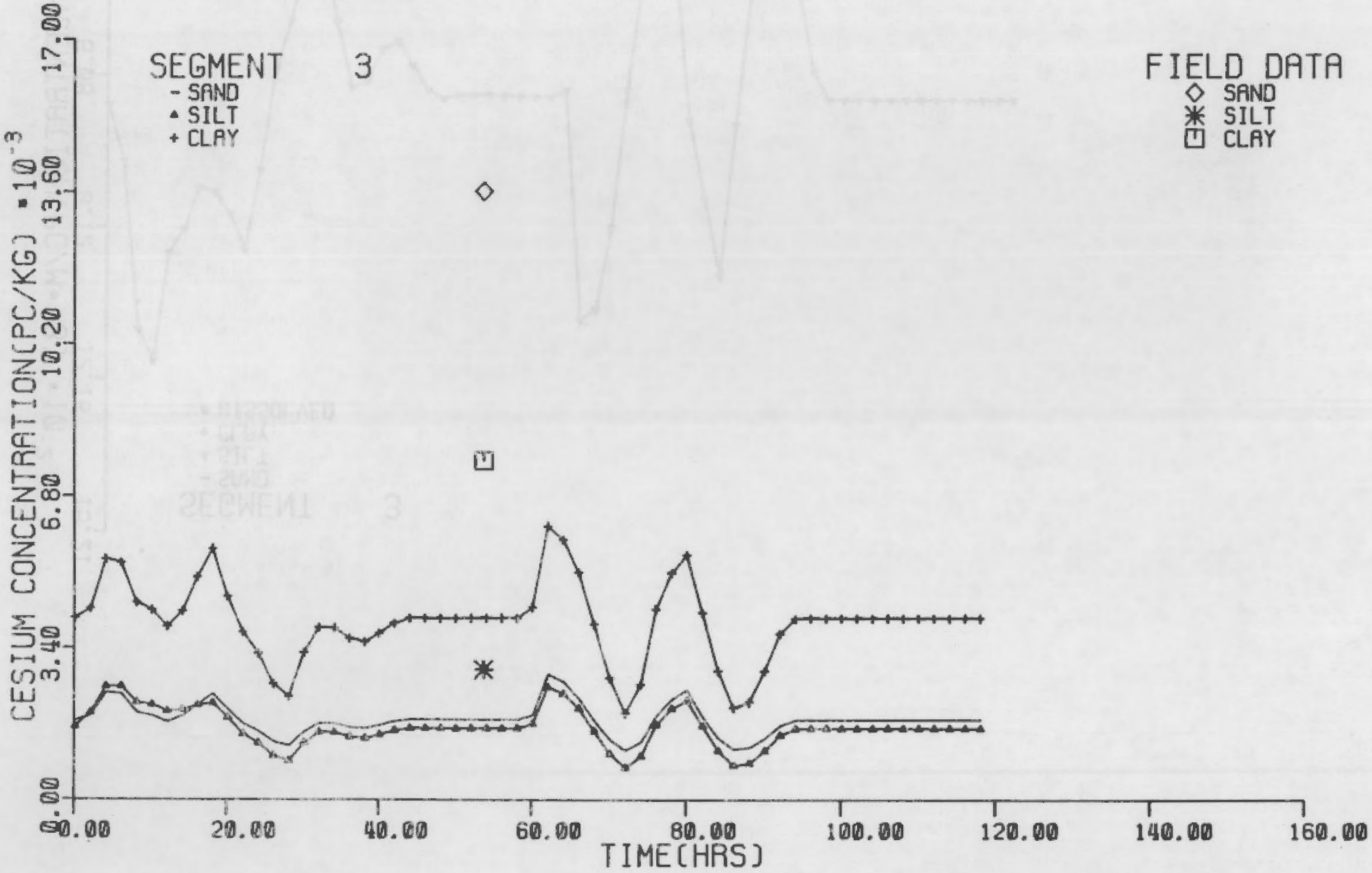

SEGMENT 14
FIELD DATA
• DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10-4
0.00
9.12
18.25
27.38
36.51
45.64
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

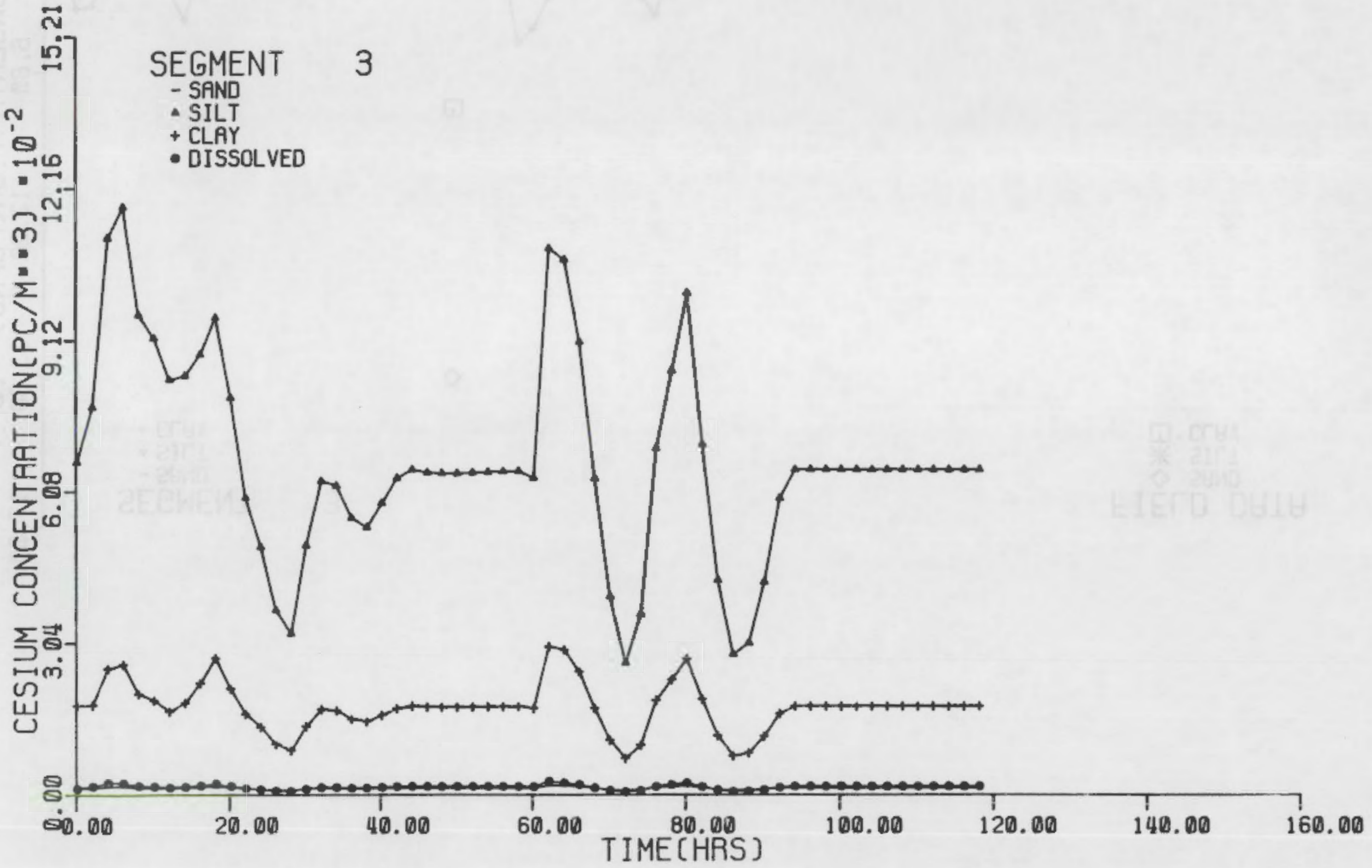

SEGMENT 34
FIELD DATA
● DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-4
37.20
29.76
22.32
14.88
7.44
0.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
TIME(HRS)

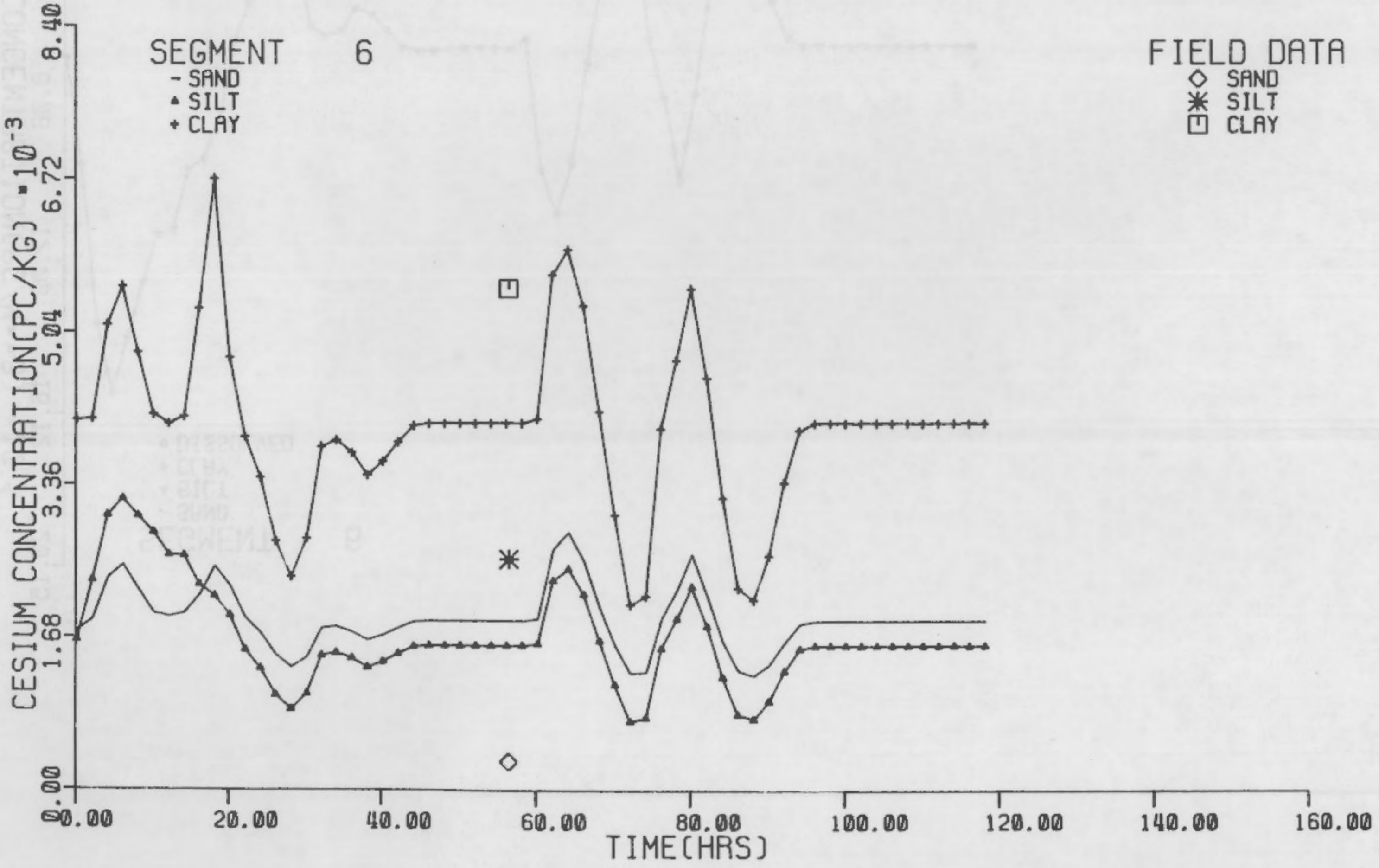
A.2.3. RADIONUCLIDE CONCENTRATIONS FOR PHASE 1

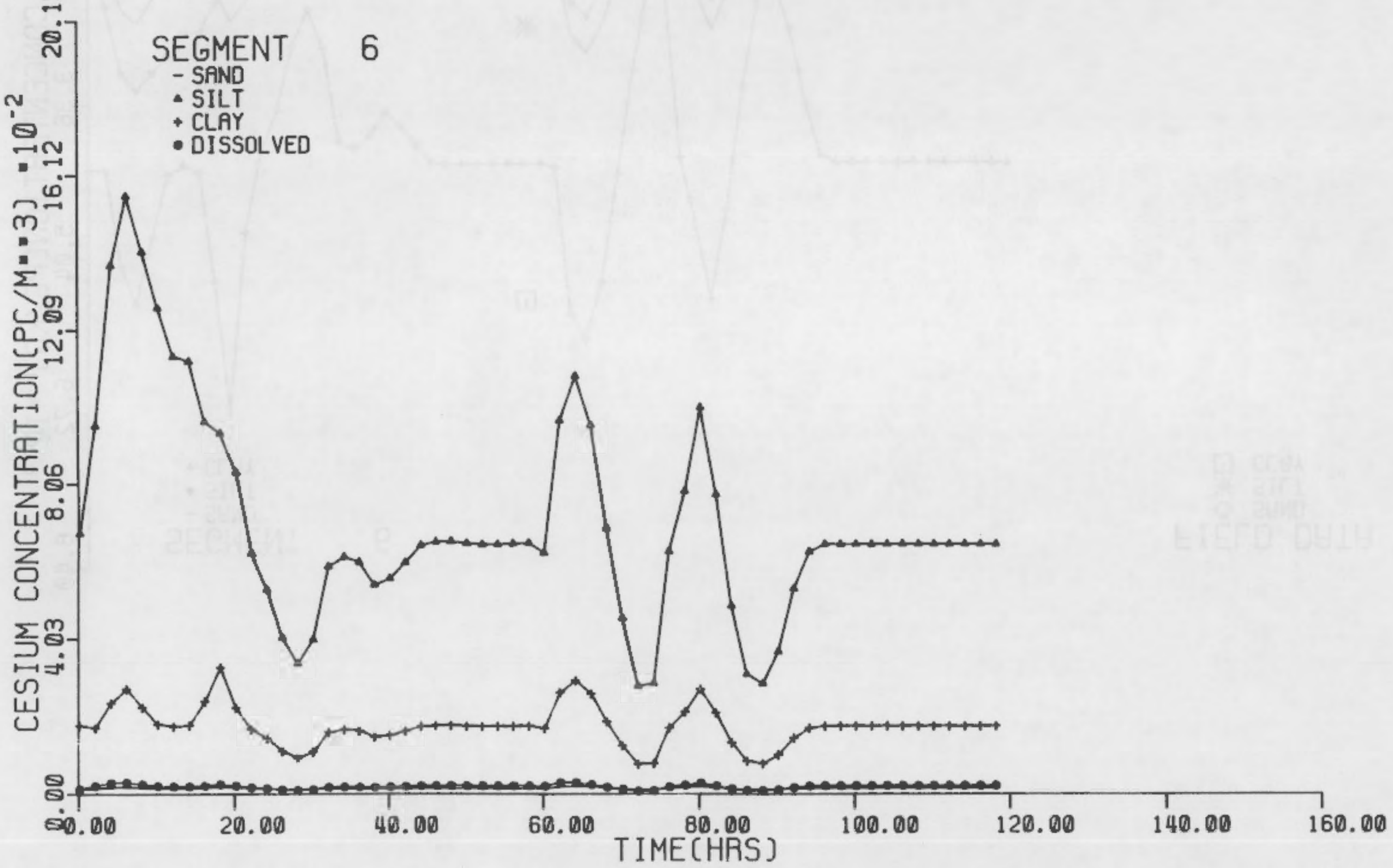

SEGMENT 1
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
2.77
5.55
8.32
11.10
13.87
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

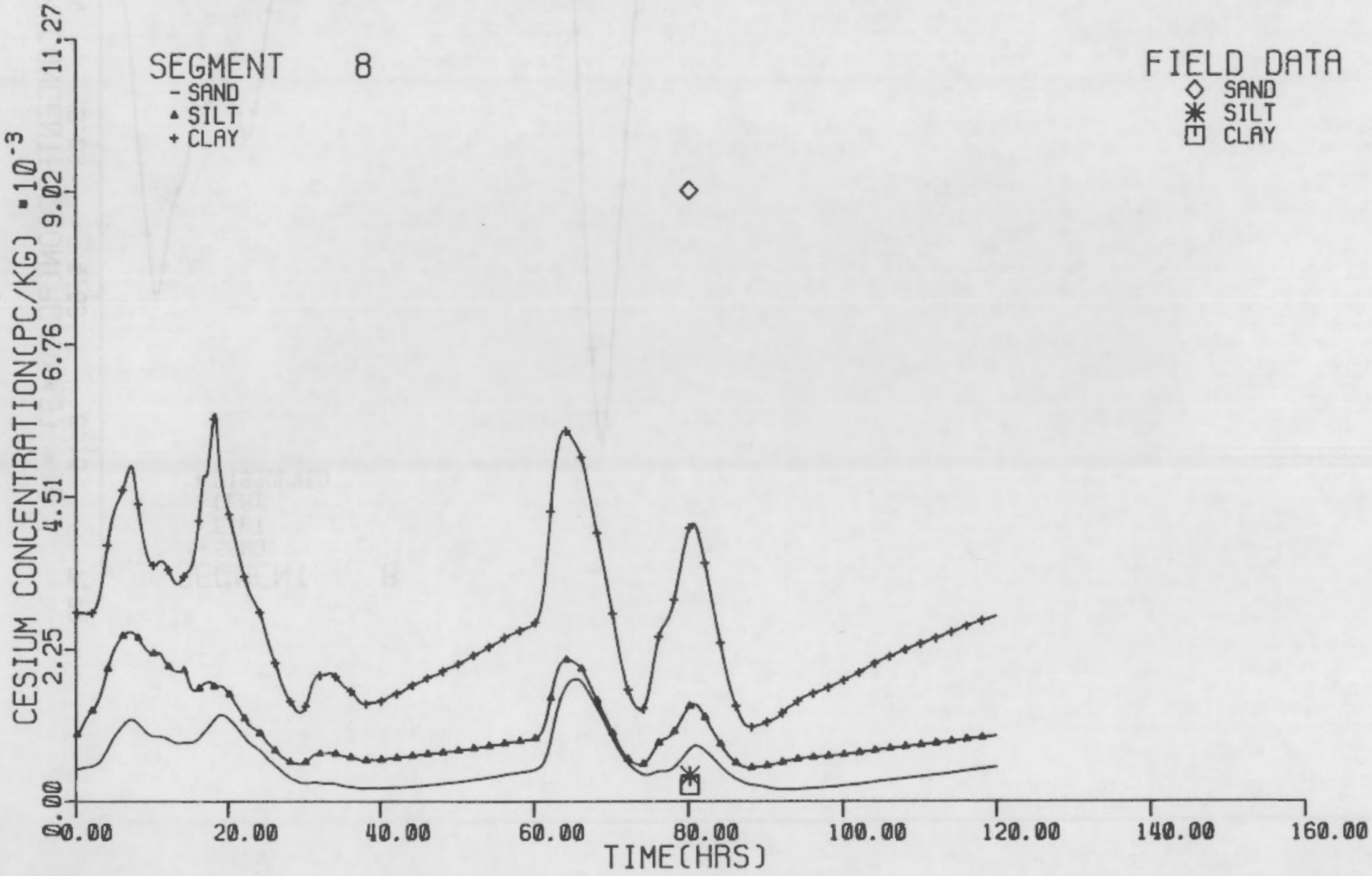

SEGMENT 1
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-2
0.00
3.15
6.31
9.46
12.62
15.78
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

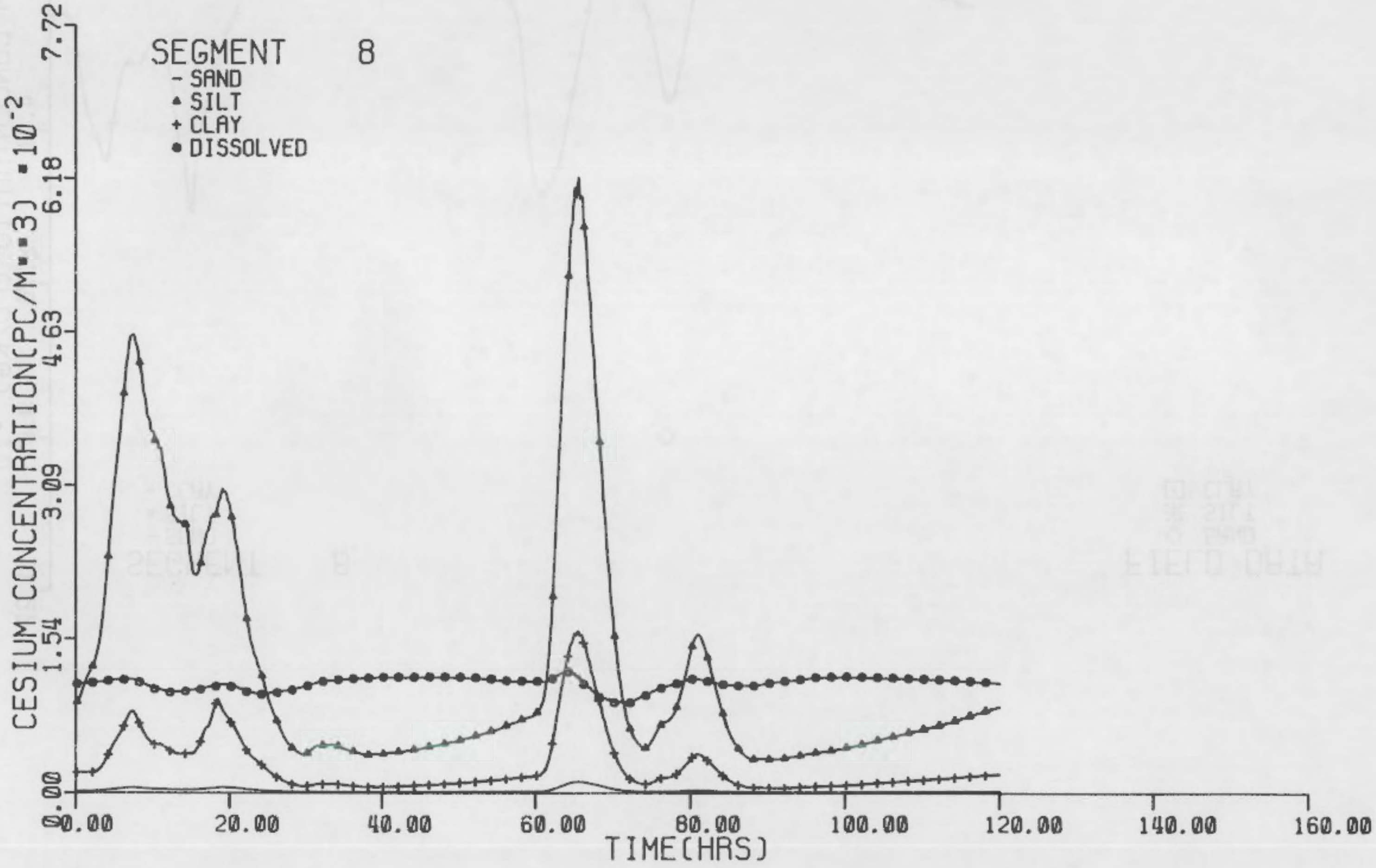

SEGMENT 3
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
□ CLAY
CESIUM CONCENTRATION(PC/KG) *10^{-3}
0.00
3.40
6.80
10.20
13.60
17.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

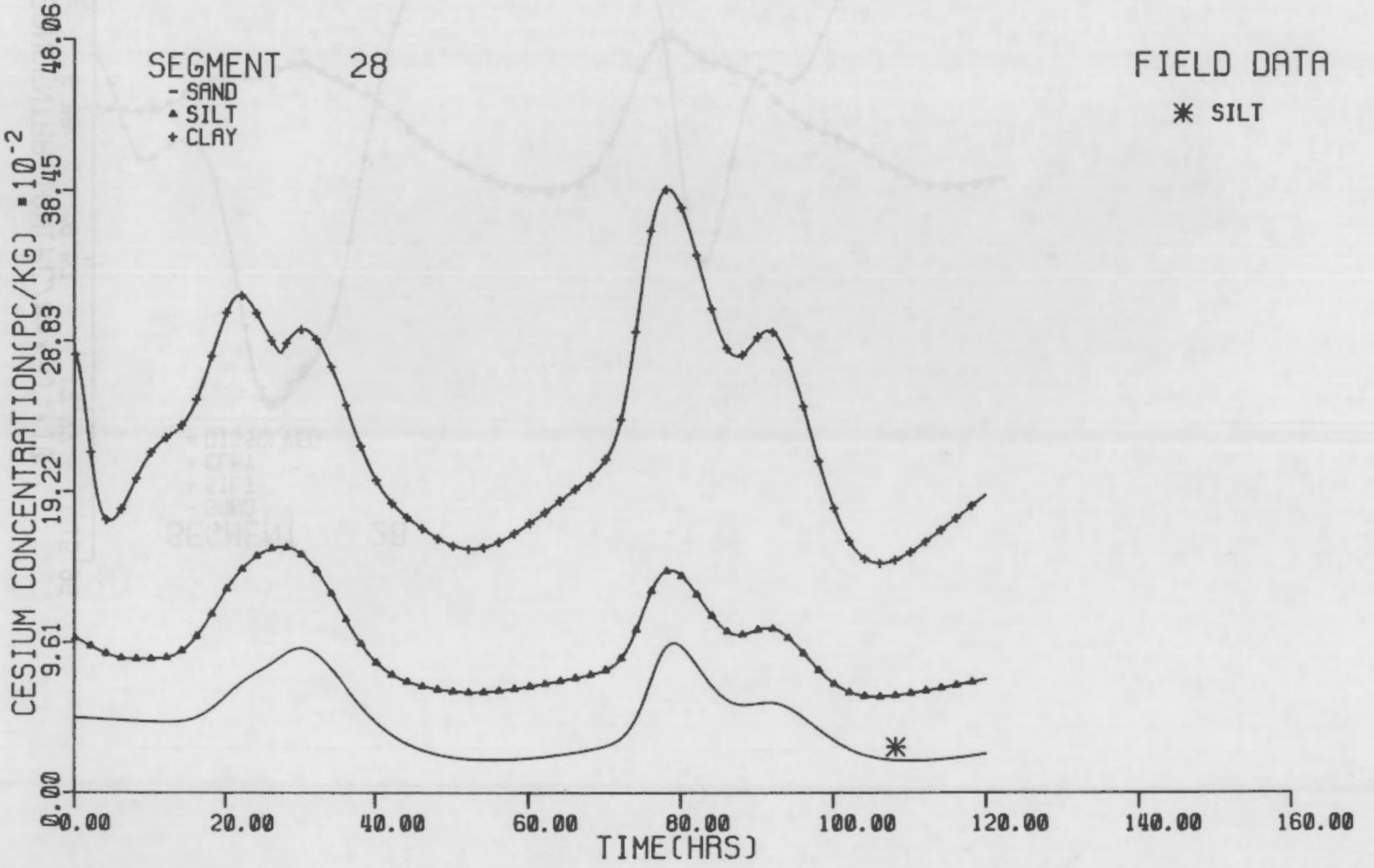

SEGMENT 3
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-2
0.00
3.04
6.08
9.12
12.16
15.21
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

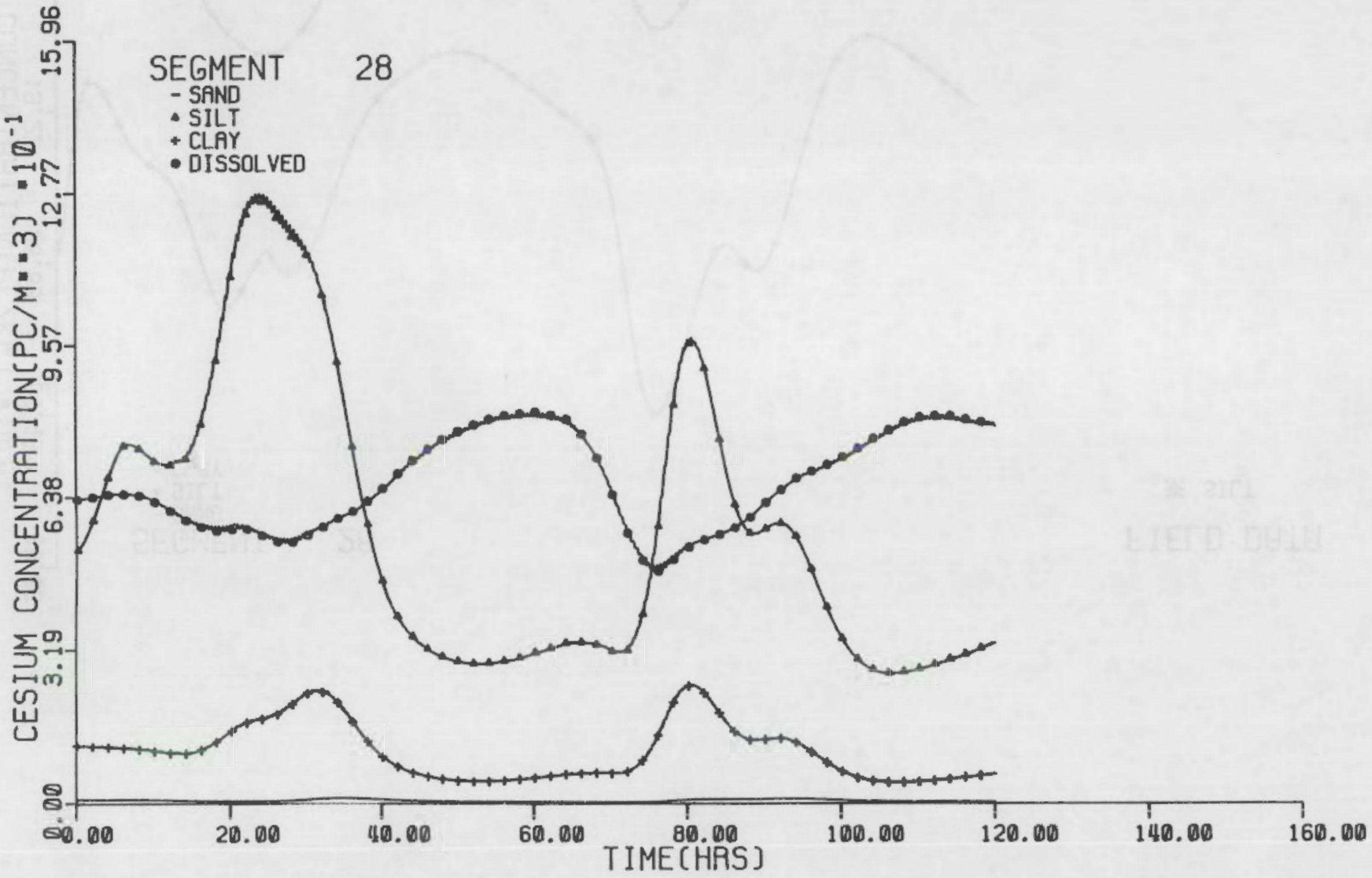

SEGMENT 6
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
1.68
3.36
5.04
6.72
8.40
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

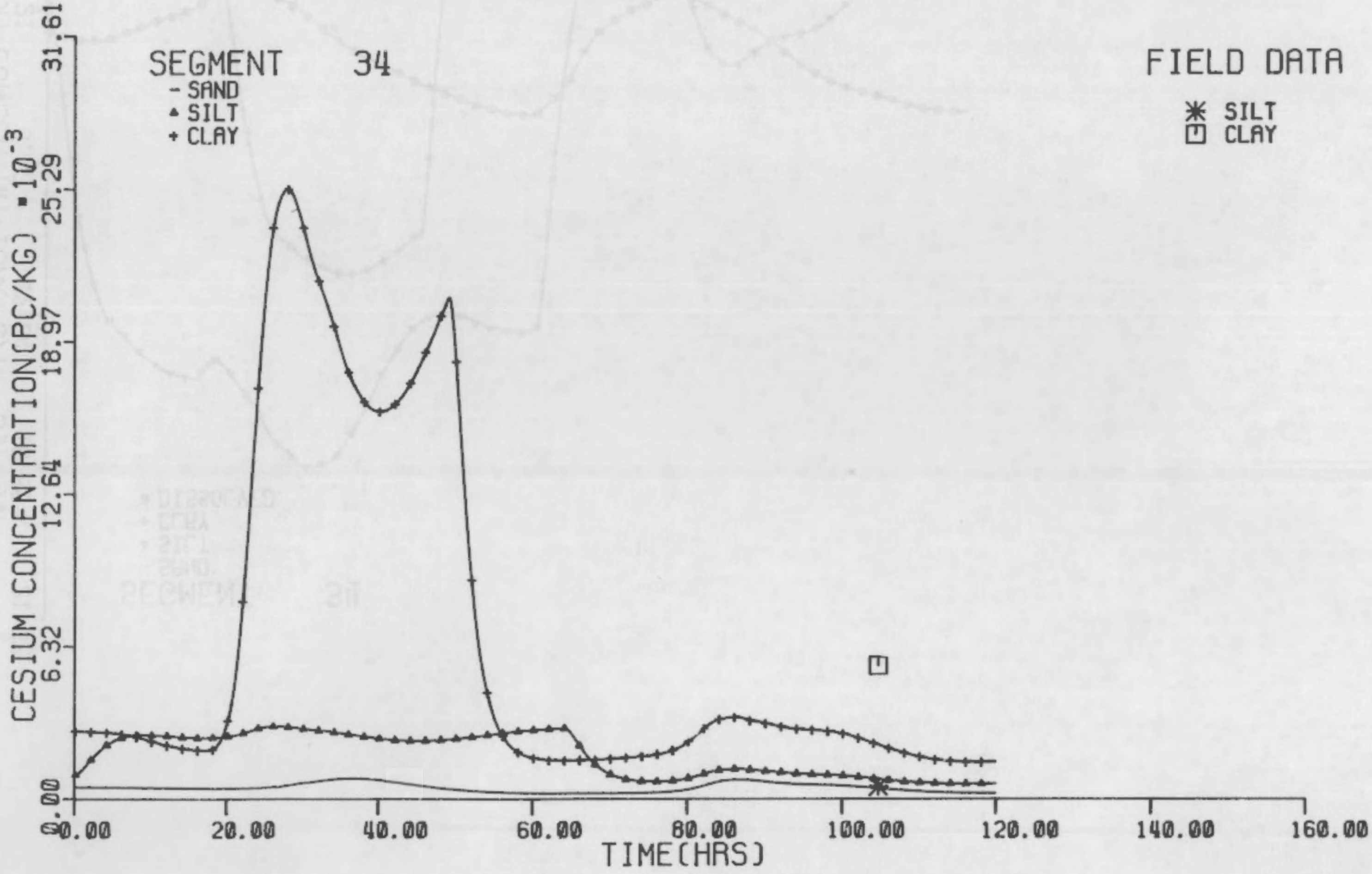

SEGMENT 6
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^{-2}
0.00
4.03
8.06
12.09
16.12
20.15
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

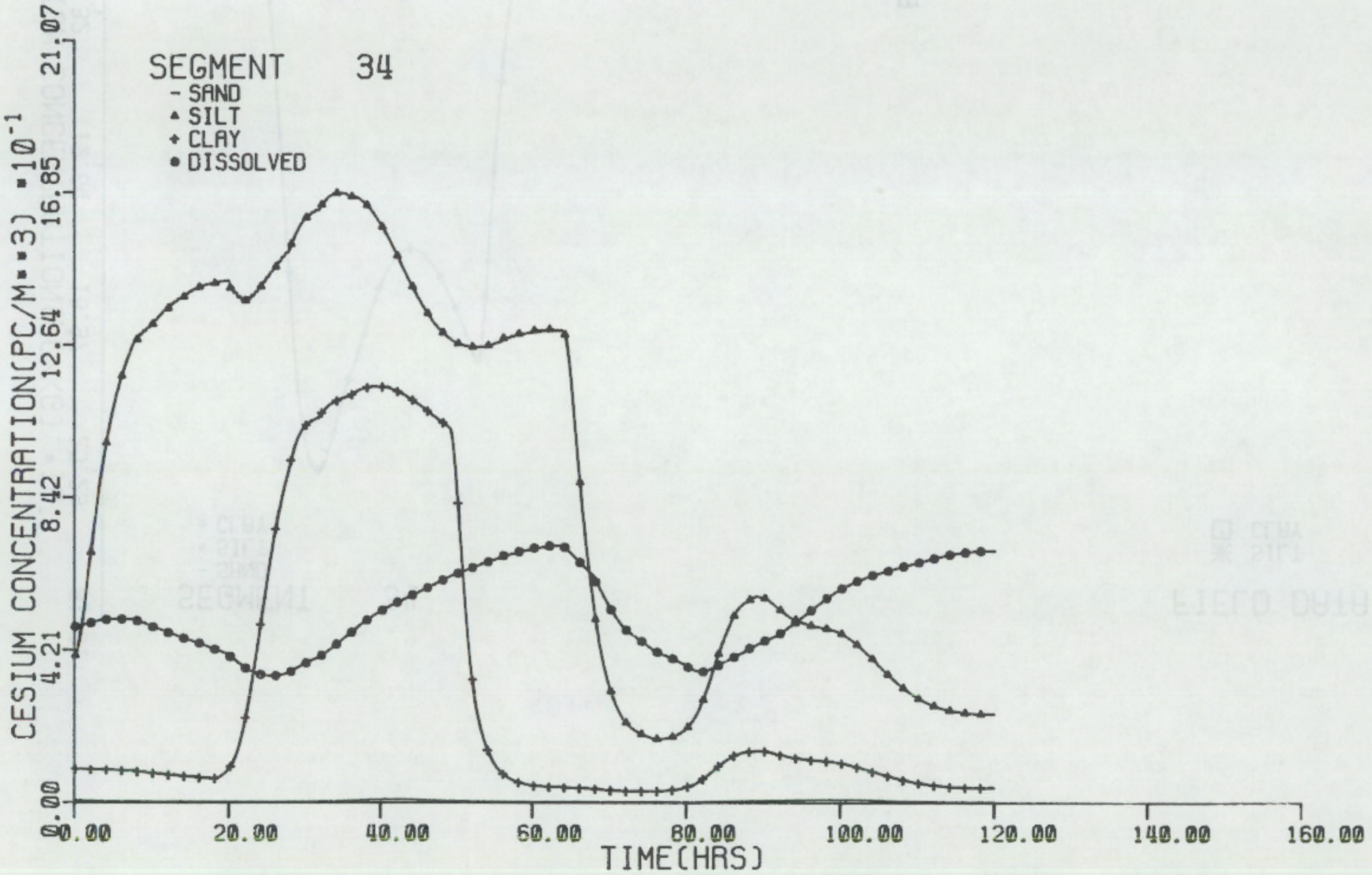

SEGMENT 8
- SAND
▲ SILT
+ CLAY
FIELD DATA
◇ SAND
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
2.25
4.51
6.76
9.02
11.27
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)

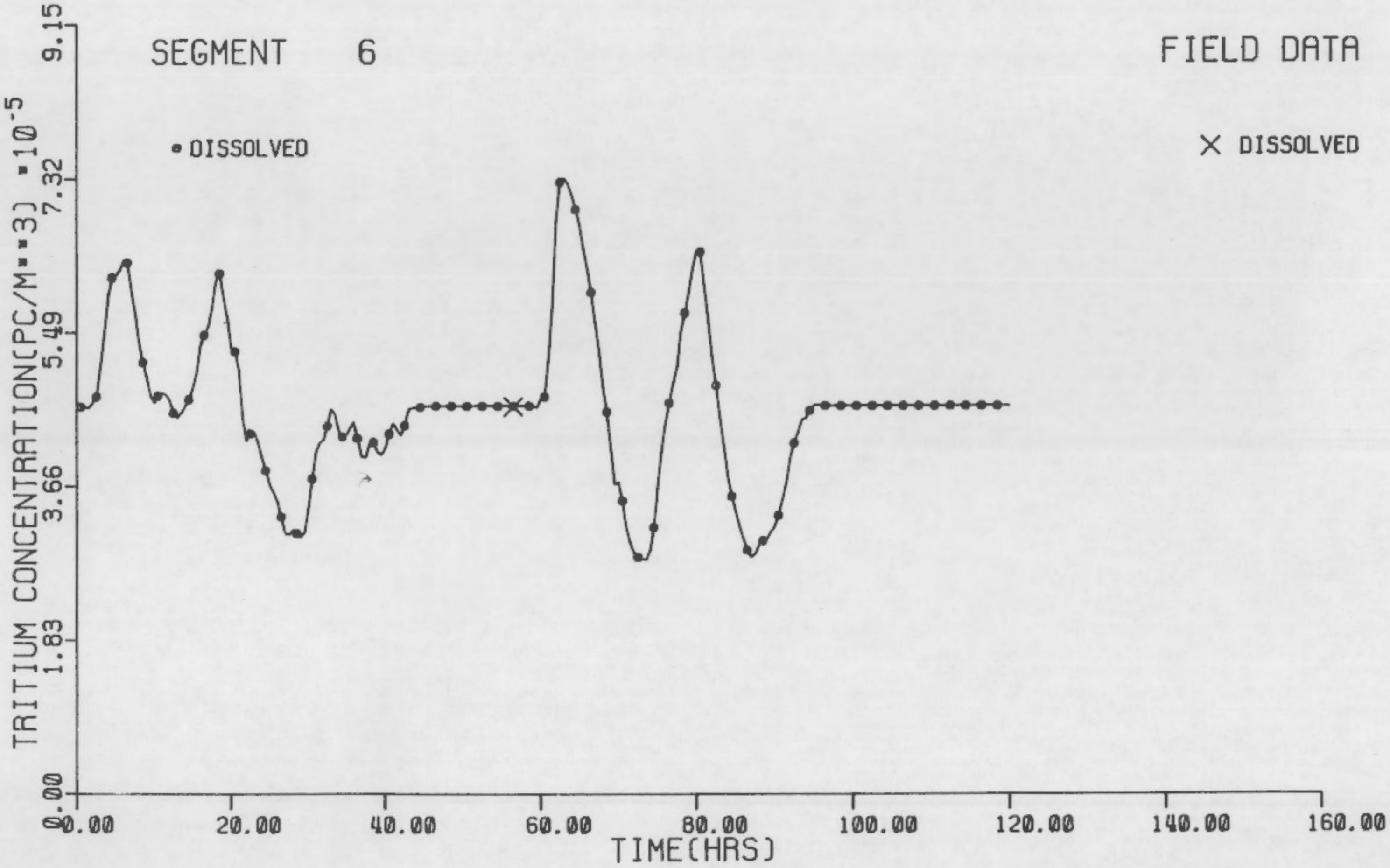

SEGMENT 8
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-2
0.00
1.54
3.09
4.63
6.18
7.72
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)


SEGMENT 28
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
CESIUM CONCENTRATION(PC/KG) *10^-2
0.00
9.61
19.22
28.83
38.45
48.06
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)


SEGMENT 28
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^{-1}
0.00
3.19
6.38
9.57
12.77
15.96
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)


SEGMENT 34
- SAND
▲ SILT
+ CLAY
FIELD DATA
✳ SILT
⊡ CLAY
CESIUM CONCENTRATION(PC/KG) *10^-3
0.00
6.32
12.64
18.97
25.29
31.61
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)


SEGMENT 34
- SAND
▲ SILT
+ CLAY
● DISSOLVED
CESIUM CONCENTRATION(PC/M**3) *10^-1
0.00
4.21
8.42
12.64
16.85
21.07
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME(HRS)


SEGMENT 6
FIELD DATA
● DISSOLVED
× DISSOLVED
TRITIUM CONCENTRATION(PC/M**3) *10^-5
0.00
1.83
3.66
5.49
7.32
9.15
TIME(HRS)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00

APPENDIX B

LISTING OF SERATRA ROUTINES

```
      ----------------------------------------

            SUBROUTINE BEDDAT(B,ECHO,NBED,AREA,BDIV,DENS,POR,XYSO,TBED)
C
C     THIS ROUTINE IS RESPONSIBLE FOR READING THE INITIAL BED CONDITIONS.
C
C       FORMAL PARAMETERS:
C         B    - INITIAL BED CONDITIONS
C         ECHO - LINE PRINTER ECHO OPTION CONTROL VARIABLE (L*1)
C         NBED - NUMBER OF BED LAYERS
C       AREA - VERTICAL PROJECTION AREA
C       BDIV - THICKNESS OF BED ELEMENTS
C       DENS - DENSITY
C       POR  - POROSITY
C       XYSO - THICKNESS OF TOP BED ELEMENT
C       TBED - WEIGHT OF MATERIAL, TOTAL OF CONTAMINANT IN BED
C
C     CALLED BY: BERATRA
C
            INCLUDE 'ELMSIZ.PRM'
C           INCLUDE 'SY:ELMSIZ.PRM'
C
            LOGICAL*1 ECHO
              INTEGER SWITCH
C
            DIMENSION B(MAXLEV,MAXCON-1), AREA(MXELEM), DENS(3), TBED(MAXCON),
           1           CELL(MAXLEV,MAXCON)
C
C     CARD B....INITIAL BED CONDITIONS
C
C       A SET OF INITIAL BED CONDITIONS ARE READ FOR EACH THE SIX
C       PARAMETERS (LAYERS ARE NUMBERED BEGINNING AT THE BOTTOM,
C       (LAYER 1), AND ENDING WITH THE SURFACE LAYER, (LAYER #NBED)).
C
C       IF THERE IS NO VERTICAL VARIATION, COLUMNS 1-5 CONTAIN A NEGATIVE
C       VALUE AND COLUMNS 6-15 CONTAIN THE CONSTANT VALUE. WHEN THE DATA
C       DOES VARY WITH DEPTH, A VALUE IS READ FOR EACH ELEMENT. THE UNITS
C       OF THE CONTAMINANT CONCENTRATIONS DEPEND UPON THE TYPE OF CONTAMINANT
C       (RADIONUCLIDE..PC/KG OR PESTICIDE..KG/KG).
C
C                     PARAMETERS ARE READ IN THE FOLLOWING ORDER:
C
C          PARAMETER 1...WEIGHT FRACTION OF SAND IN THE BED
C                    2...WEIGHT FRACTION OF SILT IN THE BED
C                    3...WEIGHT FRACTION OF CLAY IN THE BED
C                    4...CONTAMINANT CONCENTRATION IN SAND
C                    5...CONTAMINANT CONCENTRATION IN SILT
C                    6...CONTAMINANT CONCENTRATION IN CLAY
C
            DO (K=1,MAXCON-1)
            .  READ(1,2) SWITCH,VALUE
            .  WHEN (SWITCH .LT. 0)
C           .  .  *** PARAMETER DOES NOT VARY VERTICALLY ***
            .  .  DO (J=1,NBED) B(J,K) = VALUE
            .  ...FIN
```

```
           .  ELSE
C          .  .  *** PARAMETER VARIES VERTICALLY ***
           .  .  READ(1,1) (B(J,K),J=1,NBED)
           .  ...FIN
           ...FIN
           IF (ECHO)
           .  WRITE(6,3)
           .  DO (J=1,NBED)
           .  .  WRITE(6,4) J,(B(J,K),K=1,MAXCON-1)
           .  ...FIN
           ...FIN
C
           DO (J=1,MAXCON) TBED(J)=0.
           DO (J=1,MAXCON-1)
           .  DO (I=1,NBED)
           .  .  WHEN (J.LT.4)
           .  .  .  DNSITY = (1.-POR)/(B(I,1)/DENS(1)+B(I,2)/DENS(2)+
          1.  .  .               B(I,3)/DENS(3))
           .  .  .  DEL = BDIV
           .  .  .  IF (I.EQ.NBED) DEL = XYSO
           .  .  .  VOL=DEL*AREA(1)
           .  .  .  CELL(I,J) = B(I,J)*VOL*DNSITY
           .  .  ...FIN
           .  .  ELSE CELL(I,J) = CELL(1,J-3)*B(I,J)
           .  .  TBED(J) = TBED(J) + CELL(I,J)
           .  ...FIN
           ...FIN
           DO (J = 4,MAXCON-1)
           .  TBED(MAXCON) = TBED (MAXCON) + TBED(J)
           ...FIN
           RETURN
C
 1         FORMAT(8F10.0)
 2         FORMAT(I5,F10.0)
 3         FORMAT(1H0,53X,'INITIAL BED CONDITIONS'/1H0,'LAYER',
          1  3(3X,'WEIGHT FRACTION',2X),3(1X,'CONTAMINANT CONC.',2X)/
          2  14X,'IN SAND',13X,'IN SILT',13X,'IN CLAY',
          3  12X,'IN SAND',13X,'IN SILT',13X,'IN CLAY')
 4         FORMAT(2X,I2,2(7X,1PE12.5,2(8X,1PE12.5)))
C
           END

(FLECS VERSION 22.46)

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(FLECS VERSION 22.46)      17-JUN-82   14:56:06  PAGE  00001

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                SUBROUTINE BEDDK(B, DECAY, DELTD, NBED)
        C
        C   THIS ROUTINE CALCULATES THE DECAY OF THE CONTAMINANTS IN THE
        C   RIVER BED.
        C
        C     FORMAL PARAMETERS:
        C       B       = BED CONCENTRAITONS
        C       DECAY   = DECAY VALUES
        C       DELTD   = TIME STEP IN DAYS
        C       NBED    = NUMBER OF BED LAYERS
        C
        C   CALLED BY: TRANSP, SERATRA
        C
              INCLUDE 'SY:ELMSIZ.PRM'
        C
              DIMENSION B(MAXLEV,MAXCON-1), DECAY(6)
        C
              IF(DECAY(1) .NE. 0.0)
              .  DO (JJ=4,6)
        C     .  .  *** RADIONUCLIDE DECAY ***
              .  .  DO (JK=1,NBED)
              .  .  .  B(JK,JJ) = B(JK,JJ)*EXP(-DECAY(1)*DELTD)
              .  .  ...FIN
              .  ...FIN
              ...FIN
              RETURN
              END

        (FLECS VERSION 22.46)

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             SUBROUTINE BEDHIS(B, BDIV, BED, COLO, DELTD, DELZ,  DENS,
            1             FERROR, ILAYR, NBED, NELEM, POR, XNT, XYSO,
            2             DEPO, SCOUR, BEDSD)
      C
      C      THIS SUBROUTINE KEEPS A RECORD OF BED HISTORY, INCLUDING BED
      C       SURFACE ELEVATION, RATIO OF BED SEDIMENT WEIGHT FRACTIONS, AND
      C       ASSOCIATED CONCENTRATIONS IN THE BED
      C
      C      FORMAL PARAMETERS:
      C         B      - BED CONDITIONS (WEIGHT FRACTION, PC/KG)
      C         BDIV   - STANDARD BED LAYER THICKNESS (M)
      C         BED    - BED THICKNESS (M)
      C      BEDSD  - TRANSFER OF DISSOLVED TO ABSORBED (PC/M2/DAY)
      C         COLO   - CELL-CENTERED CONCENTRATION (KG/M**3,PC/M**3)
      C         DELTD  - TIME STEP (DAYS)
      C         DELZ   - STANDARD ELEMENT THICKNESS (M)
      C         DENS   - DENSITY (KG/M**3)
      C      DEPO    - DEPOSITION RATE (KG(PC)/M2/DAY)
      C         FERROR - FATAL ERROR FLAG (L*1)
      C         ILAYR  - NO. OF LAYERS COMPLETELY SCOURED BY EACH RESPECTIVE
      C                    SEDIMENT, ILAYR(J)=-1 FOR DEPOSITION
      C         NBED   - NUMBER OF BED LAYERS
      C         NELEM  - NUMBER OF ELEMENTS
      C         POR    - POROSITY
      C      SCOUR  - SCOUR RATE (KG(PC)/M2/DAY)
      C         XNT    - WEIGHT OF THE BED SEDIMENT LAYER (KG/M2)
      C         XYSO   - THICKNESS OF TOP BED LAYER (M)
      C      ZERO    - NORMALIZED TRUNCATION ERROR - SIGNIFICANT DIGITS
      C
      C      CALLED BY: TRANSP
      C
             INCLUDE 'SY:ELMSIZ.PRM'
      C
             LOGICAL*1 FERROR
      C
             DIMENSION ALEFT(3), ARAD(3), B(MAXLEV,MAXCON-1), B2(6),
            1            BEDSD(3), COLO(MXELEM,MAXCON), DENS(3), DEPO(6),
            2              ILAYR(3), SCOUR(6), SUMSD(3), SUMSDC(3), XNT(3)
             DATA ZERO/1.0E-8/
      C
             FERROR = .FALSE.
      C
             IN=ILAYR(1)
             IP=ILAYR(2)
             IQ=ILAYR(3)
      C
             DO (IJ=1,3)
             .   SUMSD(IJ)=DEPO(IJ)
             .   SUMSDC(IJ)=DEPO(IJ+3)
             .   IF(BEDSD(IJ).LT.0.0) SUMSDC(IJ)=-BEDSD(IJ)+SUMSDC(IJ)
             ...FIN
      C        ARAD  -- AMOUNT OF CHEMICALS LEFT IN TOP BED LAYER.
      C      ALEFT  -- AMOUNT OF SEDIMENT LEFT IN TOP BED LAYER.
```

```
C
        DO (II=1,3)
        .  ARAD(II)=0.0
        .  ALEFT(II)=0.0
        ...FIN
C
        IF(SCOUR(1)+SCOUR(2)+SCOUR(3).GT.0.0) GO TO 110
        TMP=(XNT(1)/DENS(1)+XNT(2)/DENS(2)+XNT(3)/DENS(3))/
       1    (1.0-POR)
        TDEPO=DEPO(1)+DEPO(2)+DEPO(3)
        DEL=(TMP - BDIV)/BDIV
        IF(TDEPO.GT.0.0.AND.ABS(DEL).LE.ZERO)
C*************************************************************
C       .  IF ONLY DEPOSITION OCCURS AND THE TOP LAYER HAS A    *
C       .  THICKNESS OF BDIV...TO AVOID HOMOGENIZING THE OLD    *
C       .  AND NEW MATERIAL WE CREATE A NEW ELEMENT WITH        *
C       .  XNT(I) = 0, AND ALEFT(I) AND ARAD(I) EQUAL TO        *
C       .  DEPOSITED MATERIAL AND CONTAMINANT RESPECTIVELY.     *
C*************************************************************
        .  XNT(1)=0.
        .  XNT(2)=0.
        .  XNT(3)=0.
        .  NBED=NBED+1
        .  DO (I=1,3)
        .  .  ALEFT(I)=SUMSD(I)*DELTD
        .  .  ARAD(I)=SUMSDC(I)*DELTD
        .  .  IF(BEDSD(I).GT.0.0) ARAD(I)=ARAD(I)-BEDSD(I)*DELTD
        .  ...FIN
        .  GO TO 270
        ...FIN
C************************************************************
C       COMPUTES SEDIMENT (KG/M2) AND CONTAMINANT (PC/M2)  *
C       RESIDING IN THE TOP LAYER                          *
C************************************************************
110     IF (IN.LT.0) IN=0
        ALEFT(1)=XNT(1)+SUMSD(1)*DELTD
        ARAD(1)=XNT(1)*B(NBED-IN,4)+SUMSDC(1)*DELTD
        IF (BEDSD(1).GT.0.0) ARAD(1)=ARAD(1)-BEDSD(1)*DELTD
        IN=ILAYR(1)
        IF (IP.LT.0) IP=0
        ALEFT(2)=XNT(2)+SUMSD(2)*DELTD
        ARAD(2)=XNT(2)*B(NBED-IP,5)+SUMSDC(2)*DELTD
        IF(BEDSD(2).GT.0.0) ARAD(2)=ARAD(2)-BEDSD(2)*DELTD
        IP = ILAYR(2)
        IF (IQ .LT. 0) IQ=0
        ALEFT(3)=XNT(3)+SUMSD(3)*DELTD
        ARAD(3)=XNT(3)*B(NBED-IQ,6)+SUMSDC(3)*DELTD
        IF(BEDSD(3).GT.0.0) ARAD(3)=ARAD(3)-BEDSD(3)*DELTD
        IQ = ILAYR(3)
C***********************************************************
C       IF SAND HAS NOT SCOURED A COMPLETE LAYER ALEFT(I) *
C       AND ARAD(I) ARE COMPLETELY DETERMINED             *
C***********************************************************
        IF (IN.LT.1) GO TO 270
C***********************************************************
C       IF SILT AND SAND EROSION (DEPOSITION) ARE WITHIN  *
```

```
C     THE SAME LAYER ... ALEFT(2), AND ARAD(2) ARE         *
C     COMPLETELY DETERMINED ...                            *
C     OTHERWISE INCLUDE ADDITIONAL LAYERS                  *
C**********************************************************
      IF(IN.GT.IP)
      .  IPP = IP +1
      .  IF (IPP.EQ.0) IPP = 1
      .  DO (IT=IPP,IN)
      .  .  NB = NBED - IT
      .  .  XND = (1.0-POR)/(B(NB,1)/DENS(1)+B(NB,2)/DENS(2)+
     1.  .        B(NB,3)/DENS(3))
      .  .  DELXNT=XND*BDIV*B(NB,2)
      .  .  ALEFT(2)=ALEFT(2) + DELXNT
      .  .  ARAD(2)=ARAD(2) + DELXNT*B(NB,5)
      .  ...FIN
      ...FIN
C***********************************************************
C     IF CLAY AND SAND EROSION (DEPOSITION) ARE WITHIN     *
C     THE SAME LAYER ... ALEFT(3) AND ARAD(3) ARE          *
C     COMPLETELY DETERMINED....                            *
C     OTHERWISE INCLUDE ADDITIONAL LAYERS                  *
C***********************************************************
      IF(IN.GT.IQ)
      .  IQQ = IQ + 1
      .  IF (IQQ.EQ.0) IQQ = 1
      .  DO (IT=IQQ,IN)
      .  .  NB = NBED - IT
      .  .  XND = (1.0-POR)/(B(NB,1)/DENS(1)+B(NB,2)/DENS(2)+
     1.  .        B(NB,3)/DENS(3))
      .  .  DELXNT=XND*BDIV*B(NB,3)
      .  .  ALEFT(3) = ALEFT(3) + DELXNT
      .  .  ARAD(3) = ARAD(3) + DELXNT*B(NB,5)
      .  ...FIN
      ...FIN
C************************************************************
C     ESTABLISH THE B MATRIX VALUES FOR THE NEWLY CREATED *
C     BED ELEMENTS                                         *
C************************************************************
270   CONTINUE
      B1 = ALEFT(1) + ALEFT(2) + ALEFT(3)
      XM = (ALEFT(1)/DENS(1) + ALEFT(2)/DENS(2) + ALEFT(3)/
     1     DENS(3))/(1.0 - POR)
      IN = XM/BDIV
      REMAIN =XM - IN*BDIV
      IF(REMAIN.GT.ZERO) IN =IN +1
      NBED =NBED - IN - 1
      IF (IN.LT.0) NBED =NBED-1
      NBED1 = NBED + 1
      NBED2 = NBED + IN
      DO (IX=1,3)
      .  B2(IX) = ALEFT(IX)/B1
      .  B2(IX+3) = 0.0
      .  IF(B2(IX).GT.ZERO) B2(IX+3) = ARAD(IX)/ALEFT(IX)
      ...FIN
      DO (IY=NBED1,NBED2)
      .  DO (IX=1,6)
```

```
          .  .  B(IY,IX). = B2(IX)
          .  ...FIN
          ...FIN
          NBED = NBED + IN
          XYSO = REMAIN
          IF (REMAIN.LE.ZERO) XYSO = BDIV
          BED = (NBED-1) * BDIV + XYSO
          IF (NBED .GT.  MAXLEY)
          .  WRITE(6,200) NBED
200       .  FORMAT(2X,'DEPOSITION EXCEEDS PERMISSIBLE BED DEPTH IN BEDHST',/,
         1.  5X,'NBED=',I5)
          .  FERROR = .TRUE.
          ...FIN
C
          RETURN
          END

(FLECS VERSION 22.46)

----------------------------------------
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```
      ----------------------------------------
      SUBROUTINE COLBY(ALEN, C, DELZ,  D50, HRAD, NELEM, QTOT,
     1                  TEMPR, VOL, GSI, FERROR)
C
C    THIS SUBROUTINE USES COLBY'S METHOD TO CALCULATE THE CAPACITY OF
C    THE FLOW TO TRANSPORT SAND.
C
C       INPUT PARAMETERS:
C         ALEN   - SEGMENT LENGTH
C         C      - NODAL VALUES OF CONCENTRATION
C         DELZ   - STANDARD ELEMENT THICKNESS
C         D50    - MEDIAN BED SEDIMENT DIAMETER (M)
C         HRAD   - HYDRAULIC RADIUS
C         NELEM  - NUMBER OF VERTICAL ELEMENTS
C         QTOT   - TOTAL FLOW WITHIN THE SEGMENT
C         TEMPR  - WATER TEMPERATURE
C         V      - AVERAGE VELOCITY
C         VOL    - VOLUME
C
C       OUTPUT PARAMETERS:
C         GSI    - TOTAL SAND TRANSPORT
C         FERROR - FATAL ERROR FLAG (L*1)
C
C    CALLED BY: SAND
C
C    THE COLBY METHOD HAS THE FOLLOWING UNITS AND APPLICABLE RANGES OF
C    VARIABLES.
C       AVERAGE VELOCITY..............V.......FPS..........1-10 FPS
C       HYDRAULIC RADIUS..............FHRAD...FT...........1-100 FY
C       WATER SURFACE WIDTH...........W.......FT...........
C       MEDIAN BED MATERIAL SIZE.....DB50....MM...........0.1-0.8 MM
C       TEMPERATURE...................TMPR....DEG F........32-100 DEG.
C       FINE SEDIMENT CONCENTRATION..FSL.....MG/LITER....0-200000 PPM
C       TOTAL SEDIMENT LOAD...........GSI.....TON..........
C
      INCLUDE 'SY:ELMSIZ.PRM'
C
      LOGICAL*1 FERROR
C
      DIMENSION C(MXELEM,MAXCON),CF(5),DF(10),DG(4),DP(11),D50G(6),
     1          F(5,10), G(4,8,6), II(2), JJ(2), KK(2), P(11), T(7,4),
     2          TEMP(7), VG(8), X(2,2), XA(2), XCT(2), XF(2,2),
     3          XG(2), XT(2,2), XX(2), YY(2), ZZ(2)
C
      DATA G(1,1,1),G(2,1,1),G(3,1,1),G(4,1,1)/1.0, 0.30, 0.06, 0.00/
      DATA G(1,2,1),G(2,2,1),G(3,2,1),G(4,2,1)/3.00, 3.30, 2.50, 2.00/
      DATA G(1,3,1),G(2,3,1),G(3,3,1),G(4,3,1)/5.40, 9.0, 10.0, 20.0/
      DATA G(1,4,1),G(2,4,1),G(3,4,1),G(4,4,1)/11.0, 26.0, 50.0,150.0/
      DATA G(1,5,1),G(2,5,1),G(3,5,1),G(4,5,1)/17., 49., 130., 500./
      DATA G(1,6,1),G(2,6,1),G(3,6,1),G(4,6,1)/29., 101., 400., 1350./
      DATA G(1,7,1),G(2,7,1),G(3,7,1),G(4,7,1)/44.,160.,700.,2500./
      DATA G(1,8,1),G(2,8,1),G(3,8,1),G(4,8,1)/60.,220.,1000.,4400./
      DATA G(1,1,2),G(2,1,2),G(3,1,2),G(4,1,2)/0.38, 0.06, 0.0, 0.0/
      DATA G(1,2,2),G(2,2,2),G(3,2,2),G(4,2,2)/1.60, 1.20, 0.65, 0.10/
```

```
      DATA G(1,3,2),G(2,3,2),G(3,3,2),G(4,3,2)/3.70, 5., 4., 3./
      DATA G(1,4,2),G(2,4,2),G(3,4,2),G(4,4,2)/10., 18., 30., 52./
      DATA G(1,5,2),G(2,5,2),G(3,5,2),G(4,5,2)/17., 40., 80., 160./
      DATA G(1,6,2),G(2,6,2),G(3,6,2),G(4,6,2)/36., 95., 230., 650./
      DATA G(1,7,2),G(2,7,2),G(3,7,2),G(4,7,2)/60., 150., 415., 1200./
      DATA G(1,8,2),G(2,8,2),G(3,8,2),G(4,8,2)/81., 215., 620., 1500./
      DATA G(1,1,3),G(2,1,3),G(3,1,3),G(4,1,3)/0.14, 0.0, 0.0, 0.0/
      DATA G(1,2,3),G(2,2,3),G(3,2,3),G(4,2,3)/1., 0.60, 0.15, 0.0/
      DATA G(1,3,3),G(2,3,3),G(3,3,3),G(4,3,3)/3.30, 3.00, 1.70, 0.50/
      DATA G(1,4,3),G(2,4,3),G(3,4,3),G(4,4,3)/11., 15., 17., 14./
      DATA G(1,5,3),G(2,5,3),G(3,5,3),G(4,5,3)/20., 35., 49., 70./
      DATA G(1,6,3),G(2,6,3),G(3,6,3),G(4,6,3)/44., 85., 150., 250./
      DATA G(1,7,3),G(2,7,3),G(3,7,3),G(4,7,3)/71., 145., 290., 500./
      DATA G(1,8,3),G(2,8,3),G(3,8,3),G(4,8,3)/100., 202., 400., 700./
      DATA G(1,1,4),G(2,1,4),G(3,1,4),G(4,1,4)/0.0, 0.0, 0.0, 0.0/
      DATA G(1,2,4),G(2,2,4),G(3,2,4),G(4,2,4)/0.70, 0.30, 0.06, 0.0/
      DATA G(1,3,4),G(2,3,4),G(3,3,4),G(4,3,4)/2.9, 2.3, 1.0, 0.06/
      DATA G(1,4,4),G(2,4,4),G(3,4,4),G(4,4,4)/11.5, 13., 12., 7./
      DATA G(1,5,4),G(2,5,4),G(3,5,4),G(4,5,4)/22., 31., 40., 50./
      DATA G(1,6,4),G(2,6,4),G(3,6,4),G(4,6,4)/47., 84., 135., 210./
      DATA G(1,7,4),G(2,7,4),G(3,7,4),G(4,7,4)/75., 140., 240., 410./
      DATA G(1,8,4),G(2,8,4),G(3,8,4),G(4,8,4)/106, 190., 350., 630./
      DATA G(1,1,5),G(2,1,5),G(3,1,5),G(4,1,5)/0.0, 0.0, 0.0, 0.0/
      DATA G(1,2,5),G(2,2,5),G(3,2,5),G(4,2,5)/0.44, 0.06, 0.0, 0.0/
      DATA G(1,3,5),G(2,3,5),G(3,3,5),G(4,3,5)/2.8, 1.8, 0.6, 0.0/
      DATA G(1,4,5),G(2,4,5),G(3,4,5),G(4,4,5)/12., 12.5, 10., 4.5/
      DATA G(1,5,5),G(2,5,5),G(3,5,5),G(4,5,5)/24., 30., 35., 37./
      DATA G(1,6,5),G(2,6,5),G(3,6,5),G(4,6,5)/52., 78., 120., 190./
      DATA G(1,7,5),G(2,7,5),G(3,7,5),G(4,7,5)/83., 180., 215., 380./
      DATA G(1,8,5),G(2,8,5),G(3,8,5),G(4,8,5)/120., 190., 305., 550./
      DATA G(1,1,6),G(2,1,6),G(3,1,6),G(4,1,6)/0.0, 0.0, 0.0, 0.0/
      DATA G(1,2,6),G(2,2,6),G(3,2,6),G(4,2,6)/0.3, 0.0, 0.0, 0.0/
      DATA G(1,3,6),G(2,3,6),G(3,3,6),G(4,3,6)/2.9, 1.4, 0.3, 0.0/
      DATA G(1,4,6),G(2,4,6),G(3,4,6),G(4,4,6)/14., 11., 7.7, 3.0/
      DATA G(1,5,6),G(2,5,6),G(3,5,6),G(4,5,6)/27., 29., 30., 30./
      DATA G(1,6,6),G(2,6,6),G(3,6,6),G(4,6,6)/57., 75., 110., 170./
      DATA G(1,7,6),G(2,7,6),G(3,7,6),G(4,7,6)/90., 140., 200., 330./
      DATA G(1,8,6),G(2,8,6),G(3,8,6),G(4,8,6)/135., 190., 290., 520./
C
      DATA F(1,1),F(1,2),F(1,3),F(1,4),F(1,5)/1., 1.1, 1.6, 2.6, 4.2/
      DATA F(1,2),F(2,2),F(3,2),F(4,2),F(5,2)/1., 1.1, 1.65, 2.75, 4.9/
      DATA F(1,3),F(2,3),F(3,3),F(4,3),F(5,3)/1., 1.1, 1.7, 3., 5.5/
      DATA F(1,4),F(2,4),F(3,4),F(4,4),F(5,4)/1., 1.12, 1.9, 3.6, 7./
      DATA F(1,5),F(2,5),F(3,5),F(4,5),F(5,5)/1., 1.17, 2.05, 4.3, 8.7/
      DATA F(1,6),F(2,6),F(3,6),F(4,6),F(5,6)/1., 1.2, 2.3, 5.5, 11.2/
      DATA F(1,7),F(2,7),F(3,7),F(4,7),F(5,7)/1., 1.22, 2.75, 8., 22./
      DATA F(1,8),F(2,8),F(3,8),F(4,8),F(5,8)/1., 1.25, 3., 9.6, 29./
      DATA F(1,9),F(2,9),F(3,9),F(4,9),F(5,9)/1., 1.3, 3.5, 12., 43./
      DATA F(1,10),F(2,10),F(3,10),F(4,10),F(5,10)/1.,1.4,4.9,22.,120./
C
      DATA T /1.2, 1.15, 1.10, 0.96, 0.90, 0.85, 0.82, 1.35, 1.25,
     1        1.12, 0.92, 0.86, 0.80, 0.75, 1.60, 1.40, 1.20, 0.89,
     2        0.80, 0.72, 0.66, 2.00, 1.65, 1.30, 0.85, 0.72, 0.63,
     3        0.55/
C
      DATA DF /0.10, 0.20, 0.30, 0.60, 1.00, 2.00, 6.00, 10.00,
```

```
      1          20.00, 1.E2/
C
       DATA CF /9.00, 1.E4, 5.E4, 1.E5, 1.5E5/
C
       DATA P /0.60, 0.90, 1.0, 1.0, 0.83, 0.60, 0.40, 0.25, 0.15,
      1         0.09, 0.05/
C
       DATA DP /0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70,
      1          0.80, 0.90, 1.00/
C
       DATA DG /0.10, 1.00, 10.0, 100./
C
       DATA VG/1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0, 10./
C
       DATA D50G/0.10, 0.20, 0.30, 0.40, 0.60, 0.80/
C
       DATA TEMP/32., 40., 50., 70., 80., 90., 100./
       DH50 = D50 * 1000.0
       FHRAD = HRAD * 3.280833
       TMPR = TEMPR * 1.8 + 32.0
       V = (QTOT * ALEN/VOL) * 3.7975E-5
       W = VOL/(HRAD*ALEN) * 3.280833
C      *** FSL....FINE SEDIMENT (I.E. COHESIVE SEDIMENT OR WASH) LOAD
C           IN MICRO GRAMS/LITER ***
       FSL = 0.0
       DO (IX=1,NELEM)
       .  FSL = FSL + 0.5*(C(IX,2) + C(IX+1,2) + C(IX,3) + C(IX+1,3))
       ...FIN
       FSL = FSL/NELEM * 1000.0
C
       IF((DH50 .LT. D50G(1)) .OR. (DB50 .GT. D50G(6)))
       .  FERROR = .TRUE.
       .  WRITE(6,1)
1      .  FORMAT(//10X,'***** FATAL ERROR -- SUBROUTINE COLBY *****')
       .  WRITE(6,2)
2      .  FORMAT(10X,'*****    DOUT    *****')
       ...FIN
       IF((FHRAD .LT. DG(1)) .OR. (FHRAD .GT. DG(4)))
       .  FERROR = .TRUE.
       .  WRITE(6,1)
       .  WRITE(6,3)
3      .  FORMAT(10X,'*****    ROUT    *****')
       ...FIN
       IF((V .LT. VG(1)) .OR. (V .GT. VG(8)))
       .  FERROR = .TRUE.
       .  WRITE(6,1)
       .  WRITE(6,4) V
4      .  FORMAT(10X,'*****    VOUT    *****',F10.5)
       ...FIN
       UNLESS (FERROR)
       .  IF(TMPR .LT. 32.0 .OR. TMPR .GT. 100.0)
       .  .  TMPR = 32.0
       .  ...FIN
       .  IO1 = 0
       .  IO2 = 0
       .  DO (I=1,3)
```

```
          .  .  IF ((FHRAD .GE. DG(I)) .AND. (FHRAD .LE. DG(I+1)))
          .  .  .  ID1 = I
          .  .  .  ID2 = I+1
          .  .  .  GO TO 114
          .  .  ...FIN
          .  ...FIN
 114      .  CONTINUE
          .  IV1 = 0
          .  IV2 = 0
          .  DO (I=1,7)
          .  .  IF ((V .GE. VG(I)) .AND. (V .LE. VG(I+1)))
          .  .  .  IV1 = I
          .  .  .  IV2 = I+1
          .  .  .  GO TO 118
          .  .  ...FIN
          .  ...FIN
 118      .  CONTINUE
          .  ID501 = 0
          .  ID502 = 0
          .  DO (I=1,5)
          .  .  IF ((DB50 .GE. D50G(I)) .AND. (DB50 .LE. D50G(I+1)))
          .  .  .  ID501 = I
          .  .  .  ID502 = I+1
          .  .  .  GO TO 122
          .  .  ...FIN
          .  ...FIN
 122      .  CONTINUE
          .  II(1) = ID1
          .  II(2) = ID2
          .  JJ(1) = IV1
          .  JJ(2) = IV2
          .  KK(1) = ID501
          .  KK(2) = ID502
          .  DO (I=1,2)
          .  .  I1 = II(I)
          .  .  XX(I) = ALOG10(DG(I1))
          .  .  DO (J=1,2)
          .  .  .  J1 = JJ(J)
          .  .  .  YY(J) = ALOG10(VG(J1))
          .  .  .  DO (K=1,2)
          .  .  .  .  K1 = KK(K)
          .  .  .  .  ZZ(K) = ALOG10(D50G(K1))
          .  .  .  .  IF (G(I1,J1,K1)-0.) 123,123,127
 123      .  .  .  .  CONTINUE
          .  .  .  .  DO (J3=J1,7)
          .  .  .  .  .  IF (G(I1,J3,K1)-0.) 124,124,126
 124      .  .  .  .  .  CONTINUE
          .  .  .  .  ...FIN
 126      .  .  .  .  CONTINUE
          .  .  .  .  X(J,K) = ALOG10(G(I1,J3,K1))+(ALOG10(VG(J1)/VG(J3)))*
       1. .  .  .  .             (ALOG10(G(I1,J3+1,K1)/G(I1,J3,K1)))/(ALOG10(VG(J3+1)/
       2. .  .  .  .             VG(J3)))
          .  .  .  .  GO TO 128
 127      .  .  .  .  CONTINUE
          .  .  .  .  X(J,K) = ALOG10(G(I1,J1,K1))
 128      .  .  .  .  CONTINUE
```

```
          .  .  .  ...FIN
          .  .  ...FIN
          .  .  XD = ALOG10(DB50) - ZZ(1)
          .  .  XN1 = X(1,2) - X(1,1)
          .  .  XN2 = X(2,2) - X(2,1)
          .  .  XDEN = ZZ(2) - ZZ(1)
          .  .  XA(1) = X(1,1) + XN1*XD/XDEN
          .  .  XA(2) = X(2,1) + XN2*XD/XDEN
          .  .  XNM = XA(2) - XA(1)
          .  .  XDY = YY(2) - YY(1)
          .  .  XG(I) = XA(1) + XNM*XV/XDY
          .  ...FIN
          .  XNM = XG(2) - XG(1)
          .  XD = ALOG10(FMRAD) - XX(1)
          .  XDEN = XX(2) - XX(1)
          .  GTUC = XG(1) + XNM*XD/XDEN
          .  GTUC = 10.**GTUC
C         .
C         .  *** GTUC IS UNCORRECTED GT IN LB/SEC/FT ***
C         .
C         .  *** NEXT APPLY FINE SEDIMENT LOAD AND TEMPERATURE CORRECTIONS ***
C         .
          .  WHEN (TMPR .EQ. 60.) CFT = 1.0
          .  ELSE
          .  .  IT1 = 0
          .  .  IT2 = 0
          .  .  DO (I=1,6)
          .  .  .  IF ((TMPR .GE. TEMP(I)) .AND. (TMPR .LE. TEMP(I+1)))
          .  .  .  .  IT1 = I
          .  .  .  .  IT2 = I+1
          .  .  .  .  GO TO 136
          .  .  .  ...FIN
          .  .  ...FIN
    136   .  .  CONTINUE
          .  .  XT(1,1) = ALOG10(T(IT1,ID1))
          .  .  XT(2,1) = ALOG10(T(IT2,ID1))
          .  .  XT(1,2) = ALOG10(T(IT1,ID2))
          .  .  XT(2,2) = ALOG10(T(IT2,ID2))
          .  .  XNT = ALOG10(TMPR/TEMP(IT1))/ALOG10(TEMP(IT2)/TEMP(IT1))
          .  .  XCT(1) = XT(1,1) + XNT*(XT(2,1) - XT(1,1))
          .  .  XCT(2) = XT(1,2) + XNT*(XT(2,2) - XT(1,2))
          .  .  CFT = XCT(1) + (XCT(2) - XCT(1))*XD/XDEN
          .  .  CFT = 10.**CFT
          .  ...FIN
C         .
C         .  *** FINE SEDIMENT LOAD CORRECTION ***
C         .
          .  WHEN (FSL .LE. 10.) CFF=1.0
          .  ELSE
          .  .  ID1 = 0
          .  .  ID2 = 0
          .  .  DO (I=1,9)
          .  .  .  IF((FMRAD .GE. DF(I)) .AND. FMRAD .LE. DF(I+1))
          .  .  .  .  ID1 = I
          .  .  .  .  ID2 = I+1
          .  .  .  .  GO TO 142
```

```
                . . . ...FIN
                . . ...FIN
        142     . . CONTINUE
                . . WHEN (FSL .GT. 1.E+5)
                . . . WRITE(6,5)
        5       . . . FORMAT(//10X,'***** SUBROUTINE COLBY -- FSL WENT > 1.E+5')
                . . . IF1 = 4
                . . . IF2 = 5
                . . ...FIN
                . . ELSE
                . . . IF1 = 0
                . . . IF2 = 0
                . . . DO (I=1,4)
                . . . . IF ((FSL .GE. CF(I)) .AND. (FSL .LE. CF(I+1)))
                . . . . . IF1 = I
                . . . . . IF2 = I+1
                . . . . . GO TO 148
                . . . . ...FIN
                . . . ...FIN
        148     . . . CONTINUE
                . . ...FIN
                . . XF(1,1) = ALOG10(F(IF1,ID1))
                . . XF(2,2) = ALOG10(F(IF2,ID2))
                . . XF(1,2) = ALOG10(F(IF1,ID2))
                . . XF(2,1) = ALOG10(F(ID2,ID1))
                . . XNT = (FSL - CF(IF1))/(CF(IF2) - CF(IF1))
                . . XCT(1) = XF(1,1) + XNT*(XF(2,1) - XF(1,1))
                . . XCT(2) = XF(1,2) + XNT*(XF(2,2) - XF(1,2))
                . .- XNT = ALOG10(FHHAD/DF(ID1))/ALOG10(OF(ID2)/DF(ID1))
                . . CFF = XCT(1) + XNT*(XCT(2) - XCT(1))
                . . CFF = 10.**CFF
                . ...FIN
                . TCF = CFT * CFF - 1.0
                . CFD = 1.
                . UNLESS ((DB50 .GE. 0.20) .AND. (DB50 .LE. 0.30))
                . . IP1 = 0
                . . IP2 = 0
                . . DO (I=1,10)
                . . . IF ((DB50 .GE. DP(I)) .AND. (DB50 .LE. DP(I+1)))
                . . . . IP1 = I
                . . . . IP2 = I+1
                . . . . GO TO 153
                . . . ...FIN
                . . ...FIN
        153     . . CONTINUE
                . . P2 = ALOG10(P(IP2))
                . . P1 = ALOG10(P(IP1))
                . . XNT = ALOG10(DB50/DP(IP1))/ALOG10(DP(IP2)/DP(IP1))
                . . CFD = P1 + XNT * (P2-P1)
                . . CFD = 10.**CFD
                . ...FIN
                . FFF = CFD * TCF
                . FFF = FFF + 1.0
                . GSI = FFF * GTUC
        C       .
        C       . *** CONVERTING GSI FROM (TONS/DAY/FT) TO (KG/DAY/M) ***
```

```
      .  GSI = GSI * 2.976328E+3
      ...FIN
      RETURN
      END

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              SUBROUTINE COLLAP(ALEN,AREA,C,DELZ,EL,IELM,K,NELEM,
             1                    CELCTR,TMASS,AWID,VSET,DFZ,CNODE,XSAREA)
        C     INTERPRETS INITIAL CONDITIONS
        C         CROSS-SECTION
        C         SEDIMENT CONCENTRATIONS KG/M3
        C         PARTICULATE CONCENTRATIONS PC/KG
        C         DISSOLVED CONCENTRATIONS PC/M3
        C     ARRIVES AT BOTH
        C         NODAL CONCENTRATIONS
        C         ELEMENT AVERAGE VALUES
        C     NOTE (1.-DELZ*WS/EZ) MUST BE > 0
        C
              REAL MSAB,MSBB,MSAT,MSBT
        C
              INCLUDE 'ELMSIZ.PRM'
        C
              DIMENSION AREA(MXELEM),C(MXELEM,MAXCON),IELM(MXELEM),
             1          EL(MXELEM),CELCTR(MXELEM,MAXCON),TMASS(MAXCON),
             2          AWID(MXELEM),VSET(3),DFZ(4),CNODE(MXELEM,MAXCON),
             3          XSAREA(MXELEM)
        C
              BLEN=1./ALEN
              ELTOP=DELZ
              WI=AREA(1)*BLEN
              WJ=AREA(2)*BLEN
              DELEV=EL(2)-EL(1)
              CI=C(1,K)
              CJ=C(2,K)
              NELMBT=1
              MSAB=DELEV*(CJ*WJ/3.+CJ*WI/6.+CI*WJ/6.+CI*WI/3.)
              MSBB=0.
              TMASS(K)=0.0
        C
              IF(K .NE. 7)
              .  GI=C(1,K+3)
              .  GJ=C(2,K+3)
              .  CON=1./12.
              .  PMSAB=DELEV*(.25*(WJ*CJ*GJ+WI*CI*GI)
             1.        +CON*(WI*CJ*GJ+WJ*CI*GJ+WJ*CJ*GI
             2.              WI*CI*GJ+WI*CJ*GI+WJ*CI*GI))
              .  PMSBB=0.
              .  TMASS(K+3)=0.0
              ...FIN
              DO(I=1,NELEM)
              .  NELMTP=IELM(I)
              .  ELTP=EL(NELMTP+1)
              .  ELBT=EL(NELMTP)
              .  WI=AREA(NELMTP)*BLEN
              .  WJ=AREA(NELMTP+1)*BLEN
              .  CI=C(NELMTP,K)
              .  CJ=C(NELMTP+1,K)
              .  FAC1=(ELTOP-ELBT)/(ELTP-ELBT)
              .  FAC2=(ELTP-ELTOP)/(ELTP-ELBT)
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          .  CTOP=CJ*FAC1+CI*FAC2
          .  WTOP=WJ*FAC1+WI*FAC2
          .  MSAT=(ELTP-ELTOP)*(CJ*WJ/3.+CJ*WTOP/6.+CTOP*WJ/6.
         1.        +CTOP*WTOP/3.)
          .  MSBT=(ELTOP-ELBT)*(CTOP*WTOP/3.+CTOP*WI/6.
         1.       +CI*WTOP/6.+CI*WI/3.)
          .  IF(K .NE. 7)
          .  .  GI=C(NELMTP,K+3)
          .  .  GJ=C(NELMTP+1,K+3)
          .  .  GTOP=GJ*FAC1+GI*FAC2
          .  .  PMSAT=(ELTP-ELTOP)*(.25*(WJ*CJ*GJ+WTOP*CTOP*GTOP)
         1.  .        +CON*(WTOP*CJ*GJ+WJ*CTOP*GJ+WJ*CJ*GTOP+
         2.  .              WTOP*CTOP*GJ+WTOP*CJ*GTOP+WJ*CTOP*GTOP))
          .  .  PMSBT=(ELTOP-ELBT)*(.25*(WTOP*CTOP*GTOP+WI*CI*GI)
         1.  .        +CON*(WI*CTOP*GTOP+WTOP*CI*GTOP+WTOP*CTOP*GI
         2.  .        +WTOP*CI*GI+WI*CTOP*GI+WI*CI*GTOP))
          .  ...FIN
          .  INDIC=NELMTP-NELMBT
          .  CMASS=0.
          .  PMASS=0.
          .  IF(INDIC .EQ. 0)
          .  .  CMASS=MSBT-MSBB
          .  .  IF(K. NE. 7) PMASS=PMSBT-PMSBM
          .  ...FIN
          .  IF(INDIC .GE. 1)
          .  .  CMASS=MSBT+MSAB
          .  .  IF(K .NE. 7) PMASS=PMSBT+PMSAB
          .  ...FIN
          .  IF(INDIC .GE. 2)
          .  .  DO(J=NELMBT+1, NELMTP-1)
          .  .  .  CI=C(J,K)
          .  .  .  CJ=C(J+1,K)
          .  .  .  WI=AREA(J)*BLEN
          .  .  .  WJ=AREA(J+1)*BLEN
          .  .  .  CMASS=CMASS+DELEV*(CJ*WJ/3.+CJ*WI/6.+CI*WJ/6.+CI*WI/3.)
          .  .  .  IF(K .NE. 7)
          .  .  .  .  GI=C(J,K+3)
          .  .  .  .  GJ=C(J+1,K+3)
          .  .  .  .  PMASS=PMASS+DELEV*(.25*(WI*CI*GI+WJ*CJ*GJ)+
         1.  .  .  .       CON*(WI*CJ*GJ+WJ*CI*GJ+WJ*CJ*GI+
         2.  .  .  .             WJ*CI*GI+WI*CJ*GI+WI*CI*GJ))
          .  .  .  ...FIN
          .  .  ...FIN
          .  ...FIN
          .  TMASS(K)=TMASS(K)+CMASS*ALEN
          .  IF(K .NE. 7) TMASS(K+3)=TMASS(K+3)+PMASS*ALEN
C         .
C         .  DETERMINE CELL CENTERED VALUES
C         .
          .  CELCTR(I,K)=CMASS/XSAREA(I)
          .  IF(K .NE. 7) CELCTR(I,K+3)=PMASS/XSAREA(I)
C         .
C         .  DEVELOP NODAL VALUES OF CONCENTRATION
C         .
          .  WHEN(I .EQ. 1)
          .  .  WHEN(K .LE. 3)
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      C     .  .  .
      C     .  .  .  NOTE: CMASS IN KG/M
      C     .  .  .
            .  .  .  COEF=0.
            .  .  .  HS=VSET(K)*AREA(1)/(ANID(1)*ALEN)
            .  .  .  EZ=DFZ(K)
            .  .  .  CNODE(1,K)=(2.*CMASS/XSAREA(1)-COEF*DELZ/EZ)/(2.-DELZ*HS/EZ)
            .  .  .  CNODE(2,K)=2.*CMASS/XSAREA(1)-CNODE(1,K)
            .  .  .  CNODE(1,K+3)=(2.*PMASS/XSAREA(1)-COEF*DELZ/EZ)/(2.-HS*DELZ/EZ)
            .  .  .  CNODE(2,K+3)=2.*PMASS/XSAREA(1)-CNODE(1,K+3)
            .  .  ...FIN
            .  .  ELSE
            .  .  .  CNODE(1,K)=CMASS/XSAREA(1)
            .  .  .  CNODE(2,K)=CNODE(1,K)
            .  .  ...FIN
            .  ...FIN
            .  ELSE
            .  .  CNODE(I+1,K)=2.*CMASS/XSAREA(I)-CNODE(I,K)
            .  .  IF(K .LE. 3)CNODE(I+1,K+3)=2.*PMASS/XSAREA(I)-CNODE(I,K+3)
            .  ...FIN
      C     .
      C     .  OVERWRITE BOTTOM ELEMENTAL NODE INFORMATION
      C     .
            .  HSAB=HSAT
            .  HSBB=HSBT
            .  ELTOP=ELTOP+DELZ
            .  NELMBT=NELMTP
            .  IF(K .NE. 7)
            .  .  PHSAB=PHSAT
            .  .  PHSBB=PHSBT
            .  ...FIN
            ...FIN
            RETURN
            END

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              SUBROUTINE COMB(M, S, Z, R)
        C
        C     THIS SUBROUTINE MULTIPLIES THE UNSYMMETRIC BAND MATRIX (S)
        C     BY THE KNOW  LOAD VECTOR <Z> AND ADDS THE RESULT TO <R>.
        C
        C     CALLED BY TRANSP.
        C
              INCLUDE 'ELMSIZ.PRM'
        C
              REAL*8 R,S,Y
        C
              DIMENSION S(MXELEM,3), R(MXELEM), Y(MXELEM), Z(MXELEM)
        C
              R(1)=R(1)+S(1,2)*Z(1)+S(1,3)*Z(2)
              R(M)=R(M)+S(M,1)*Z(M-1)+S(M,2)*Z(M)
              DO(I=2,M-1)
              .  Y(I)=S(I,1)*Z(I-1)+S(I,2)*Z(I)+S(I,3)*Z(I+1)
              .  R(I)=R(I)+Y(I)
              ...FIN
              RETURN
              END

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       SUBROUTINE DIAG(ECHO2, ECHO3, ECHO4, ECHO5, ECHO6, ECHO7,
      1                ECHO8, ECHO9, ECHO10, ISEG, JSEG, SAVECH)
       LOGICAL*1 ECHO2, ECHO3, ECHO4, ECHO5, ECHO6, ECHO7, ECHO8,
      1         ECHO9, ECHO10, SAVECH, WRTSEG
       DIMENSION JSEG(5), SAVECH(10)
       ECHO2=.FALSE.
       ECHO3=.FALSE.
       ECHO4=.FALSE.
       ECHO5=.FALSE.
       ECHO6=.FALSE.
       ECHO7=SAVECH(6)
       ECHO8=.FALSE.
       ECHO9=.FALSE.
       ECHO10=.FALSE.
       WRTSEG=.FALSE.
       WHEN(JSEG(1).EQ.0) WRTSEG=.TRUE.
       ELSE
       .  DO (J=1,5)
       .  .  IF(JSEG(J).EQ.ISEG) WRTSEG=.TRUE.
       .  ...FIN
       ...FIN
       IF(WRTSEG)
       .  ECHO2=SAVECH(1)
       .  ECHO3=SAVECH(2)
       .  ECHO4=SAVECH(3)
       .  ECHO5=SAVECH(4)
       .  ECHO6=SAVECH(5)
       .  ECHO8=SAVECH(7)
       .  ECHO9=SAVECH(8)
       .  ECHO10=SAVECH(9)
       ...FIN
       RETURN
       END

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      SUBROUTINE DIMDAT(ALEN, AREA, BDIV, BED, DLZSAV, ECHO, ELEV,
     1                  HLDERR, ISEG, NBED, NELEM, NUMERR, PELEV,
     2                  POR, RIVER, XYBD,  EL)
C
C   THIS ROUTINE IS RESPONSIBLE FOR READING AND PROCESSING THE DATA
C   DESCRIBING THE SEGMENT DIMENSIONS AND AREAS
C
C     FORMAL PARAMETERS:
C       ALEN   - SEGMENT LENGTH
C       AREA   - SEGMENT AREA
C       BDIV   - STANDARD BED THICKNESS
C       BED    - INITIAL BED THICKNESS
C       DLZSAV   - STANDARD ELEMENT THICKNESS
C       ECHO   - LINE PRINTER ECHO OPTION CONTROL VARIABLE (L*1)
C     EL     - ELEVATIONS ABOVE THE BED CORRESPONDING TO THE SEGMENT AREAS
C       ELEV   - ELEVATION OF THE SEGMENT
C       HLDERR - HOLDING ARRAY FOR ERROR NUMBERS (BYTE)
C       ISEG   - CURRENT SEGMENT NUMBER
C       NBED   - NUMBER OF BED LAYERS
C       NELEM  - NUMBER OF VERTICAL ELEMENTS
C       NUMERR - NUMBER OF INPUT ERRORS DETECTED
C       PELEV  - UPSTREAM ELEVATION OF SEGMENT NUMBER 1
C       POR    - PORISITY
C       RIVER  - SHEAR STRESS COMPUTATION CONTROL VARIABLE
C       XYBD   - THICKNESS OF THE TOP BED LAYER
C
C   CALLED BY: SERATRA
C   CALLS: PUTERR
C
      INCLUDE 'ELMSIZ.PRM'
C
      BYTE HLDERR(100)
C
      LOGICAL*1 ECHO,RIVER
C
      DIMENSION AREA(MXELEM), EL(MXELEM)
C
C     CARD 1...........SEGMENT DIMENSIONS
C
C       COL.  1- 5...NELEM.....NUMBER OF VERTICAL ELEMENTS
C             6-10...NBED......NUMBER OF BED LAYERS
C            11-20...DLZSAV....STANDARD ELEMENT THICKNESS (METERS)
C            21-30...BDIV......STANDARD BED LAYER THICKNESS
C            31-40...BED.......INITIAL BED THICKNESS (METERS)
C            41-50...ALEN......LENGTH OF THE SEGMENT (METERS)
C            51-60...ELEV......ELEVATION OF THE SEGMENT (METERS)
C            61-70...POR.......POROSITY
C            71-80...PELEV.....UPSTREAM ELEVATION OF SEGMENT 1 ONLY
C                              =0.0;SHEAR STRESS COMPUTED USING VELOCITY
C                                   DISTRIBUTION AND BED ROUGHNESS
C                                   (RESERVOIR)
C                             <>0.0;SHEAR STRESS COMPUTED USING BOTTOM
C                                    SLOP, HYDRAULIC RADIUS AND SPECIFIC
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C                                        WEIGHT OF WATER (FREE FLOWING
C                                        RIVER)
C
      WHEN (ISEQ .EQ. 1)
      .  READ(1,1) NELEM,NBED,DLZBAV,BDIV,BED,ALEN,ELEV,POR,PELEV
      .  WHEN (PELEV .EQ. 0.0) RIVER = .FALSE.
      .  ELSE RIVER = .TRUE.
      ...FIN
      ELSE
      .  READ(1,11) NELEM,NBED,DLZBAV,BDIV,BED,ALEN,ELEV,POR,RIVER
      ...FIN
C
C     *** XYSO -- THICKNESS OF THE TOP BED LAYER
C
      XYSO = BED - (NBED-1) * BDIV
      IF (ECHO)
      .  WRITE(6,5) ISEG
      .  WRITE(6,2) NELEM,NBED,DLZBAV,BDIV,BED,ALEN,ELEV,POR,XYSO
      .  IF (ISEG .EQ. 1)
      .  .  WRITE(6,6) PELEV
      .  .  WHEN (PELEV .EQ. 0.0) WRITE(6,7)
      .  .  ELSE WRITE(6,8)
      .  ...FIN
      ...FIN
C
      IF (NELEM .LT. 0 .OR. NELEM+1 .GT. MXELEM)
      .  WRITE(6,100)NELEM,MXELEM
100   .  FORMAT(5X'FROM DIMDAT: NELEM='I3'     MXELEM='I3)
C     .
      .  CALL PUTERR(13,NUMERR,HLDERR)
      ...FIN
      IF (NBED .LE. 0) CALL PUTERR(6,NUMERR,HLDERR)
      IF (NBED .GT. MAXLEV) CALL PUTERR(4,NUMERR,HLDERR)
      IF (DLZBAV .LE. 0.0) CALL PUTERR(7,NUMERR,HLDERR)
      IF (BDIV .LE. 0.0) CALL PUTERR(8,NUMERR,HLDERR)
      IF (BED .GT. NBED*BDIV .OR. BED .LE. (NBED-1)*BDIV)
      .  CALL PUTERR(9,NUMERR,HLDERR)
      ...FIN
      IF (ALEN .LE. 0.0) CALL PUTERR(10,NUMERR,HLDERR)
      IF (ELEV .LE. 0.0) CALL PUTERR(11,NUMERR,HLDERR)
      IF (POR .GT. 1.0) CALL PUTERR(12,NUMERR,HLDERR)
C
C     CARD 2..........AREA OF EACH ELEMENT
C
C*************************************************************
C    6/9/81
C
C     WARNING:
C     A NONZERO SURFACE AREA IS REQUIRED FOR THE
C     CHANNEL BOTTOM.
C
C************************************************************
      DO (I=1,MXELEM)
      .  AREA(I)=0.0
      .  EL(I)=0.0
      ...FIN
```

```
      READ(1,9) NAREA, VPAREA, DELEV
      WHEN (NAREA .EW. 0)
      .  ELE=0.
      .  DO(I=1,MXELEM)
      .  .  AREA(I)=VPAREA
      .  .  EL(I)=ELE
      .  .  ELE=ELE+DELEV
      .  ...FIN
      ...FIN
      ELSE
      .  READ (1,3) (AREA(I), I=1,NAREA)
      .  READ(1,3) (EL(I), I=1,NAREA)
      .  IF (NAREA.LT.MXELEM)
      .  .  DO (I = NAREA+1,MXELEM)
      .  .  .  AREA(I) = VPAREA
      .  .  .  EL(I) = EL(I-1) + DELEV
      .  .  ...FIN
      .  ...FIN
      ...FIN
      IF(ECHO)
      .  WRITE(6,4) (I, AREA(I), I=1,MXELEM)
      .  WRITE(6,10)(I,EL(I),I=1,MXELEM)
      ...FIN
C
      RETURN
C
    1 FORMAT(2I5,7F10.0)
    2 FORMAT(1H0,13X,I5,'...NUMBER OF VERTICAL ELEMENTS'/
     1  14X,I5,'...NUMBER OF BED LAYERS'/
     2  7X,1PE12.5,'...STANDARD ELEMENT THICKNESS (METERS)'/
     3  7X,1PE12.5,'...STANDARD BED LAYER THICKNESS (METERS)'/
     4  7X,1PE12.5,'...INITIAL BED THICKNESS (METERS)'/
     5  7X,1PE12.5,'...LENGTH OF THE SEGMENT (METERS)'/
     6  7X,1PE12.5,'...SEGMENT ELEVATION (METERS)'/
     7  7X,1PE12.5,'...POROSITY'/
     8  7X,1PE12.5,'...THICKNESS OF THE TOP BED LAYER (CALCULATED)')
    3 FORMAT(8F10.0)
   4  FORMAT(1H0,58X,'ELEMENT AREAS'/4(27X,5(I3,1PE12.5)/))
   5  FORMAT(1H0,54X,'INPUT DATA FOR SEGMENT ',I3)
   6  FORMAT(7X,1PE12.5,'...UPSTREAM ELEVATION (METERS)')
  7   FORMAT(19X,'...SHEAR STRESS VALUES COMPUTED USING METHOD'
     1 ' FOR RESERVOIR')
  8   FORMAT(19X,'...SHEAR STRESS VALUES COMPUTED USING METHOD'
     1 ' FOR FREE FLOWING RIVERS')
   9  FORMAT(I5, 7F10.0)
   10 FORMAT(1H0,58X,'NODAL ELEVATIONS'/4(27X,5(I3,1PE12.5)/))
  11  FORMAT(2I5,6F10.0,L5)
C
      END

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      SUBROUTINE DISOLV(ABAR,  B, BDIV, C, CCIN, COLD, DECAY, DELZ,
     1                    DELTD, DENS, DIAM,  I, KAY1, KAY2,
     2           NELEM, NBED, PCOEF, POR, QHIN, QHOUT, QV, SORBK, ALFA,
     3                   BETA, VEL1, VEL2, BETA1, BETA2,
     4                   DEPO, SCOUR, BEDSD, XYSO, AREA, DSORB, DLOC)
C
C   THIS SUBROUTINE CALCULATES COEFFICIENTS OF CONVECTIVE, DECAY
C    AND SOURCE/SINK TERMS OF DISSOLVED POLLUTANT CONVECTION-DIFFUSION
C   EQUATION
C
C       INPUT PARAMETERS:
C          ABAR    - AVERAGE AREA
C       AREA   - VERTICAL PROJECTION AREAS (M2)
C          B       - BED CONCENTRATIONS
C          BDIV    - STANDARD BED LAYER THICKNESS
C          C       - NODAL CONCENTRATION
C          CCIN    - CONCENTRATION OF INFLOW
C          COLD    - CELL-CENTERED CONCENTRATION
C          DECAY   - DECAY VALUES
C          DELTD   - TIME STEP IN DAYS
C          DENS    - DENSITY
C       DEPO   - DEPOSITION RATE (KG(PC)/M2/DAY)
C          DIAM    - PARTICLE DIAMETERS
C          DELZ     - THICKNESS OF THE ELEMENT
C          I       - ELEMENT INDEX
C          KAY1    - LIGHT EXTINCTION COEFFICIENT OF WATER
C          KAY2    - LIGHT EXTINCTION COEFFICIENT OF SUSPENDED
C                    SEDIMENT IN WATER
C          NELEM   - NUMBER OF VERTICAL ELEMENTS
C          PCOEF   - 1ST TERM OF THE PHOTOLYSIS RATE EQUATION, COMPUTED
C                    IN SUBROUTINE PHOINP.
C          POR     - POROSITY
C          QHIN    - INFLOW DISCHARGE
C          QHOUT   - OUTFLOW DISCHARGE
C          QV      - VERTICAL DISCHARGE
C       SCOUR  - SCOUR RATE (KG(PC)/M2/DAY)
C          SORBK   - ADSORPTION ON SEDIMENT
C       DSORB  - DESORPTION FROM SEDIMENT
C       XYSO   - TOP BED LAYER THICKNESS
C       OUTPUT PARAMETERS:
C          ALFA    - DECAY TERM
C       BEDSD  - SCOUR OR DEPOSITION OF ABSORBED CONTAMINANT
C                (PC/M2/DAY) WHEN NO SCOUR IS TAKING PLACE
C          BETA    - SOURCE OR SINK TERM
C       BETA1  - INFLUENT SOURCE TERM FOR I-TH NODE
C       BETA2  - INFLUENT SOURCE TERM FOR I+1 TH NODE
C          VEL1    - FIRST CONVECTIVE TERM
C          VEL2    - SECOND CONVECTIVE TERM
C
C       CALLED BY TRANSP.
C
      INCLUDE 'ELMSIZ.PRM'
C
```

```
C
        REAL KAY,KAY1,KAY2,INFRAC
C
        DIMENSION ABAR(MXELEM),  B(MAXLEV,MAXCON-1), BEDSD(3),
       1          CCIN(MXELEM,MAXCON),COLD(MXELEM,MAXCON), DECAY(6),
       2          QHIN(MXELEM), QHOUT(MXELEM), QV(MXELEM), SORBK(9),
       3          DENS(3), DIAM(3), C(MXELEM,MAXCON),CBAR(MXELEM,MAXCON),
       4    DEPO(6), SCOUR(6), AREA(MXELEM), DSORB(9),
       5    OLDC(MXELEM,MAXCON)
C
        DATA ZERO/1.0E-30/
C
C       CONVECTIVE TERM
C
        AQ =QV(I)
        VEL1=AQ/ABAR(I)
        AQ=QV(I+1)
        VEL2=AQ/ABAR(I)
C     DECAY TERM
        TOTDK = 0.0
        WHEN (PCOEF .NE. 0.0) COMPUTE-PHOTOLYSIS-RATE-FOR-ELEMENT-I
        ELSE PHOTO = 0.0
        DO (IJI=1,5) TOTDK = TOTDK + DECAY(IJI)
        ALFA=QHOUT(I)/(ABAR(I)*DELZ)+TOTDK+PHOTO
        IF(I .EQ. NELEM) ALFA = ALFA + DECAY(6)
C
C     SOURCE OR SINK TERM
        BETA1=QHIN(I)/(ABAR(I)*DELZ)*(CCIN(I,7)/3.+CCIN(I+1,7)/6.)
        BETA2=QHIN(I)/(ABAR(I)*DELZ)*(CCIN(I,7)/6.+CCIN(I+1,7)/3.)
C ***********************************************************************
C *                                                                     *
C *  WARNING: THE VALUE OF CBAR SHOULD BE UPDATED BY ITERATIVELY        *
C *           SOLVING FOR C AT THE ADVANCED TIME, AND APPROXIMATING     *
C *           CBAR AS THE NEW AVERAGE CONCENTRATION OVER THE TIME       *
C *           STEP.                                                     *
C *                                                                     *
C ***********************************************************************
        DO (IE = 1,NELEM)
        .  INFRAC = 0.5*QHIN(IE)*DELTO/ABAR(IE)/DELZ
        .  EXFRAC = 1.0-INFRAC
        .  DO (IC = 1,MAXCON)
        .  .  CBAR(IE,IC) = CCIN(IE,IC)*INFRAC+OLDC(IE,IC)*EXFRAC
        .  ...FIN
        ...FIN
C
        DO (J = 1,3)
        .  JP3 = J + 3
        .  IP1 = I + 1
        .  IF(CBAR(I,J).GT.0.0.AND.CBAR(IP1,J).GT.0.0)
        .  .  ADSB1 =          (SORBK(J)*SORBK(JP3)/12.*(3.*CBAR(I,J)*CBAR(I,7)
       1.  .                   +CBAR(I,J)*CBAR(IP1,7)+CBAR(IP1,J)*CBAR(I,7)+
       2.  .                   CBAR(IP1,J)*CBAR(IP1,7)) - SORBK(JP3)/6.*(2.*
       3.  .                   CBAR(I,JP3) + CBAR(IP1,JP3)))
        .  .  DSAD1 =          (DSORB(J)*DSORB(JP3)/12.*(3.*CBAR(I,J)*CBAR(I,7)
       1.  .                   +CBAR(I,J)*CBAR(IP1,7)+CBAR(IP1,J)*CBAR(I,7)+
       2.  .                   CBAR(IP1,J)*CBAR(IP1,7)) - DSORB(JP3)/6.*(2.*
```

```
     3.  .                 CBAR(I,JP3) + CBAR(IP1,JP3)))
      .  .  ADDS2 =       (SORBK(J)*SORBK(JP3)/12.*(CBAR(I,J)*CBAR(I,7)+
     1.  .                CHAR(I,J)*CBAR(IP1,7)+CBAR(IP1,J)*CBAR(I,7)+
     2.  .                3.*CBAR(IP1,J)*CBAR(IP1,7)) - SORBK(JP3)/6.*
     3.  .                (CHAR(1,JP3) + 2.*CBAR(I+1,JP3)))
      .  .  DSAD2 =       (DSORB(J)*DSORB(JP3)/12.*(CBAR(I,J)*CBAR(I,7)+
     1.  .                CBAR(I,J)*CBAR(IP1,7)+CBAR(IP1,J)*CBAR(I,7)+
     2.  .                3.*CBAR(IP1,J)*CBAR(IP1,7)) - DSORB(JP3)/6.*
     3.  .                (CBAR(I,JP3) + 2.*CBAR(I+1,JP3)))
      .  .  IF(ADDS1.GT.0.0.OR.ADDS1.EQ.DSAD1)BETA1=BETA1-ADDS1
      .  .  IF(DSAD1.LT.0.0)BETA1=BETA1-DSAD1
      .  .  IF(ADDS2.GT.0.0.OR.ADDS2.EQ.DSAD2)BETA2=BETA2-ADDS2
      .  .  IF(DSAD2.LT.0.0)BETA2=BETA2-DSAD2
      .  ...FIN
C     .
      ...FIN
C***********************************************************************
C     TRANSFER BETWEEN DISSOLVED STREAM CONTAMINANT AND ABSORPED    *
C     BED CONTAMINANT IS INCLUDED WHENEVER NO SCOURING OCCURS FOR   *
C     A PARTICULAR SEDIMENT SIZE (EG SAND, SILT, OR CLAY)           *
C***********************************************************************
      BETA = 0.0
      IF (I.EQ.1)
      .  DO (J=1,3)  BEDSD(J) = 0.0
      .  IF(NBED.GT.0)
      .  .  DO (J=1,3)
      .  .  .  WHEN(SCOUR(J).GT.0.0.OR.B(NBED,J).LE.ZERO)
      .  .  .  .  BEDSD(J)=0.0
      .  .  .  ...FIN
      .  .  .  ELSE
      .  .  .  .  RHOJ=B(NBED,J)*(1.0-POR)*DENS(J)
      .  .  .  .  D = DIAM(J)
      .  .  .  .  IF(D.GT.XYSO) D=XYSO
      .  .  .  .  RATE = SORBK(J+6)*(SORBK(J)*(CBAR(1,7)+CBAR(2,7))/2.
     1.  .  .  .          -B(NBED,J+3))* D * RHOJ
      .  .  .  .  BETA = BETA - RATE /DELZ
      .  .  .  .  BEDSD(J)=-RATE
      .  .  .  ...FIN
      .  .  ...FIN
      .  ...FIN
      ...FIN
      RETURN

----------------------------------------

      TO COMPUTE-PHOTOLYSIS-RATE-FOR-ELEMENT-I
      .  AVGSED = 0.0
      .  WHEN (I .EQ. NELEM)
      .  .  DO (IJI=1,3) AVGSED = AVGSED + C(I+1,IJI)
      .  ...FIN
      .  ELSE
      .  .  DO (IK=I+1,NELEM+1)
      .  .  .  DO (IJI=1,3) AVGSED = AVGSED + C(IK,IJI)
      .  .  ...FIN
      .  .  AVGSED = AVGSED / (NELEM+1-I)
      .  ...FIN
```

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  00163          .  KAY = KAY1 + KAY2 * AVGSED
  00164          .  WHEN (I .EQ. NELEM) TERM1 = 1.0
  00165          .  ELSE TERM1 = EXP (-KAY*(NELEM-I)*DELZ)
  00166          .  TERM2 = (1.0 - EXP(-KAY*DELZ)) / (KAY*DELZ)
  00167          .  PHOTO = PCOEF * TERM1 * TERM2
  00168          ...FIN
  00169          END

        ----------------------------------------

             PROCEDURE CROSS-REFERENCE TABLE

        00152 COMPUTE-PHOTOLYSIS-RATE-FOR-ELEMENT-I
              00074


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            SUBROUTINE EQUPCS(PXSAR, UWID, UEL, XSAREA, NELEM, MELEM,
           1              RATIO, IELP, HEQXS, FERROR, DELTA)
      C
      C     THIS SUBROUTINE FINDS CROSS-SECTIONAL AREAS AND HEIGHTS WITHIN THE
      C     UPSTREAM CROSS-SECTION WHICH CORRESPONDS TO THE SEGMENT IMMEDIATELY
      C     DOWNSTREAM.
      C
            INCLUDE 'ELMSIZ.PRH'
            LOGICAL*1 FERROR
      C
            DIMENSION PXSAR(MXELEM), UWID(MXELEM), UEL(MXELEM),
           1             XSAREA(MXELEM), IELP(MXELEM), HEQXS(MXELEM)
      C
            FERROR=.FALSE.
            IP=1
            PXS=PXSAR(1)
            UBTM=UWID(1)
            ELBTM=UEL(1)
            TEMPXS=0.
      C
            DO(I=1,NELEM)
            .  XS=RATIO*XSAREA(I)
            .  UNTIL(XS .LE. PXS .OR. IP .EQ. MELEM)
            .  .  IP=IP+1
            .  .  TEMPXS=PXS
            .  .  UBTM=UWID(IP)
            .  .  ELBTM=UEL(IP)
            .  .  PXS=PXS+PXSAR(IP)
            .  ...FIN
            .  IELP(I)=IP
            .  WHEN(XS .EQ. PXS)
            .  .  HEQXS(I)=UEL(IP+1)
            .  .  IF(I.EQ.NELEM) HEQXS(I)= UEL(IP) + DELTA
            .  .  ELBTM=UEL(IP+1)
            .  .  UBTM=UWID(IP+1)
            .  .  PXS=0
            .  .  TEMPXS=0
            .  ...FIN
            .  ELSE
            .  .  A=(UWID(IP+1)-UBTM)/(2.*(UEL(IP+1)-ELBTM))
            .  .  B=UBTM
            .  .  C=XS-TEMPXS
            .  .  WHEN (A .EQ. 0.) HEQXS(I)=C/B+ELBTM
            .  .  ELSE
            .  .  .  BSQ4AC=B*B+4.*A*C
            .  .  .  IF (BSQ4AC .LT. 0.) GO TO 200
            .  .  .  HEQXS(I)=(SQRT(BSQ4AC)-B)/2./A+ELBTM
            .  .  ...FIN
            .  .  UBTM=2.*A*(HEQXS(I)-ELBTM)+B
            .  .  ELBTM=HEQXS(I)
            .  .  PXS=PXS-XS
            .  .  TEMPXS=0.
            .  ...FIN
```

```
        ...FIN
        RETURN
  200   CONTINUE
        FERROR=.TRUE.
        WRITE(6,1)
  1     FORMAT(10X,'FATAL ERROR - B9Q4AC IN EQUPCB SUBROUTINE IS < 0')
        RETURN
        END

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                SUBROUTINE EQUPXS(PXSBAR, PHID,PDELZ,XSAREA,NELEM,MELEM,
               1             RATIO, IELP, HEQXS)
          C
                INCLUDE 'SY:ELMSIZ.PRM'
          C
                DIMENSION PXSAR(MXELEM), PHID(MXELEM), XSAREA(MXELEM),
               1            IELP(MXELEM), HEQXS(MXELEM)
          C
                IP=1
                PXS=PXSBAR(1)
                HBTM=PHID(1)
                ELBTM=0.
                TEMPXS=0.
          C
                DO(I=1,NELEM)
                .  XS=RATIO*XSAREA(I)
                .  UNTIL(XS .LE. PXS .OR. IP .EQ. MELEM)
                .  .  IP=IP+1
                .  .  TEMPXS=PXS
                .  .  HBTM=PHID(IP)
                .  .  ELBTM=PDELZ*(IP-1)
                .  .  PXS=PXS+PXSBAR(IP)
                .  ...FIN
                .  IELP(I)=IP
                .  WHEN(XS .EQ. PXS)
                .  .  HEQXS(I)=PDELZ * IP
                .  .  PXS=0.
                .  .  TEMPXS=0.
                .  .  ELBTM=IP*PDELZ
                .  .  HBTM=PHID(IP+1)
                .  ...FIN
                .  ELSE
                .  .  HEQXS(I)=(XS-TEMPXS)/HBTM+ELBTM
                .  .  PXS=PXS-XS
                .  .  TEMPXS=0.
                .  .  ELBTM=HEQXS(I)
                .  ...FIN
                ...FIN
                RETURN
                END

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       ----------------------------------------

      SUBROUTINE FCUDE(FNAME,BASE,NBRTP,FTYPE,DEV,UIC1,UIC2)
C
C   THIS ROUTINE BUILDS A FILE SPECIFICATION INTO THE OUTPUT
C   PARAMETER FNAME
C
C     BASE  - FIRST FIVE CHARATERS OF THE FILE NAME (BYTE ARRAY)
C     NBRTP - TIME PLANE NUMBER. THIS BECOMES THE LAST 4 CHARACTERS
C                OF THE 9 CHARACTER FILE NAME (INTEGER)
C     FTYPE - THESE 3 CHARACTERS BECOME THE EXTENSION (BYTE ARRAY)
C     DEV   - DEVICE (BYTE ARRAY)
C     UIC1  - 1ST UIC (BYTE ARRAY)
C     UIC2  - 2ND UIC (BYTE ARRAY)
C
C   CALLED BY: SERATRA
C
      BYTE FNAME(27),FTYPE(3),DEV(3),UIC1(3),UIC2(3),COLON,LBRAK,
     1     RBRAK,PERIOD,COMMA,BLANK,BASE(5)
C
      DATA COLON/':'/
      DATA LBRAK/'['/
      DATA RBRAK/']'/
      DATA PERIOD/'.'/
      DATA COMMA/','/
      DATA BLANK/' '/
C
      ICAR=1
C
C     *** DETERMINE IF A DEVICE HAS BEEN SPECIFIED AND IF SO THE NUMBER
C         CHARACTERS IN THE SPECIFICATION ***
C
      N=0
      DO (I=1,3)
      .  IF(DEV(I) .NE. BLANK) N=N+1
      ...FIN
      IF (N .NE. 0)
C     .  *** TRANSFER DEVICE SPECIFICATION ***
      .  DO (I=1,N)
      .  .  FNAME(ICAR)=DEV(I)
      .  .  ICAR=ICAR+1
      .  ...FIN
C     .  *** INSERT ":" ***
      .  FNAME(ICAR)=COLON
      .  ICAR=ICAR+1
      ...FIN
C
C     *** HAVE UIC'S BEEN SPECIFIED ***
      N=0
      DO (I=1,3)
      .  IF(UIC1(I) .NE. BLANK) N=N+1
      ...FIN
      IF (N .NE. 0)
C     .
C     .  *** INSERT LEFT BRACKET ***
```

```
               .  FNAME(ICAR)=LBRAK
               .  ICAR=ICAR+1
       C       .
       C       .  *** TRANSFER 1ST UIC ***
               .  DO (I=1,N)
               .  .  FNAME(ICAR)=UIC1(I)
               .  .  ICAR=ICAR+1
               .  ...FIN
       C       .
       C       .  *** INSERT COMMA ***
               .  FNAME(ICAR)=COMMA
               .  ICAR=ICAR+1
       C       .
       C       .  *** TRANSFER 2ND UIC***
               .  DO (I=1,3)
               .  .  IF (UIC2(I) .NE. BLANK)
               .  .  .  FNAME(ICAR)=UIC2(I)
               .  .  .  ICAR=ICAR+1
               .  .  ...FIN
               .  ...FIN
       C       .
       C       .  *** INSERT RIGHT BRACKET ***
               .  FNAME(ICAR)=RBRAK
               .  ICAR=ICAR+1
               ...FIN
       C
       C       *** TRANSFER 5 CHARACTER BASE FILE NAME, ASSUME ALL 5 CHARACTER
       C            ARE BEING USED ***
               DO (I=1,5)
               .  FNAME(ICAR)=BASE(I)
               .  ICAR=ICAR+1
               ...FIN
       C
       C       *** CONVERT TIME PLANE NUMBER TO ASCII AND INSERT IT INTO FNAME **
       C
               N=NBRTP
               IDIG=N/1000
               FNAME(ICAR)=IDIG+48
               N=N-IDIG*1000
               IDIG=N/100
               FNAME(ICAR+1)=IDIG+48
               N=N-IDIG*100
               IDIG=N/10
               FNAME(ICAR+2)=IDIG+48
               FNAME(ICAR+3)=(N-IDIG*10)+48
               ICAR=ICAR+4
       C
       C       *** INSERT PERIOD ***
               FNAME(ICAR)=PERIOD
               ICAR=ICAR+1
       C
       C       *** TRANSFER THE 3 CHARACTER EXTENSION ***
               DO (I=1,3)
               .  FNAME(ICAR)=FTYPE(I)
               .  ICAR=ICAR+1
               ...FIN
```

```
C
C     *** INSERT NULL CHARACTER ***
      FNAME(ICAR)=0
      RETURN
      END

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      SUBROUTINE FDCODE(FNAME,BASE,NBRTP,FTYPE,DEV,UIC1,UIC2)
C
C   THIS ROUTINE SPERATES FNAME INTO 6 COMPONENTS
C
C     BASE  = 5 CHARACTER BASE FILE NAME (BYTE ARRAY)
C     NBRTP = TIME PLANE NUMBER THAT IS THE LAST 4 CHARACTERS OF THE
C             9 CHARACTER FILE NAME (INTEGER)
C     FTYPE = FILE EXTENSION (BYTE ARRAY)
C     DEV   = PHICAL DEVICE SPECIFICATION (BYTE ARRAY)
C     UIC1  = 1ST UIC
C     UIC2  = 2ND UIC
C
C   THE OPTIONAL PARAMETERS DEV, UIC1, AND UIC2 WILL BE SET
C   TO BLANKS IF NOT PRESENT IN THE ORIGINAL FILE SPECIFICATION.
C
C   CALLED BY: STRTUP
C
      BYTE FNAME(27),BASE(5),FTYPE(3),DEV(3),UIC1(3),UIC2(3),
     1    LBRAK,RBRAK,COMMA,PERIOD,COLON,BLANK
C
      DATA LBRAK/'['/
      DATA RBRAK/']'/
      DATA COMMA/','/
      DATA PERIOD/'.'/
      DATA COLON/':'/
      DATA BLANK/' '/
C
C     *** FILE SPECIFICATION HAVE FOUR POSSIBLE FORMS ***
C         (1) FILENAME.EXT
C         (2) DEV:FILENAME.EXT
C         (3) [UIC1,UIC2]FILENAME.EXT
C         (4) DEV:[UIC1,UIC2]FILENAME.EXT
C
C     THE FORM CAN BE DETERMINED BY COUNTING THE FOUR SPECIAL
C     CHARACTERS [  ]  .  :
C
      N=0
      DO (I=1,27)
      .  SELECT (FNAME(I))
      .  .  (COLON) N=N+1
      .  .  (LBRAK) N=N+1
      .  .  (RBRAK) N=N+1
      .  .  (PERIOD) N=N+1
      .  ...FIN
      ...FIN
      ICAR=1
      DO (I=1,3)
      .  DEV(I)=BLANK
      .  UIC1(I)=BLANK
      .  UIC2(I)=BLANK
      ...FIN
      SELECT (N)
      .  (1) DECODE-FORM1
```

```
          .  (2) DECODE-FORM2
          .  (3) DECODE-FORM3
          .  (4) DECODE-FORM4
          ...FIN
          RETURN
C

----------------------------------------

          TO DECODE-FORM1
          .  DECODE-FILENAME-EXTENSION
          ...FIN
C

----------------------------------------

          TO DECODE-FORM2
          .  DECODE-DEVICE
          .  DECODE-FILENAME-EXTENSION
          ...FIN
C

----------------------------------------

          TO DECODE-FORM3
          .  DECODE-UIC
          .  DECODE-FILENAME-EXTENSION
          ...FIN
C

----------------------------------------

          TO DECODE-FORM4
          .  DECODE-DEVICE
          .  DECODE-UIC
          .  DECODE-FILENAME-EXTENSION
          ...FIN
C

----------------------------------------

          TO DECODE-FILENAME-EXTENSION
          .  DO (I=1,5)
          .  .  BASE(I)=FNAME(ICAR)
          .  .  ICAR=ICAR+1
          .  ...FIN
          .  WHEN (FNAME(ICAR) .NE. PERIOD)
          .  .  ICHAR1=FNAME(ICAR)
          .  .  ICHAR2=FNAME(ICAR+1)
          .  .  ICHAR3=FNAME(ICAR+2)
          .  .  ICHAR4=FNAME(ICAR+3)
          .  .  NBRTP=(ICHAR1-48)*1000+(ICHAR2-48)*100+(ICHAR3-48)*10+ICHAR4-48
C         .  .  *** SKIP OVER PERIOD ***
          .  .  ICAR=ICAR+5
          .  ...FIN
          .  ELSE
```

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 00095          .  .  ICAR=ICAR+1
 00096          .  .  NBRIP=0
 00097          .  ...FIN
 00098          .  DO (I=1,3)
 00099          .  .  FTYPE(I)=FNAME(ICAR)
 00100          .  .  ICAR=ICAR+1
 00101          .  ...FIN
 00102          ...FIN
 00103    C

          ---------------------------------------

 00104          TO DECODE-DEVICE
 00105          .  I=1
 00106          .  REPEAT WHILE (FNAME(ICAR) .NE. COLON)
 00107          .  .  DEV(I)=FNAME(ICAR)
 00108          .  .  ICAR=ICAR+1
 00109          .  .  I=I+1
 00110          .  ...FIN
 00111    C     .  *** SKIP OVER COLON ***
 00112          .  ICAR=ICAR+1
 00113          ...FIN
 00114    C

          ---------------------------------------

 00115          TO DECODE-UIC
 00116    C     .  *** SKIP OVER LEFT BRACKET ***
 00117          .  ICAR=ICAR+1
 00118          .  I=1
 00119          .  REPEAT WHILE (FNAME(ICAR) .NE. COMMA)
 00120          .  .  UIC1(I)=FNAME(ICAR)
 00121          .  .  ICAR=ICAR+1
 00122          .  .  I=I+1
 00123          .  ...FIN
 00124    C     .  *** SKIP OVER COMMA ***
 00125          .  ICAR=ICAR+1
 00126          .  I=1
 00127          .  REPEAT WHILE (FNAME(ICAR) .NE. RBRAK)
 00128          .  .  UIC2(I)=FNAME(ICAR)
 00129          .  .  ICAR=ICAR+1
 00130          .  .  I=I+1
 00131          .  ...FIN
 00132    C     .  *** SKIP OVER RIGHT BRACKET ***
 00133          .  ICAR=ICAR+1
 00134          ...FIN
 00135          END

          ---------------------------------------

                PROCEDURE CROSS-REFERENCE TABLE

          00060 DECODE-FORM1
                00053

          00064 DECODE-FORM2
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              00054

          00115 DECODE-UIC
                00070  00076

          00069 DECODE-FORM3
                00055

          00074 DECODE-FORM4
                00056

          00080 DECODE-FILENAME-EXTENSION
                00061  00066  00071  00077

          00104 DECODE-DEVICE
                00065  00075

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      SUBROUTINE GETSPC(BASE,BEGSEG,BEGTIM,CHAIN,EXT,DEV,FILNAM,GUIC,
     1                  INTSEG,INTTIM,LSTSEG,LSTTIM,TSTEP,UNITS,UUIC)
C
C     THIS ROUTINE IS RESPONSIBLE FOR INTERROGATING THE USER TO LEARN
C     THE SPECIFICATION NEEDED FOR POST PROCESSING.
C
C     FORMAL PARAMETERS:
C     BASE - 5 CHARACTER BASE FILE NAME FOR CHAINED OPERATIONS
C     BEGSEG - BEGINNING SEGMENT NUMBER FOR CHAINED OPERATIONS
C     BEGTIM - BEGINNING TIME PLANE NUMBER
C     CHAIN - LOGICAL FLAG FOR CHAINED OPERATIONS
C     EXT - BASE FILE NAME EXTENSION FOR CHAINED OPERATIONS
C     DEV - BASE FILE NAME DEVICE FOR CHAINED OPERATIONS
C     FILNAM - FILE SPECIFICATION FOR UNCHAINED PROCESSING
C     GUIC - GROUP UIC FOR CHAINED PROCESSING
C     INTSEG - SEGMENT INTERVAL FOR CHAINED PROCESSING
C     INTTIM - TIME PLANE INTERVAL
C     LSTSEG - ENDING SEGMENT NUMBER FOR CHAINED PROCESSING
C     TSTEP - TIME STEP SIZE
C     UNITS - MNEMONICS FOR CONCENTRATION OF CONTAMINANT ATTACHED TO
C             SEDIMENTS (PC OR KG)
C     UUIC - USER UIC FOR CHAINED PROCESSING
C
C     CALLED BY SPPH
C     CALLS FDCODE
C
      BYTE ANSWER,YES,FILNAM(30),BASE(5),EXT(3),DEV(3),GUIC(3),UUIC(3)
C
      INTEGER*2 UNITS,BEGSEG
      INTEGER*4 BEGTIM,LSTTIM
C
      LOGICAL*1 CHAIN
C
      DATA YES/'Y'/
C
      WRITE(1,1)
      READ(1,19)ANSWER
      WHEN (ANSWER.EQ.YES)
      .  CHAIN =.TRUE.
      .  WRITE(1,3)
      .  READ(1,19)FILNAM
      .  CALL FDCODE(FILNAM,BASE,JSEG,EXT,DEV,GUIC,UUIC)
      .  WRITE(1,4)
      .  READ(1,5)BEGSEG
      .  WRITE(1,6)
      .  READ(1,5)LSTSEG
      .  WRITE(1,7)
      .  READ(1,5)INTSEG
      .  NSEG=(LSTSEG-BEGSEG)/INTSEG+1
      ...FIN
      ELSE
      .  NSEG=1
      .  CHAIN=.FALSE.
```

```
           .  WRITE(1,9)
           .  READ(1,2) NCHR,(FILNAM(I),I=1,NCHR)
           .  FILNAM(NCHR+1) = 0
           .  INTSEG=1
           ...FIN
C
           WRITE(1,10)
           READ(1,11)BEGTIM
           WRITE(1,12)
           READ(1,11)LSTTIM
           WRITE(1,13)
           READ(1,11)INTTIM
           NTIM = (LSTTIM-BEGTIM)/INTTIM + 1
C
           WRITE(1,17)
           READ(1,18) TSTEP
           WRITE(1,15)
           READ(1,16) UNITS
C
           WRITE(1,8) NSEG
           WRITE(1,14) NTIM
C
           RETURN
C
     1     FORMAT(//10X,'********  SERATRA POST PROCESSING *******'//
          1 '$IS THIS TO BE A CHAINED OPERATION (Y OR N)>')
     2     FORMAT(Q,30A1)
     3     FORMAT('$ENTER BASE FILE NAME>')
     4     FORMAT('$ENTER BEGINNING SEGMENT NUMBER (I4)>')
     5     FORMAT(I4)
     6     FORMAT('$ENTER ENDING SEGMENT NUMBER (I4)>')
     7     FORMAT('$ENTER INTERVAL BETWEEN SEGMENTS (I4)>')
     8     FORMAT(/10X,I6,'SEGMENTS (FILES) WILL BE PROCESSED')
     9     FORMAT('$ENTER THE NAME OF THE FILE TO BE PROCESSED (28A1)>')
    10     FORMAT('$ENTER BEGINNING TIME PLANE NUMBER (I10)>')
    11     FORMAT(I10)
    12     FORMAT('$ENTER ENDING TIME PLANE NUMBER (I10)>')
    13     FORMAT('$ENTER INTERVAL BETWEEN TIME PLANES (I10)>')
    14     FORMAT(/10X,I6,' TIME PLANES FOR EACH SEGMENT WILL BE PROCESSED')
    15     FORMAT('$ENTER THE CONCENTRATION UNITS (PC OR KG)>')
    16     FORMAT(A2)
    17     FORMAT('$ENTER THE TIME STEP SIZE (F10.0)>')
    18     FORMAT(F10.0)
    19     FORMAT(30A1)
           END

      (FLECS VERSION 22.46)

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        SUBROUTINE HYDDAT(ALEN, AREA, DELTH, DELZ, D50, ECHO, HLDERR,
       1                  NSETS, NUMERR, SIMLEN, DEPMIN, DLZSAV, EL)
C       DEPMIN HAS BEEN ADDED TO THE SUBROUTINE CALL
C
C     THIS ROUTINE IS RESPONSIBLE FOR READING AND PROCESSING THE
C     HYDROLOGY DATA.  THE DATA IS READ FROM THE INPUT STREAM (LUN 1)
C     AND WRITTEN TO "HYDROLOGY.TMP" (LUN 4) FOR USE DURING THE
C     SIMULATION.
C
C       FORMAL PARAMETERS:
C         ALEN   - SEGMENT LENGTH
C         AREA   - CROSS SECTIONAL AREA OF EACH ELEMENT
C         DELTH  - TIME STEP IN SECONDS
C         DELZ   - STANDARD ELEMENT THICKNESS
C         D50    - MEDIAN BED SEDIMENT DIAMETER
C         ECHO   - LINE PRINTER OPTION CONTROL VARIABLE (L*1)
C         HLDERR - HOLDING ARRAY FOR ERROR NUMBERS (BYTE)
C         NSETS  - NUMBER OF TIMES INITIAL CONDITIONS MUST BE WRITTEN
C                  TO OUTFLO. (NSETS * DELTH) = THE AMOUNT OF TIME IT
C                  TAKES THE FLOW TO PASS THROUGH THE SEGMENT.
C         NUMERR - NUMBER OF INPUT ERRORS
C         SIMLEN - SIMULATION LENGTH - SECONDS (I*4)
C
C     CALLED BY: SERATRA
C     CALLS: PUTERR
C
        INCLUDE 'ELMSIZ.PRM'
C
        BYTE HLDERR(100)
C
        INTEGER*4 ENDTIM,PRETIM,SIMLEN
C
        REAL INFRAC
C
        LOGICAL*1 ECHO
C
        DIMENSION ABAR(MXELEM), AREA(MXELEM), AWID(MXELEM),
       1          EL(MXELEM),XSAREA(MXELEM),BWID(MXELEM),IELM(MXELEM)
C
        REWIND 4
        NSETS=1
        PEND = 0.0
        IDELTH=IFIX(DELTH)
        REPEAT UNTIL (ENDTIM .EQ. -9999)
C       .
C       .  CARD 12.........HYDROLOGY DATA -- THIS DATA IS WRITTEN TO LUN 4
C       .
C       .    COL.  1-10...ENDTIM...ENDING TIME FOR THEDATA ON THE CARD. (SEC)
C       .                          AN ENTRY OF -9999 TERMINATES THE DATA.
C       .         11-20...QI.......TOTAL DISCHARGE OF THIS SEGMENT (M**3/SEC)
C       .         21-30...QO.......TOTAL DISCHARGE OUT OF THIS SEGMENT M**3/SEC)
C       .         31-40...DEPTH....FLOW DEPTH (METERS)
C       .         41-50...TEMPR....WATER TEMPERATURE
```

```
C       .
        .  READ(1,1) ENDTIM,QI,QO,DEPTH,TEMPR
        .  IF (ENDTIM .NE. -9999)
        .  .  IF (MOD(ENDTIM,IDELTH) .NE. 0)
        .  .  .  WRITE(11,10) ENDTIM,IDELTH
   10   .  .  .  FORMAT(' WARNING**** ENDTIM',I10,' IS NOT A MUTIPLE OF DELTH',I10)
        .  .  .  ENDTIM=(ENDTIM/IDELTH+1)*IDELTH
        .  .  ...FIN
        .  ...FIN
C       .
C       .
        .  IF (ENDTIM .NE. -9999) PRETIM = ENDTIM
        .  UNLESS (ENDTIM .EQ. -9999)
C       .  .  MINIMUM DEPTH FLAG TO DIVERT FROM FURTHER CALCULATION
        .  .  NELEM=0
        .  .  VOL=0.
        .  .  VEL=0.
        .  .  DO(I=1,MXELEM)
        .  .  .  AWID(I)=0.
        .  .  .  BWID(I)=0.
        .  .  .  ABAR(I)=0.
        .  .  .  IELM(I)=0.
        .  .  .  XSAREA(I)=0.
        .  .  ...FIN
        .  .  IF (DEPTH .GT. DEPMIN)
C       .  .  .
C       .  .  .  *** COMPUTE: NELEM....NUMBER OF ELEMENTS CONTAINED WITHIN DEPTH
C       .  .  .               ABAR(I)..AVERAGE AREA OF ELEMENTS I AND I+1
C       .  .  .               AWID(I)..WIDTH OF ELEMENT
C       .  .  .               VOL......TOTAL VOLUME OF THE SEGMENT
        .  .  .  VOL=0.
        .  .  .  NELEM=DEPTH/DLZSAV
        .  .  .  DELZ=DEPTH/NELEM
        .  .  .  WHEN(NELEM .LE. 1 .OR. NELEM+1 .GT. MXELEM)
        .  .  .  .  WRITE(6,100)NELEM,MXELEM
  100   .  .  .  .  FORMAT(5X'FROM HYDDAT:  NELEM='I3'   MXELEM='I3)
        .  .  .  .  CALL PUTERR (14, NUMERR, HLDERR)
        .  .  .  .  WRITE(6,6)
        .  .  .  ...FIN
        .  .  .  ELSE
        .  .  .  .  CALL TRNPOS(ABAR,AREA,AWID,ALEN,BWID,DELZ,EL,IELM,NELEM,
       1.  .  .  .  XSAREA,VOL)
        .  .  .  .  CALL RADIUS (ALEN, AREA, CROSEC, DEPTH, EL, HRAD)
        .  .  .  ...FIN
C       .  .  .
C       .  .  .  IT IS IMPLICITLY ASSUMED THAT A DOWNSTREAM COURANT
C       .  .  .  NUMBER AT OR NEAR UNITY HAS BEEN EMPLOYED IN THIS
C       .  .  .  ANALYSIS
C       .  .  .
        .  .  .  INFRAC=0.5*QI*DELTH/VOL
        .  .  .  EXFRAC=1.0-INFRAC
        .  .  .  VEL=(INFRAC*QI+EXFRAC*QO)*ALEN/VOL
        .  .  ...FIN
        .  .  WRITE(4) ENDTIM,NELEM,DELZ,QI,QO,VOL,VEL,AWID,AREA,TEMPR,
       1.  .  XSAREA,IELM,DEPTH,BWID,ABAR, HRAD, CROSEC
C       .  .
```

```
          .  .  IF (ECHO)
          .  .  .  WRITE(6,2) ENDTIM,NELEM,TEMPR,QI,QO,DEPTH
          .  .  .  WRITE(6,3)
          .  .  .  DO (I=1,NELEM)
          .  .  .  .  WRITE(6,4)I,AWID(I),ABAR(I),AREA(I),EL(I)
          .  .  .  ...FIN
          .  .  ...FIN
          .  ...FIN
          ...FIN
          IF (PRETIM .LT. SIMLEN) CALL PUTERR(25, NUMERR, HLDERR)
          REWIND 4
C
          RETURN
C
  1       FORMAT(I10,4F10.0)
  2       FORMAT(1H0,58X,'HYDROLOGY DATA'/
         1  9X,I10,'...DATA SET ENDING TIME'/
         2  14X,I5,'...NUMBER OF ELEMENTS WITHIN THE FLOW DEPTH'/
         3  7X,1PE12.5,'...WATER TEMPERATURE'/
         6  7X,1PE12.5,'...TOTAL DISCHARGE OF THIS SEGMENT'/
         7  7X,1PE12.5,'...TOTAL DISCHARGE OUT OF THIS SEGMENT'/
         8  7X,1PE12.5,'...FLOW DEPTH')
  3       FORMAT(1H0,'ELEMENT',4X,'SEGMENT',14X,'AVERAGE',12X,'NODE VP-AREA',
         1  11X,'NODE ELEV'/1X,'NUMBER',6X,'WIDTH',12X,'ELEMENT AREA')
  4       FORMAT(3X,I2,4X,1PE12.5,9X,1PE12.5,10X,1PE12.5,10X,1PE12.4)
  6       FORMAT(//50X,'DEPTH TOO GREAT FOR THE MAXIMUM NUMBER OF'
         1                 ' ELEMENTS'//)
C
          END .

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      SUBROUTINE HYDFLO(ALEN, AREA, AWID, DELZ,  DEPTH, D50,
     1                  ELEV, ENDHYD, ETIME, FERROR, HRAD, NELEM,
     2                  NEWQI, PELEV, QHIN, QHOUT, QV, RIVER, SLOPE,
     3                  STRESS, TEMPR, VEL, VOL, DEPMIN,
     4                  XSAREA, BWID, ABAR, QI, CROSEC,QO,IELM)
C
C   THIS SUBROUTINE IS CALLED EACH TIME STEP  TO READ ANY NEW HYDROLOGY
C   DATA THAT WAS WRITTEN TO LUN 4 BY SUBROUTINE HYDDAT.
C
C     FORMAL PARAMETERS:
C       ALEN   - LENGTH OF THE SEGMENT
C       AREA   - AREA OF EACH ELEMENT
C       AWID   - ELEMENT WIDTHS
C       DELZ   - STANDARD ELEMENT THICKNESS
C       DEPTH  - FLOW DEPTH
C       D50    - MEDIAN BED SEDIMENT DIAMETER (METER)
C       ELEV   - SEGMENT ELEVATION
C       ENDHYD - ENDING TIME OF THE CURRENT HYDROLOGY DATA (I*4)
C       ETIME  - ELAPSED TIME OF THE SIMULATION (I*4)
C       FERROR - FATAL ERROR FLAG (L*1)
C       HRAD   - HYDRAULIC RADIUS
C       NELEM  - NUMBER OF ELEMENTS
C       NEWQI  - NEW QI DATA FLAG (L*1)
C       PELEV  - ELEVATION OF THE UPSTREAM SEGMENT
C       QHIN   - INFLOW DISCHARGE
C       QHOUT  - OUTFLOW DISCHARGE
C       QV     - VERTICAL FLOWS
C       RIVER  - SHEAR STREES COMPUTATION CONROL VARIABLE (L*1)
C       SLOPE  - BED SLOPE
C       STRESS - BED SHEAR STRESS
C       TEMPR  - WATER TEMPERATURE
C       VEL    - FLOW VELOCITY OF QHOUT
C       VOL    - SEGMENT VOLUME
C
C   CALLED BY: SERATRA
C   CALLS: SHEARR, SHEARS, PROFIL
C
      INCLUDE 'ELMSIZ.PRM'
C
      INTEGER*4 ETIME,ENDHYD
C
      LOGICAL*1 NEWQI,RIVER,FERROR
C
      DIMENSION AREA(MXELEM), AWID(MXELEM), QHIN(MXELEM),
     1            QHOUT(MXELEM), QV(MXELEM),
     2           XSAREA(MXELEM), BWID(MXELEM), ABAR(MXELEM),
     3           IELM(MXELEM),DUMMY(MXELEM)
C
      DATA SECDAY/86400./
      DATA RHO/1000./
      DATA ZERO/1.0E-05/
C
C
```

```
            FERROR = .FALSE.
            NEWQI = .FALSE.
            IF (ETIME .GT. ENDHYD)
            .  NEWQI = .TRUE.
            .  REPEAT UNTIL (ETIME .LE. ENDHYD)
            .  .  READ(4,END=200) ENDHYD,NELEM,DELZ,QI,QO,VOL,VEL,AWID,AREA,TEMPH,
           1.  .                 XSAREA,IELM,DEPTH,BWID,ABAR,HRAD,CROSEC
            .  ...FIN
            .    IF (DEPTH .GE. DEPMIN)
            .  .  WHEN (RIVER)
C           .  .  .
            .  .  .  CALL SHEARS(ALEN,ELEV,HRAD,PELEV,SLOPE,STRESS,USTAR)
C           .  .  .
            .  .  ...FIN
            .  .  ELSE
            .  .  .  CALL SHEARR(DEPTH,D50,STRESS,USTAR,VEL)
            .  .  .  SLOPE=STRESS/(RHO*HRAD)
            .  .  ...FIN
            .  .  CALL PROFIL(ALEN, AWID, DELZ,  DEPTH, NELEM, QI, USTAR,
           1.  .              VOL, QHIN,DUMMY,0,DELZ)
            .  .  CALL PROFIL(ALEN, AWID, DELZ,  DEPTH, NELEM, QO, USTAR,
           1.  .              VOL, QHOUT,DUMMY,0,DELZ)
C           .  .  *** CONVERT UNITS TO M**3/DAY ***
            .  .  DO (J=1,NELEM)
            .  .  .  QHIN(J) = QHIN(J) * SECDAY
            .  .  .  QHOUT(J) = QHOUT(J) * SECDAY
            .  .  ...FIN
C           .  .
C           .  .  *** COMPUTE VERTICAL FLOWS ***
            .  .  QV(1) = 0.0
            .  .  DO (J=1,NELEM)
            .  .  .  QV(J+1) = QHIN(J) - QHOUT(J) + QV(J)
            .  .  ...FIN
            .  ...FIN
            ...FIN
            RETURN
C
  200       CONTINUE
            FERROR = .TRUE.
            WRITE(6,1)
1           FORMAT(10X,'FATAL ERROR - HYDROLOGY DATA EXHAUSTED')
            RETURN
300         CONTINUE
            FERROR=.TRUE.
            WRITE(6,3)
            WRITE(6,2) (J,QV(J),J=1,NELP1)
3           FORMAT(10X,'FATAL ERROR - VERTICAL FLUX COMPUTATION')
2           FORMAT(15X,I5,1PE12.4)
            RETURN
C
            END

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       SUBROUTINE ICFLO(CCIN,DEPTH,DELZ,D50,ENDIC,ETIME,FERROR,
     1                   INFLO, ISEG, NELEM,  NEWIC,
     2                   QNIN,QI,DEPMIN,ALEN,
     3    UEL, UWID, XSAREA, AREA, AWID, DFZ, VSET,
     4                   EL,ELEV,PELEV,RIVER,NEWQI,NEWTRB,
     5                   NM,PDEPTH,CNODE)
C
C
C      THIS ROUTINE IS CALLED EACH TIME STEP  TO READ THE INITIAL
C      CONDITIONS TO THE FIRST SEGMENT OR THE INFLOWS
C      FROM THE PREVIOUS SEGMENT.
C
C         FORMAL PARAMETERS:
C            CCIN   - CONCENTRATION OF INFLOWS- CELL CENTERED
C            DEPTH  - FLOW DEPTH OF THE CURRENT SEGMENT
C            DELZ   - STANDARD ELEMENT THICKNESS OF THE CURRENT SEGMENT
C            ENDIC  - ENDING TIME OF THE CURRENT INITIAL CONDITIONS DATA
C            ETIME  - ELAPSED TIME OF THE SIMULATION (I*4)
C            FERROR - FATAL ERROR FLAG (L*1)
C            INFLO  - LOGICAL UNIT NUMBER FOR DATA FROM PREVIOUS SEGMENT
C            ISEG   - CURRENT SEGMENT NUMBER
C            NELEM  - NUMBER OF ELEMENTS IN THE CURRENT SEGMENT
C            NELEMB - NUMBER OF ELEMENTS IN THE PREVIOUS SEGMENT
C            NEWIC  - INITIAL CONDITIONS FLAG (L*1)
C            PDELZ  - STANDARD ELEMENT THICKNESS OF THE PREVIOUS SEGMENT
C            PDEPTH - FLOW DEPTH OF THE PREVIOUS SEGMENT
C            QNIN   - INFLOW DISCHARGE
C            QHOLD  - DISCHARGE INTO THE SEGMENT FROM THE PREVIOUS ONE
C
C         CALLED BY: SERATRA
C         CALLS: EQUPCS, EQUPXS, PROFIL, RADIUS
C
       INCLUDE 'ELMSIZ.PRM'
C
       INTEGER*4 ENDIC,ETIME
C
       LOGICAL*1 NEWIC,NEWQI,NEWTRB,FERROR,RIVER
C
       DIMENSION CCIN(MXELEM,MAXCON), CNODE(MXELEM,MAXCON),
     1           QHIN(MXELEM), QHOLD(MXELEM),XSAREA(MXELEM),
     2   PXSAR(MXELEM),IELP(MXELEM),UWID(MXELEM),UWDAVG(MXELEM),
     3    NEWXS(MXELEM), UEL(MXELEM),TMASS(MAXCON),PWID(MXELEM),
     4           DCNODE(MXELEM,MAXCON),
     5           AREA(MXELEM), AWID(MXELEM), DFZ(4), VSET(3),
     6    EL(MXELEM), UAREA(MXELEM)
       DATA RHO/1000./
       DATA SECDAY/86400./
C
       FERROR = .FALSE.
       NEWIC = .FALSE.
       IDIM=MXELEM
       JDIM=MAXCON
       WHEN (ISEG .EQ. 1)
```

```
C       .  DISTRIBUTES INITIAL CONDITIONS UPSTREAM OF INITIAL SEGMENT BY
C       .  CONSERVING RELATIVE CROSS-SECTIONAL AREAS AND DISCHARGES---
C       .  ASSUMES LINEAR PROFILE OF BOTH SEDIMENT AND PARTICULATE, AND
C       .  WIDTH A LINEAR FUNCTION OF DEPTH.
C       .  *** INITIAL CONDITIONS ***
        .  IF (ETIME .GT. ENDIC) NEWIC = .TRUE.
        .  IF(NEWIC.OR.NEWQI.OR.NEWTRB)
        .  .  UNTIL (ETIME .LE. ENDIC)
        .  .  .  READ(2,END=200)ENDIC,NM,PDEPTH,((CNODE(I,J),J=1,MAXCON),I=1,NM)
        .  .  ...FIN
        .  .  IF(DEPTH .LE. DEPMIN) RETURN
        .  .  XS=0.
        .  .  PXS=0.
        .  .  CON=1./12.
        .  .  DO(I=1,NM)
        .  .  .  IF(PDEPTH .LE. UEL(I)) GO TO 10
        .  .  .  WT=UWID(I+1)
        .  .  .  WB=UWID(I)
        .  .  .  ET =UEL(I+1)
        .  .  .  EB=UEL(I)
        .  .  .  IF (PDEPTH .LT. ET)
        .  .  .  .  WT=WB+(WT-WB)*(PDEPTH-EB)/(ET-EB)
        .  .  .  .  ET=PDEPTH
        .  .  .  ...FIN
        .  .  .  DELTA=ET-EB
        .  .  .  PXSAR(I)=(WT+WB)*DELTA/2.
        .  .  .  PXS=PXS+PXSAR(I)
        .  .  .  MELEM=I
        .  .  ...FIN
  10    .  .  CONTINUE
        .  .  DO (I=1,NELEM) XS=XS+XSAREA(I)
        .  .  RATIO=PXS/XS
        .  .  CALL EQUPCS(PXSAR,UWID,UEL,XSAREA,NELEM,MELEM,RATIO,IELP,
       1.  .              HEQXS,FERROR, DELTA)
        .  .  IF(FERROR) RETURN
        .  .  DO(I=1,MELEM-1) UWDAVG(I)=(UWID(I)+UWID(I+1))/2.
        .  .  UWDAVG(MELEM)=(UWID(MELEM)+WT)/2.
        .  .  UDEL=UEL(2)
        .  .  UVOL=PXS*ALEN
        .  .  VEL=QI/PXS
C***********************************************************************
C       .  .  CHANGE 3/12/81
C       .  .
        .  .  DO (I =1,MXELEM) UAREA(I)=UWID(I)*ALEN
        .  .  CALL RADIUS (ALEN,UAREA,CROSEC,PDEPTH,UEL,HRAD)
        .  .  WHEN(RIVER)
        .  .  .  CALL SHEARS(ALEN,ELEV,HRAD,PELEV,SLOPE,STRESS,USTAR)
        .  .  ...FIN
        .  .  ELSE
C       .  .  .
C***********************************************************************
        .  .  .  CALL SHEARR(PDEPTH,D50,STRESS,USTAR,VEL)
        .  .  .  SLOPE=STRESS/(RHO*HRAD)
        .  .  ...FIN
        .  .  CALL PROFIL(ALEN,UWDAVG,UDEL,PDEPTH,MELEM,QI,USTAR,UVOL,QHOLD,
       1.  .              UEL,1,DELTA)
```

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     .  .  DO (I=1,MELEM-1)
     .  .  .  WHOLD(I)=WHOLD(I)*SECDAY/(UWDAVG(I)*(UEL(I+1)-UEL(I)))
     .  .  ...FIN
     .  .  WHOLD(MELEM)=WHOLD(MELEM)*SECDAY/(UWDAVG(MELEM)*DELTA)
     .  .  DO(K=1,MAXCON)
     .  .  .  IF(K .LE. 3 .OR. K .EQ. 7)
     .  .  .  .  UPSQD=WHOLD(1)
     .  .  .  .  WT=UWID(2)
     .  .  .  .  WB=UWID(1)
     .  .  .  .  DEL=UEL(2)-UEL(1)
     .  .  .  .  CT=CNODE(2,K)
     .  .  .  .  CB=CNODE(1,K)
     .  .  .  .  NELMBT=1
     .  .  .  .  CMSAB=DEL*(CT*WT/3.+CT*WB/6.+CB*WT/6.+CB*WB/3.)*UPSQD
     .  .  .  .  CMSBB=0.
     .  .  .  .  TMASS(K)=0.0
     .  .  .  .  IF (K .NE. 7)
     .  .  .  .  .  GT=CNODE(2,K+3)
     .  .  .  .  .  GB=CNODE(1,K+3)
     .  .  .  .  .  PMSAB=DEL*(0.25*(WT*CT*GT+WB*CB*GB)+
  1. .  .  .  .  .  CON*(WT*CB*GB+WB*CT*GB+WB*CB*GT+
  2. .  .  .  .  .  WB*CT*GT+WT*CB*GT+WT*CT*GB))*UPSQD
     .  .  .  .  .  PMSBB=0.
     .  .  .  .  .  TMASS(K+3)=0.
     .  .  .  .  ...FIN
     .  .  .  .  DO(I=1,NELEM)
     .  .  .  .  .  NELMTP=IELP(I)
     .  .  .  .  .  UPSQD=WHOLD(NELMTP)
     .  .  .  .  .  ET=UEL(NELMTP+1)
     .  .  .  .  .  EB=UEL(NELMTP)
     .  .  .  .  .  WT=UWID(NELMTP+1)
     .  .  .  .  .  WB=UWID(NELMTP)
     .  .  .  .  .  CT=CNODE(NELMTP+1,K)
     .  .  .  .  .  CB=CNODE(NELMTP,K)
     .  .  .  .  .  HEL=HEWXS(I)
     .  .  .  .  .  FAC1=(HEL-EB)/(ET-EB)
     .  .  .  .  .  FAC2=(ET-HEL)/(ET-EB)
     .  .  .  .  .  CTOP=CT*FAC1+CB*FAC2
     .  .  .  .  .  WTOP=WT*FAC1+WB*FAC2
     .  .  .  .  .  CMSAT=(ET-HEL)*(CT*WT/3.+CT*WTOP/6.+CTOP*WT/6.+CTOP*WTOP/3.)
  1. .  .  .  .  .  *UPSQD
     .  .  .  .  .  CMSBT=(HEL-EB)*(CTOP*WTOP/3.+CTOP*WB/6.+CB*WTOP/6.+CB*WB/3.)
  1. .  .  .  .  .  *UPSQD
     .  .  .  .  .  IF(K.NE.7)
     .  .  .  .  .  .  GT=CNODE(NELMTP+1,K+3)
     .  .  .  .  .  .  GB=CNODE(NELMTP,K+3)
     .  .  .  .  .  .  GTOP=GT*FAC1+GB*FAC2
     .  .  .  .  .  .  PMSAT=(ET-HEL)*(.25*(WT*CT*GT+WTOP*CTOP*GTOP)
  1. .  .  .  .  .  .  +CON*(WT*CTOP*GTOP+WTOP*CT*GTOP+WTOP*CTOP*GT+
  2. .  .  .  .  .  .  WTOP*CT*GT+WT*CTOP*GT+WT*CT*GTOP))*UPSQD
     .  .  .  .  .  .  PMSBT=(HEL-EB)*(0.25*(WTOP*CTOP*GTOP+WB*CB*GB)
  1. .  .  .  .  .  .  +CON*(WTOP*CB*GB+WB*CTOP*GB+WB*CB*GTOP+
  2. .  .  .  .  .  .  WB*CTOP*GTOP+WTOP*CB*GTOP+WTOP*CTOP*GB))*UPSQD
     .  .  .  .  .  ...FIN
     .  .  .  .  .  INDIC=NELMTP-NELMBT
     .  .  .  .  .  CMASS=0.
```

```
          .  .  .  .  .  PMASS=0.
          .  .  .  .  .  IF(INDIC .EQ. 0)
          .  .  .  .  .  .  CMASS=CMSBT-CMSBB
          .  .  .  .  .  .  IF(K.NE.7) PMASS=PMSBT-PMSBB
          .  .  .  .  .  ...FIN
          .  .  .  .  .  IF(INDIC.GE.1)
          .  .  .  .  .  .  CMASS=CMSBT+CMSAB
          .  .  .  .  .  .  IF(K.NE.7) PMASS=PMSBT+PMSAB
          .  .  .  .  .  ...FIN
          .  .  .  .  .  IF(INDIC.GE.2)
          .  .  .  .  .  .  DO(J=NELMBT+1,NELMTP-1)
          .  .  .  .  .  .  .  DEL=UEL(J+1)-UEL(J)
          .  .  .  .  .  .  .  CT=CNODE(J+1,K)
          .  .  .  .  .  .  .  CB=CNODE(J,K)
          .  .  .  .  .  .  .  UPSQO=QHOLD(J)
          .  .  .  .  .  .  .  WT=UWID(J+1)
          .  .  .  .  .  .  .  WB=UWID(J)
          .  .  .  .  .  .  .  CMASS=CMASS+DEL*(CT*WT/3.+CT*WB/6.+CB*WT/6.+CB*WB/3.)*UPSQO
          .  .  .  .  .  .  .  IF(K.NE.7)
          .  .  .  .  .  .  .  .  GT=CNODE(J+1,K+3)
          .  .  .  .  .  .  .  .  GB=CNODE(J,K+3)
          .  .  .  .  .  .  .  .  PMASS=PMASS+DEL*(0.25*(WT*CT*GT+WB*CB*GB)
        1.  .  .  .  .  .  .  .  +CON*(WB*CT*GT+WT*CB*GT+WT*CT*GB+WT*CB*GB+WB*CT*GB+WB*CB*GT))
        2.  .  .  .  .  .  .  .  *UPSQO
          .  .  .  .  .  .  .  ...FIN
          .  .  .  .  .  .  ...FIN
          .  .  .  .  .  ...FIN
          .  .  .  .  .  THASS(K)=THASS(K)+CMASS
          .  .  .  .  .  CMASS=CMASS/QMIN(I)
          .  .  .  .  .  CMSAB=CMSAT
          .  .  .  .  .  CMSBB=CMSBT
          .  .  .  .  .  NELMBT=NELMTP
          .  .  .  .  .  IF(K.NE.7)
          .  .  .  .  .  .  PMSAB=PMSAT
          .  .  .  .  .  .  PMSBB=PMSBT
          .  .  .  .  .  .  THASS(K+3)=THASS(K+3)+PMASS
          .  .  .  .  .  .  PMASS=PMASS/QMIN(I)
          .  .  .  .  .  ...FIN
  C       .  .  .  .  .
  C       .  .  .  .  .  NOTE: CMASS IS IN (KG/M**3)
  C       .  .  .  .  .
          .  .  .  .  .  COMPUTE-PROFILE-VALUES
          .  .  .  .  ...FIN
          .  .  .  ...FIN
          .  .  ...FIN
          .  ...FIN
          ...FIN
  C       DISTRIBUTES INITIAL CONDITIONS UPSTREAM OF SUBSEQUENT SEGMENTS BY
  C       CONSERVING MASS FLUX -- ASSUMES LINEAR UPSTREAM DISTRIBUTIONS AND
  C       CONSTANT WIDTHS.
          ELSE
          .  NEWIC=.TRUE.
          .  READ(INFLO)PDEPTH,PDELZ,MELEM,(QHOLD(J),PXSAR(J),PWID(J),J=1,
        1.  MELEM),((CNODE(J,K),K=1,MAXCON),J=1,MELEM+1),
        2.  ((UCNODE(J,K),K=1,MAXCON),J=1,MELEM+1)
          .  IF(DEPTH.LE.DEPMIN) GO TO 300
```

```
                .  XS=0.
                .  PXS=0.
                .  DO (I=1,NELEM) XS=XS+XSAREA(I)
                .  DO (I=1,NELEM) PXS=PXS+PXSAR(I)
                .  RATIO=PXS/XS
                .  CALL EQUPXS(PXSAR,PHID,PDELZ,XSAREA,NELEM,MELEM,RATIO,IELP,
               1.  HEQXS)
    C           .  ALLOCATES MASS BY CONSERVING RELATIVE CROSS-SECTIONAL AREAS
                .  DO (K=1,MAXCON)
                .  .  IF(K.LE.3.OR.K.EQ.7)
                .  .  .  K3=K+3
                .  .  .  UPSQO=QHOLD(1)
                .  .  .  CT=(CNODE(2,K)+ UCNODE(2,K))/2.
                .  .  .  CB=(CNODE(1,K) + OCNODE(1,K))/2.
                .  .  .  NELMBT=1
                .  .  .  CMSAB=(CT+CB)/2.*UPSQO
                .  .  .  CMSBB=0.
                .  .  .  TMASS(K)=0.
                .  .  .  IF (K .NE. 7)
                .  .  .  .  GT=(CNODE(2,K3)+ OCNODE(2,K3))/2.
                .  .  .  .  GB=(CNODE(1,K3) + OCNODE(1,K3))/2.
                .  .  .  .  PMSAB=UPSQO*(GT+GB)/2.
                .  .  .  .  PMSBB=0.
                .  .  .  .  TMASS(K3)=0.
                .  .  .  ...FIN
                .  .  .  DO (I=1,NELEM)
                .  .  .  .  NELMTP=IELP(I)
                .  .  .  .  NT=NELMTP+1
                .  .  .  .  NB=NELMTP
                .  .  .  .  ET=NB*PDELZ
                .  .  .  .  EB=(NB-1)*PDELZ
                .  .  .  .  UPSQO=QHOLD(NB)
                .  .  .  .  CT=(CNODE(NT,K) + UCNODE(NT,K))/2.
                .  .  .  .  CB=(CNODE(NB,K) + OCNODE(NB,K))/2.
                .  .  .  .  HEL=HEQXS(I)
                .  .  .  .  FAC1=(HEL-EB)/PDELZ
                .  .  .  .  FAC2=(ET-HEL)/PDELZ
                .  .  .  .  CTOP=CT*FAC1+CB*FAC2
                .  .  .  .  CMSAT=FAC2*(CT+CTOP)*UPSQO/2.
                .  .  .  .  CMSBT=FAC1*(CTOP+CB)/2.*UPSQO
                .  .  .  .  IF(K.NE.7)
                .  .  .  .  .  GT=(CNODE(NT,K3) + OCNODE(NT,K3))/2.
                .  .  .  .  .  GB=(CNODE(NB,K3) + OCNODE(NB,K3))/2.
                .  .  .  .  .  GTOP=GT*FAC1+GB*FAC2
                .  .  .  .  .  PMSAT=FAC2*(GT+GTOP)*UPSQO/2.
                .  .  .  .  .  PMSBT=FAC1*(GTOP+GB)*UPSQO/2.
                .  .  .  .  ...FIN
                .  .  .  .  INDIC=NELMTP-NELMBT
                .  .  .  .  CMASS=0.
                .  .  .  .  PMASS=0.
                .  .  .  .  IF(INDIC.EQ.0)
                .  .  .  .  .  CMASS=CMSBT-CMSBB
                .  .  .  .  .  IF(K.NE.7) PMASS=PMSBT-PMSBB
                .  .  .  .  ...FIN
                .  .  .  .  IF(INDIC.GE.1)
                .  .  .  .  .  CMASS=CMSBT+CMSAB
```

```
            .   .   .   .   .  IF(K.NE.7) PMASS=PMSBT+PMSAB
            .   .   .   .  ...FIN
            .   .   .   .  IF(INDIC.GE.2)
            .   .   .   .   .  DO(J=NELMBT+1,NELMTP-1)
            .   .   .   .   .   .  CT=(CNODE(J+1,K) + OCNODE(J+1,K))/2.
            .   .   .   .   .   .  CB=(CNODE(J,K) + OCNODE(J,K))/2.
            .   .   .   .   .   .  Q=QHOLD(J)
            .   .   .   .   .   .  CMASS=CMASS+(CT+CB)/2.*Q
            .   .   .   .   .   .  IF(K.NE.7)
            .   .   .   .   .   .   .  GT=(CNODE(J+1,K3) + OCNODE(J+1,K3))/2.
            .   .   .   .   .   .   .  GB=(CNODE(J,K3) + OCNODE(J,K3))/2.
            .   .   .   .   .   .   .  PMASS=PMASS+(GT+GB)/2.*Q
            .   .   .   .   .   .  ...FIN
            .   .   .   .   .  ...FIN
            .   .   .   .  ...FIN
            .   .   .   .  TMASS(K)=TMASS(K)+CMASS
            .   .   .   .  CMASS=CMASS/QHIN(I)
            .   .   .   .  CMSAB=CMSAT
            .   .   .   .  CMSBB=CMSBT
            .   .   .   .  NELMBT=NELMTP
            .   .   .   .  IF(K.NE.7)
            .   .   .   .   .  TMASS(K3)=TMASS(K3)+PMASS
            .   .   .   .   .  PMASS=PMASS/QHIN(I)
            .   .   .   .   .  PMSAB=PMSAT
            .   .   .   .   .  PMSBB=PMSBT
            .   .   .   .  ...FIN
            .   .   .   .  COMPUTE-PROFILE-VALUES
            .   .   .  ...FIN
            .   .  ...FIN
            .  ...FIN
            ...FIN
            RETURN
      200   CONTINUE
            FERROR = .TRUE.
            WRITE(6,1)
      1     FORMAT(10X,'FATAL ERROR - INITIAL CONDITIONS TO SEGMENT 1',
           1 ' HAVE BEEN EXHAUSTED')
            RETURN
      300   CONTINUE
            WRITE(6,2)
            WRITE(6,3) ISEG
      2     FORMAT(10X,'POTENTIAL DIFFICULTY - DEPTH.LE.DEPMIN')
      3     FORMAT(10X,'SEGMENT NUMBER =',I5)
            RETURN

      -------------------------------------

            TO COMPUTE-PROFILE-VALUES
            .  WHEN(I.EQ.1)
            .   .  WHEN(K.EQ.7)
            .   .   .  CCIN(1,K)=CMASS
            .   .   .  CCIN(2,K)=CMASS
            .   .  ...FIN
            .   .  ELSE
            .   .   .  COEF=0.
            .   .   .  KK=K+3
```

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  00331          .   .   .   HS=VSET(K)*AREA(1)/(AWID(1)*ALEN)
  00332          .   .   .   EZ=DFZ(K)
  00333          .   .   .   CCIN(1,K)=(2.*CMASS-COEF*DELZ/EZ)/(2.-HS*DELZ/EZ)
  00334          .   .   .   CCIN(2,K)=2.*CMASS-CCIN(1,K)
  00335          .   .   .   CCIN(1,KK)=(2.*PMASS-COEF*DELZ/EZ)/(2.-HS*DELZ/EZ)
  00336          .   .   .   CCIN(2,KK)=2.*PMASS-CCIN(1,KK)
  00337          .   .   ...FIN
  00338          .   ...FIN
  00339          .   ELSE
  00340          .   .   CCIN(I+1,K)=2.*CMASS-CCIN(I,K)
  00341          .   .   IF (K.NE.7)
  00342          .   .   .   CCIN(I+1,K+3)=2.*PMASS-CCIN(I,K+3)
  00343          .   .   ...FIN
  00344          .   ...FIN
  00345          ...FIN
  00346          END

        ----------------------------------------

              PROCEDURE CROSS-REFERENCE TABLE

        00322 COMPUTE-PROFILE-VALUES
              00207  00304


        (FLECS VERSION 22.46)

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--------------------------------------------
      SUBROUTINE INIDAT(ANALMT,ANALYS, DELTH, ECHO, HLDERR, ITPRT,
     1            NSEG, NSTEPS, NUMERR, SIMLEN, DEPMIN)
C
C   THIS ROUTINE READS THE INITIAL DATA COMMON TO ALL SEGMENTS AND IS
C   ONLY CALLED FOR SEGMENT NUMBER 1.
C
C     FORMAL PARAMETERS:
C        ANALMT - ANALYSIS CONCENTRATION LIMIT
C        ANALYS - TIME SERIES ANALYSIS CONTROL VARIABLE (L*1)
C        DELTH  - TIME STEP LENGTH (SECONDS)
C        ECHO   - LINE PRINTER ECHO CONTROL VARIABLE (L*1)
C        HLDERR - HOLDING ARRAY FOR ERROR NUMBERS (BYTE)
C        ITPRT  - PRINT FREQUENCY
C        NSEG   - NUMBER OF SEGMENTS
C        NSTEPS - NUMBER OF TIME STEPS TO BE TAKEN (I*4)
C        NUMERR - NUMBER OF INPUT ERRORS DETECTED
C        SIMLEN - SIMULATION LENGTH (SECONDS - I*4)
C     DEPMIN - MINIMUM (CUTOFF) FLOW DEPTH (METERS)
C
C   CALLED BY: SERATRA
C   CALLES: PUTERR
C
      BYTE HLDERR(100)
C
      INTEGER*4 SIMLEN,NSTEPS
C
      LOGICAL*1 ECHO,ANALYS
C
      DIMENSION TITLE(40)
C
      DATA MAXSEG /35/
      IF (ECHO)
C     .
C     .  *** PRINT HEADING ***
      .  WRITE(6,1)
      .  WRITE(6,2)
      ...FIN
C
C     CARDS 1 AND 2.....SIMULATION IDENTIFICATION TITLE
C
      READ(1,3) (TITLE(I),I=1,40)
      IF (ECHO) WRITE(6,4) (TITLE(I),I=1,40)
C
C     CARD 3............GENERAL INFORMATION COMMON TO ALL SEGMENTS
C
C      COL.  1-10...NSTEPS....NUMBER OF TIME STEPS TO BE TAKEN
C           11-15...NSEG......NUMBER OF SEGMENTS
C           16-20...ITPRT.....PRINT FREQUENCY
C           21-25...ANALYS....TIME SERIES ANALYSIS CONTROL VARIABLE
C           26-35...DELTH.....TIME STEP LENGTH (SECONDS)
C           36-45...ANALMT....LOWER LIMIT OF AVERAGE DISSOLVED
C                             CONCENTRATION, BEFORE THE RESULTS OF A
C                             TIME STEP ARE SAVED, THE AVERAGE
```

```
C                               DISSOLVED CONC. MUST BE > ANALMT.
C          46-55...DEPMIN....MINIMUM (CUTOFF) FLOW DEPTH BELOW WHICH
C                         THE CHANNEL IS CONSIDERED DRIED.
C
        READ(1,5) NSTEPS,NSEG,ITPRT,ANALYS,DELTH,ANALMT,DEPMIN
C
C       *** COMPUTE SIMULATION LENGTH (SECONDS) ***
        SIMLEN = DELTH
        SIMLEN = SIMLEN * NSTEPS
        IF (ECHO)
        .  WRITE(6,6) NSTEPS,NSEG,ITPRT,ANALYS,DELTH,ANALMT,SIMLEN,DEPMIN
        ...FIN
C
        IF (NSTEPS .LE. 0) CALL PUTERR(1,NUMERR,HLDERR)
        IF (NSEG.LE.0 .OR. NSEG.GT.MAXSEG) CALL PUTERR(2,NUMERR,HLDERR)
        IF (ITPRT .LE. 0) CALL PUTERR(3,NUMERR,HLDERR)
        IF (DELTH .LE. 0.0) CALL PUTERR(5,NUMERR,HLDERR)
C
        RETURN
    1   FORMAT(1H0,34X,'SEDIMENT AND CONTAMINANT TRANSPORT SIMULATION',
       1  ' PROGRAM - SERATRA')
    2   FORMAT(1H0,54X,'PROBLEM SPECIFICATIONS')
    3   FORMAT(20A4)
    4   FORMAT(1H0,25X,20A4/26X,20A4)
    5   FORMAT(I10,2I5,L5,2F10.0,E10.3)
    6   FORMAT(1H0,8X,I10,'...NUMBER OF TIME STEPS TO BE TAKEN'/
       1  14X,I5,'...NUMBER OF SEGMENTS'/
       2  14X,I5,'...PRINT FREQUENCY (# OF TIME STEPS)'/
       4  18X,L1,'...TIME SERIES ANALYSIS CONTROL'/
       5  7X,1PE12.5,'...TIME STEP LENGTH (SECONDS)'/
       6  7X,1PE12.5,'...TIME SERIES CONCENTRATION LIMIT'/
       7  9X,I10,'...COMPUTED SIMULATION LENGTH (SECONDS)'/
       8  9X,E10.3,'...MINIMUM (CUTOFF) FLOW DEPTH (METERS)')
C
        END

        (FLECS VERSION 22.46)

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                 SUBROUTINE LISTER(BASE,BEGSEG,BEGTIM,CHAIN,DEV,EXT,FILNAM,GUIC,
                1                   INTSEG,INTTIM,LSTSEG,LSTTIM,TSTEP,UNITS,UUIC)
        C
        C          THIS ROUTINE HAS THE RESPONSIBILITY OF LOCATING AND PRINTING THE
        C          SPECIFIED MATRICES FROM THE SPECIFIED FILES.
        C
        C       FORMAL PARAMETERS:
        C          BASE   = 5 CHARACTER BASE FILE NAME FOR CHAINED OPERATIONS
        C          BEGSEG = BEGINNING SEGMENT NUMBER FOR CHAINED OPERATIONS
        C          BEGTIM = BEGINNING TIME PLANE NUMBER
        C          CHAIN  = LOGICAL FLAG FOR CHAINED OPERATIONS
        C          DEV    = BASE FILE NAME DEVICE FOR CHAINED OPERATIONS
        C          EXT    = BASE FILE NAME EXTENSION FOR CHAINED OPERATIONS
        C          FILNAM = FILE SPECIFICATION FOR UNCHAINED PROCESSING
        C          GUIC   = GROUP UIC FOR CHAINED PROCESSING
        C          INTSEG = SEGMENT INTERVAL FOR CHAINED PROCESSING
        C          INTTIM = TIME PLANE INTERVAL
        C          LSTSEG = LAST SEGMENT NUMBER FOR CHAINED OPERATIONS
        C          LSTTIM = LAST TIME PLANE NUMBER
        C          TSTEP  = TIME STEP SIZE
        C          UNITS  = MNEMONICS FOR CONCENTRATION OF CONTAMINANT ATTACHED TO
        C                   SEDIMENTS (PC OR KG)
        C          UUIC   = USER UIC FOR CHAINED PROCESSING
        C
        C          CALLED BY: SPPR
        C          CALLS: FCODE
        C
                 INCLUDE 'ELMSIZ.PRM'
                 BYTE BASE(5),DEV(3),EXT(3),FILNAM(30),GUIC(3),UUIC(3)
        C
                 INTEGER*2 BEGSEG,UNITS
                 INTEGER*4 BEGTIM,ITIM,LSTTIM,NSTEP
        C
                 LOGICAL*1 CHAIN
        C
                 DIMENSION WELEV(MXELEM), C(MXELEM,7), CMASS(MXELEM),
                1           CVOLM(MXELEM), CTOTL(MXELEM), BEL(10), B(10,6),
                2           BAVG(10), D(MXELEM,3), CELAV(MXELEM,MAXCON),
                3    QCIN(MXELEM,MAXCON), QCOUT(MXELEM,MAXCON),
                4    QVCEL(MXELEM,MAXCON), SELAV(MAXLEV,MAXCON-1),
                5    QVDIF(MXELEM,MAXCON),JJ(MXELEM),
                6           BAL(MAXCON),DIF(MAXCON),TSED(MAXCON),TOTDIF(MAXCON)
        C
                 DO (JSEG=BEGSEG,LSTSEG,INTSEG)
                 .  IF (CHAIN)CALL FCODE (FILNAM,BASE,JSEG,EXT,DEV,GUIC,UUIC)
                 .  OPEN(UNIT=2,NAME=FILNAM,TYPE='OLD',READONLY,FORM='UNFORMATTED')
                 .  WRITE(1,9) FILNAM
        C        .
                 .  READ(2) NUMSEG
        C        .
                 .  IF(BEGTIM .NE. 1)
                 .  .  NM = BEGTIM - 1
                 .  .  SKIP-NM-MATRICES
```

```
       .  ...FIN
       .  DO (ITIM=BEGTIM,LSTTIM,INTTIM)
       .  .  IF(INTTIM .NE. 1 .AND. ITIM .NE. BEGTIM)
       .  .  .  NM = INTTIM - 1
       .  .  .  SKIP-NM-MATRICES
       .  .  ...FIN
       .  .  READ (2) NSTEP,NELEM,NBED,ELEV,DELZ,BDIV,XYSD,STRESS
       .  .  READ (2) (WELEV(J),(C(J,K),K=1,7),CMASS(J),CVOLM(J),CTOTL(J),
      1.  .           J=1,NELEM)
       .  .  READ(2) ((D(J,K), K=1,3), J=1,NELEM)
       .  .  READ (2) (BEL(J),(B(J,K),K=1,6),BAVG(J),J=1,NBED)
       .  .  NELMO=NELEM-1
       .  .  DO(J=1,NELEM) JJ(J)=J-1
       .  .  READ(2)VOLUME
       .  .  READ(2) ((CELAV(J,K), K=1,MAXCON), J=1,NELEM)
       .  .  READ(2) ((QCIN(J,K), K=1,MAXCON), J=1,NELEM)
       .  .  READ(2) ((QCOUT(J,K), K=1,MAXCON), J=1,NELEM)
       .  .  READ(2) ((QVCEL(J,K), K=1,MAXCON), J=1,NELMO)
       .  .  READ(2) ((QVDIF(J,K), K=1,MAXCON), J=1,NELMO)
       .  .  READ(2) (BAL(J),J=1,MAXCON),TBAL
       .  .  READ(2) (DIF(J),J=1,MAXCON),TDIF
       .  .  READ(2) ((BELAV(J,K), K=1,MAXCON-1), J=1,NBED)
       .  .  READ(2) (TBED(J),J=1,MAXCON)
       .  .  READ(2) (TOTDIF(J),J=1,MAXCON)
       .  .  ELAPSE = TSTEP*NSTEP
       .  .  WRITE(3,1)
       .  .  WRITE(3,2) NUMSEG,NSTEP,ELAPSE,ELEV,NELMO,DELZ,NBED,BDIV,
      1.  .                XYSD,STRESS
       .  .  WRITE(3,3)
       .  .  WRITE(3,4) (UNITS,J=1,6)
       .  .  DO (J=1,NELEM)
       .  .  .  WRITE(3,5) WELEV(J),C(J,1),C(J,2),C(J,3),C(J,7),C(J,4),C(J,5),
      1.  .  .              C(J,6),CMASS(J),CTOTL(J)
       .  .  ...FIN
       .  .  WRITE(3,6)
       .  .  WRITE(3,7) (UNITS,J=1,4)
       .  .  DO (J=1,NBED)
       .  .  .  WRITE(3,8) BEL(J),(B(J,K),K=1,6),BAVG(J)
       .  .  ...FIN
       .  .  WRITE(3,12)
       .  .  WRITE(3,13) (UNITS, J=1,4)
       .  .  WRITE(3,14) (WELEV(J), (D(J,K), K=1,3), CVOLM(J), J=1,NELEM)
       .  .  WRITE(3,15)
       .  .  WRITE(3,16) (UNITS, J=1,4)
       .  .  WRITE(3,17) (JJ(J), (CELAV(J,K), K=1,MAXCON), J=1,NELEM)
       .  .  WRITE(3,18)
       .  .  WRITE(3,16) (UNITS,J=1,4)
       .  .  WRITE(3,17) (JJ(J), (QCIN(J,K), K=1,MAXCON), J=1,NELEM)
       .  .  WRITE(3,19)
       .  .  WRITE(3,16) (UNITS, J=1,4)
       .  .  WRITE(3,17) (JJ(J), (QCOUT(J,K), K=1,MAXCON), J=1,NELEM)
C      .  .  WRITE(3,20)
C      .  .  WRITE(3,16) (UNITS, J=1,4)
C      .  .  WRITE(3,17) (J, (QVCEL(J,K), K=1,MAXCON), J=1,NELMO)
C      .  .  WRITE(3,24)
C      .  .  WRITE(3,16) (UNITS, J=1,4)
```

```
C     .  .  WRITE(3,17) (J,(WVDIF(J,K), K=1,MAXCON), J=1,NELMO)
      .  .  WRITE(3,21)
      .  .  WRITE(3,22) (UNITS, J=1,3)
      .  .  WRITE(3,23) (J, (BELAV(J,K), K=1,MAXCON-1), J=1,NMED)
      .  .  WRITE(3,25)
      .  .  WRITE(3,26) (UNITS,J=1,5)
      .  .  WRITE(3,27) (BAL(J),J=1,MAXCON),TBAL
      .  .  WRITE(3,27) (DIF(J),J=1,MAXCON),TDIF
      .  .  WRITE(3,29) (TBED(J),J=1,MAXCON)
      .  .  WRITE(3,29) (TOTDIF(J),J=1,MAXCON)
      .  ...FIN
      .  CLOSE (UNIT=2)
      ...FIN
      CLOSE (UNIT=3)
      RETURN
C
    1 FORMAT(1H1)
    2 FORMAT(//10X,'RIVER SEGMENT NUMBER:        ',8X,I6/
     1         10X,'TIME STEP NUMBER:            ';8X,I6/
     2         10X,'ELAPSED TIME:                ',3X,F11.2/
     3         10X,'DATUM:                       ',4X,F10.4/
     4         10X,'NUMBER OF ELEMENTS:          ',8X,I6/
     5         10X,'STANDARD ELEMENT THICKNESS:  ',1PE14.7/
     7         10X,'NUMBER OF BED LAYERS:        ',8X,I6/
     8         10X,'STANDARD BED LAYER THICKNESS:',1PE14.7/
     9         10X,'TOP LAYER THICKNESS:         ',1PE14.7/
     1         10X,'SHEAR STRESS VALUE:          ',1PE14.7)
    3 FORMAT(//55X,'WATER CONCENTRATIONS')
    4 FORMAT(//10X,3(3X,'SUSPENDED'),5X,'DISSOLVED ',1X,3(' CONTAM'
     1  'INANT'),5X,'TOTAL',6X,' TOTAL'/
     2  2X,'ELEVATION',4X,'SAND',8X,
     3  'SILT',8X,'CLAY',5X,'CONTAMINANT   WITH SAND   WITH SILT',
     4  3X,'WITH CLAY',3X,'PARTICULATE',4X,'CONC.'/
     5  3X,'(METERS)',3X,3('KG/M**3',5X),1X,A2,'/M**3',5X,2(A2,'/M**3',
     6  5X),A2,'/M**3',5X,A2,'/M**3',5X,A2,'/M**3')
    5 FORMAT(1X,F10.4,1P10E12.4)
    6 FORMAT(//56X,'BED CONCENTRATIONS')
    7 FORMAT(//16X,'SAND WEIGHT',5X,'SILT WEIGHT',5X,'CLAY WEIGHT',
     1  3(5X,'CONTAMINANT'),7X,'AVERAGE'/2X,'ELEVATION',6X,
     2  3('FRACTION',8X),'WITH SAND',7X,'WITH SILT',7X,'WITH CLAY',
     3  9X,'CONC.'/
     4  3X,'(METERS)',7X,3(7X,9X),1X,3(A2,'/KG',11X),A2,'/KG')
    8 FORMAT(1X,F10.4,7(2X,1PE14.7))
    9 FORMAT(' PROCESSING- ',30A1)
   10 FORMAT(50X,'(IMPLICIT FALL VELOCITY SCHEME)')
   11 FORMAT(48X,'(POST-MATRIX-SOLUTION FALL ROUTINE)')
   12 FORMAT(//45X,'CONTAMINANT ASSOCIATED WITH SEDIMENT')
   13 FORMAT(//42X,3('CONTAMINANT '),2X,'AVERAGE'/31X,'ELEVATION',
     13X,'WITH SAND',3X,'WITH SILT',3X,'WITH CLAY',4X,'CONC.'/
     232X,'(METERS)',5X,A2,'/KG',7X,A2,'/KG',7X,A2,'/KG',6X,A2,'/KG')
   14 FORMAT(30X,0PF10.4,1P4E12.4)
   15 FORMAT(//35X,'INTEGRATED VALUES OF TOTAL MASS OR CONTAMINANT IN EA
     1CH ELEMENT')
   16 FORMAT(//28X,3('SUSPENDED   '),3('CONTAMINANT '),'  DISSOLVED'/
     120X,'ELEMENT    SAND',3X,'SILT',8X,'CLAY',7X,'WITH SAND',3X,
     2'WITH SILT   WITH CLAY',3X,'CONTAMINANT'/31X,'KG',10X,'KG',
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  00166           310X,'KG',11X,A2,10X,A2,10X,A2,12X,A2)
  00167        17  FORMAT(22X,I2,2X,1P3E12.4,1X,1P2E12.4,1X,1PE12.4,1X,1PE12.4)
  00168        18  FORMAT(//37X,'FLUX OF SEDIMENT MASS OR CONTAMINANT INFLUENT TO ELE
  00169           1MENT')
  00170        19  FORMAT(//37X,'FLUX OF SEDIMENT MASS OR CONTAMINANT EFFLUENT FROM E
  00171           1LEMENT')
  00172        20  FORMAT(//34X,'VERTICAL FLUX OF SEDIMENT MASS OR CONTAMINANT TO EAC
  00173           1H ELEMENT')
  00174        21  FORMAT(//36X,'INTEGRATED VALUES OF TOTAL MASS OR CONTAMINANT IN TH
  00175           1E BED')
  00176        22  FORMAT(//14X,'ELEMENT',5X,'SAND WEIGHT',5X,'SILT WEIGHT',5X,'CLAY
  00177           1 WEIGHT',3(5X,'CONTAMINANT')/75X,'WITH SAND',7X,'WITH SILT',7X,'
  00178           2WITH CLAY'/30X,'KG',2(14X,'KG'),15X,A2,2(14X,A2))
  00179        23  FORMAT(16X,I3,2X,1P6E16.7)
  00180        24  FORMAT(//36X,'DISPERSION OF SEDIMENT MASS OR CONTAMINANT THROUGH E
  00181           1ACH ELEMENT')
  00182       26   FORMAT('0',9X,'SAND',12X,'SILT',12X,'CLAY',11X,'W/SAND',10X,'W/SIL
  00183           1T',10X,'W/CLAY',7X,'DISSOLVED',3X,'TOTAL CONTAMINANT'/11X,'KG',
  00184           214X,'KG',14X,'KG',14X,A2,14X,A2,14X,A2,14X,A2,14X,A2)
  00185       27   FORMAT(2X,8(2X,1PE14.7))
  00186       28   FORMAT('0','(1)  OLDC + INFLUENT - EFFLUENT'/' ',
  00187           1            '(2)  NEWC = (1)'/' ',
  00188           2            '(3)  NEWBED = SUMMATION (B(I,J)*VOLUME*DENSITY)'/' ',
  00189           3            '(4)  NEWBED = OLDBED + (2)')
  00190       29   FORMAT(2X,6(2X,1PE14.7),16X,1PE16.7)
  00191       C

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  00192            TO SKIP-NM-MATRICES
  00193            . DO (M=1,NM)
  00194       C    . . *** THERE ARE 15 RECORDS FOR EACH TIME STEP ***
  00195            . . DO (M=1,15) READ (2)
  00196            . ...FIN
  00197            ...FIN
  00198       C
  00199            END

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                PROCEDURE CROSS-REFERENCE TABLE

          00192 SKIP-NM-MATRICES
                00053  00058


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      SUBROUTINE PARTIC(ABAR, ALEN, B, C, CCIN, COLD, DECAY, DELTD,
     1           DFZ, I, J, NBED, NELEM, QHOUT, QHIN, QV, SORBK,
     2            SD, SR, ALFA, BETA, VEL1, VEL2, VSET,
     3 DELZ, DEPTH, BWID, AWID, BETA1, BETA2, DSORB, OLDC)
C
C    THIS SUBROUTINE CALCULATES COEFFICIENTS OF CONVECTIVE, DECAY AND
C     SOURCE TERMS FOR TRANSPORT OF POLLUTANT ATTACHED TO SEDIMENT.
C
C      INPUT PARAMETERS:
C         ABAR   - AVERAGE ELEMENT AREAS
C         B      - BED CONDITIONS
C         C      - WATER CONDITIONS
C         CCIN   - CONCENTRATION OF INFLOW
C         COLD   - CELL-CENTERED CONCENTRATION
C         DECAY  - FIRST ORDER DECAY
C         DELTD  - TIME STEP (DAYS)
C         DFZ    - DIFFUSION COEFFICIENT
C         DELZ    - ELEMENT THICKNESS
C         I      - ELEMENT INDEX
C         J      - PARAMETER INDEX
C         NBED   - NUMBER OF BED LAYERS
C         NELEM  - NUMBER OF ELEMENTS
C         QHIN   - INFLOW DISCHARGE
C         QV     - VERTICAL DISCHARGE
C         SORBK  - ADSORBTION ON SEDIMENT, (1-3) M**3/KG, (4-9) 1/DAY
C      DSORB  - DESORPTION FROM SEDIMENT, (1-3) M**3/KG, (4-9) 1/DAY
C         SR     - EROSION RATE, KG(PC)/M**3/DAY
C      SD     - DEPOSITION RATE, KG(PC)/M3/DAY
C      OUTPUT PARAMETERS:
C         ALFA   - DECAY TERM, 1/DAY
C         BETA   - SOURCE OR SINK TERM, PC (KG)/M**3/DAY
C      BETA1  - INFLUENT SOURCE TERM FOR I-TH NODE, PC (KG)/M**3/DAY
C         BETA2  - INFLUENT SOURCE TERM FOR I+1 TH NODE, PC (KG)/M**3/DAY
C         VEL1   - FIRST CONVECTIVE TERM, M/DAY
C         VEL2   - SECOND CONVECTIVE TERM, M/DAY
C
C      CALLED BY TRANSP.
C
       INCLUDE 'ELMSIZ.PRM'
C
       REAL INFRAC
C
       DIMENSION ABAR(MXELEM), AREA(MXELEM), B(MAXLEY,MAXCON-1),
     1           CCIN(MXELEM,MAXCON), DECAY(6), DFZ(4), QHIN(MXELEM),
     2           QV(MXELEM), SORBK(9), SR(6), COLD(MXELEM,MAXCON),
     3           C(MXELEM,MAXCON), VSET(3), QHOUT(MXELEM),
     4    SD(MXELEM,6), BWID(MXELEM), AWID(MXELEM), CBAR(MXELEM,MAXCON)
     5    , DSORB(9), OLDC(MXELEM,MAXCON)
C
C
      ZERO = 1.0E-10
      JM3=J - 3
      IP1 = I + 1
```

```
C
C   *** CONVECTIVE TERM ***
C
      AQ = QV(I)
      VEL1 =(AQ-VSET(JM3)*BWID(I)*ALEN)/ABAR(I)
C
      AQ = QV(IP1)
      VEL2=(AQ-VSET(JM3)*BWID(I+1)*ALEN)/ABAR(I)
C
C   *** DECAY TERM ***  (EFFLUENT)
C
      ALFA=QHOUT(I)/(ABAR(I)*DELZ) + DECAY(1)
C
C   *** SOURCE OR SINK TERM ***  (INFLUENT)
C
      BETA1=QHIN(I)/(ABAR(I)*DELZ)*(CCIN(I,J)/3.+CCIN(I+1,J)/6.)
      BETA2=QHIN(I)/(ABAR(I)*DELZ)*(CCIN(I,J)/6.+CCIN(I+1,J)/3.)
C *****************************************************************
C *                                                               *
C *  WARNING: CCIN IS WRITTEN INTO CBAR AS A FIRST                *
C *           APPROXIMATION TO THE EVENTUAL AVERAGE               *
C *           CONCENTRATION.  THE ONLY MEANS BY WHICH             *
C *           TO ASSURE THE ACCURACY OF THIS                      *
C *           ASSUMPTION IS TO ITERATE TO THE CORRECT             *
C *           SOLUTION, AND USE NEW ITERATES TO BETTER            *
C *           APPROXIMATE CBAR.                                   *
C *                                                               *
C *****************************************************************
C
C   *** ABSORPTION / DESORPTION ***
C
      DO (IE = 1,NELEM)
C     .
      .  INFRAC = 0.5*QHIN(IE)*DELTD/ABAR(IE)/DELZ
      .  EXFRAC = 1.0 - INFRAC
      .  DO (IC = 1,MAXCON)
      .  .  CBAR(IE,IC) = CCIN(IE,IC)*INFRAC+DLOC(IE,IC)*EXFRAC
      .  ...FIN
      ...FIN
      IF(CBAR(I,JM3).GT.0.0.AND.CBAR(I+1,JM3).GT.0.0)
      .  ADDS1=      SORBK(J)*SORBK(JM3)/12.*(3.*CBAR(I,JM3)*CBAR(I,7)
     1.  +CBAR(I,JM3)*CBAR(I+1,7)+CBAR(I+1,JM3)*CBAR(I,7)+
     2.  CBAR(I+1,JM3)*CBAR(I+1,7))-SORBK(J)/6.*(2.*CBAR(I,J)+
     3.  CBAR(I+1,J))
      .  DSAD1=      DSORB(J)*DSORB(JM3)/12.*(3.*CBAR(I,JM3)*CBAR(I,7)
     1.  +CBAR(I,JM3)*CBAR(I+1,7)+CBAR(I+1,JM3)*CBAR(I,7)+
     2.  CBAR(I+1,JM3)*CBAR(I+1,7))-DSORB(J)/6.*(2.*CBAR(I,J)+
     3.  CBAR(I+1,J))
      .  ADDS2=      SORBK(J)*SORBK(JM3)/12.*(CBAR(I,JM3)*CBAR(I,7)
     1.  +CBAR(I,JM3)*CBAR(I+1,7)+CBAR(I+1,JM3)*CBAR(I,7)
     2.  +3.*CBAR(I+1,JM3)*CBAR(I+1,7))-SORBK(J)/6.*(CBAR(I,J)
     3.  +2.*CBAR(I+1,J))
      .  DSAD2=      DSORB(J)*DSORB(JM3)/12.*(CBAR(I,JM3)*CBAR(I,7)
     1.  +CBAR(I,JM3)*CBAR(I+1,7)+CBAR(I+1,JM3)*CBAR(I,7)
     2.  +3.*CBAR(I+1,JM3)*CBAR(I+1,7))-DSORB(J)/6.*(CBAR(I,J)
     3.  +2.*CBAR(I+1,J))
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              .  IF(ADDS1.GT.0.0.OR.ADDS1.EQ.DSAD1)BETA1=BETA1+ADDS1
              .  IF(DSAD1.LT.0.0)BETA1=BETA1+DSAD1
              .  IF(ADDS2.GT.0.0.OR.ADDS2.EQ.DSAD2)BETA2=BETA2+ADDS2
              .  IF(DSAD2.LT.0.0)BETA2=BETA2+DSAD2
              ...FIN
        C
        C    *** SCOUR OR DEPOSITION ***
        C
              BETA = SR(J) - BD(I,J)
              RETURN
              END

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      SUBROUTINE PHOINP(ECHO,JULIAN,KAY1,KAY2,PCOEF)
C
C   THIS SUBROUTINE IS RESPONSIBLE FOR READING THE PHOTOLYSIS INPUT
C   DATA AND COMPUTING THE FIRST TERM OF THE RATE OF CHANGE EQUATION.
C
C     FORMAL PARAMETERS:
C       ECHO   - LINE PRINTER ECHO CONTROL VARIABLE - L*1
C       JULIAN - JULIAN STARTING DATE OF THE SIMULATION
C       KAY1   - LIGHT EXTINCTION COEFFICIENT OF WATER
C       KAY2   - LIGHT EXTINCTION COEFFICIENT OF SUSPENDED SEDIMENTS
C                IN WATER
C       PCOEF  - FIRST TERM OF THE RATE OF CHANGE EQUATION
C
C   CALLED BY: SERATRA
C
      INTEGER*4 SECDAY
      LOGICAL*1 ECHO
C
      REAL KAY1,KAY2
C
      DIMENSION E(18),SI(18,4),WL(18),PCOEF(4)
C
      DATA SECDAY/86400/
C     *** THESE ARE THE SUNLIGHT WAVE LENGTHS THAT DATA IS EXPECTED FOR
      DATA WL / 300.00, 303.75, 308.75, 313.75, 318.75, 323.10,
     1          346.00, 370.00, 400.00, 430.00, 460.00, 490.00,
     2          536.25, 586.50, 637.50, 687.50, 756.00, 800.00/
C
C     ....FIRST DATA SET
C          COL.  1- 5...JULIAN....JULIAN STARTING DATE OF THE SIMULATION
C                                 WHEN THIS IS INPUT AS A ZERO, NO
C                                 PHOTOLYSIS CALCULATIONS ARE MADE.
C                 6-15...PHI.......THE REACTION QUANTUM YIELD FOR THE
C                                 CHEMICAL IN AIR-SATURATED, PURE WATER.
C                                 A MEASURE OF THE EFFICIENCY WITH WHICH
C                                 A PHOTOCHEMICAL PROCESS CONVERTS
C                                 ADSORBED LIGHT INTO CHEMICAL REACTION.
C                16-25...KAY1......LIGHT EXTINCTION COEFFICIENT OF WATER
C                                 (1/M)
C                26-35...KAY2......LIGHT EXTINCTION COEFFICIENT OF
C                                 SUSPENDED SEDIMENTS IN WATER (SELF-
C                                 SHADING COEFFICIENT) M**4/KG**2
C
      READ(1,1) JULIAN,PHI,KAY1,KAY2
      WHEN (JULIAN .EQ. 0)
      .  DO (I=1,4) PCOEF(I) = 0.0
      .  PHI = 0.0
      .  KAY1 = 0.0
      .  KAY2 = 0.0
      .  IF (ECHO) WRITE(6,2)
      ...FIN
      ELSE
C     .
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C      .  ....SECOND DATA SET - ADSORBTION COEFFICIENTS TABLE
C      .        THIS IS THE TABLE OF ADSORTION COEFFICIENTS FOR 18
C      .        DIFFERENT WAVELENGTHS THAT ARE A MEASURE OF THE CHEMICAL'S
C      .        ABILITY TO ADSORB LIGHT AT THE DIFFERENT WAVELENGTHS.
C      .        WAVELENGTH UNITS ARE NANO METERS.
C      .    ....RECORD 1
C      .         COL.  1-10...E( 1)...COEF. FOR WAVELENGTH OF 300.00
C      .              11-20...E( 2)...COEF. FOR WAVELENGTH OF 303.75
C      .              21-30...E( 3)...COEF. FOR WAVELENGTH OF 308.75
C      .              31-40...E( 4)...COEF. FOR WAVELENGTH OF 313.75
C      .              41-50...E( 5)...COEF. FOR WAVELENGTH OF 318.75
C      .              51-60...E( 6)...COEF. FOR WAVELENGTH OF 323.10
C      .              61-70...E( 7)...COEF. FOR WAVELENGTH OF 346.00
C      .              71-80...E( 8)...COEF. FOR WAVELENGTH OF 370.00
C      .
C      .   ....RECORD 2
C      .        COL.  1-10...E( 9)...COEF. FOR WAVELENGTH OF 400.00
C      .             11-20...E(10)...COEF. FOR WAVELENGTH OF 430.00
C      .             21-30...E(11)...COEF. FOR WAVELENGTH OF 460.00
C      .             31-40...E(12)...COEF. FOR WAVELENGTH OF 490.00
C      .             41-50...E(13)...COEF. FOR WAVELENGTH OF 536.25
C      .             51-60...E(14)...COEF. FOR WAVELENGTH OF 587.50
C      .             61-70...E(15)...COEF. FOR WAVELENGTH OF 637.50
C      .             71-80...E(16)...COEF. FOR WAVELENGTH OF 687.50
C      .
C      .   ....RECORD 3
C      .        COL.  1-10...E(17)...COEF. FOR WAVELENGTH OF 756.00
C      .             11-20...E(18)...COEF. FOR WAVELENGTH OF 800.00
C      .
       .  READ(1,4) (E(L),L=1,18)
C      .
C      .  ....THIRD DATA SET - SOLAR INTENSITY TABLE
C      .        THIS TABLE CONSISTS OF FOUR SETS OF 18 VALUES, THE
C      .        FOUR SETS CORRESPOND TO SPRING, SUMMER, FALL, AND WINTER,
C      .        RESPECTIVELY. THE 18 VALUES CORRESPOND TO THE 18 WAVELENGTHS
C      .        AS DESCRIBED ABOVE IN THE ADSORPTION COEFFICIENT TABLE.
C      .        THE INCLUSIVE DATES FOR EACH SEASON ARE GIVEN BELOW:
C      .                   CALENDER DATES         JULIAN DATES
C      .                   --------------         ------------
C      .      SPRING     MARCH 1 - MAY 31          60-151
C      .      SUMMER     JUNE 1  - AUG. 31        152-243
C      .      FALL       SEP. 1  - NOV. 30        244-334
C      .      WINTER     DEC. 1  - FEB. 28        335-365; 1-59
C      .
       .  READ(1,4) ((SI(L,I),L=1,18),I=1,4)
C      .
       .  IF (ECHO)
       .  .  WRITE(6,3)
       .  .  WRITE(6,7) JULIAN,PHI,KAY1,KAY2
       .  .  WRITE(6,5)
       .  .  DO (L=1,18)
       .  .  .  WRITE(6,6) WL(L),E(L),(SI(L,I),I=1,4)
       .  .  ...FIN
       .  ...FIN
C      .
C      .  *** THE JULIAN DATE IS ADJUSTED TO MAKE THE FIRST DAY OF
```

```
C      .        SPRING JULIAN DAY 1 ***
       .  WHEN (JULIAN .GE. 60) JULIAN = JULIAN - 59
       .  ELSE JULIAN = JULIAN + 306
C      .
C      .  *** COMPUTE THE FIRST TERM OF THE RATE OF CHANGE EQUATION
C      .        FOR EACH OF THE FOUR SEASONS ***
       .  DO (I=1,4)
       .  .  PCOEF(I) = 0.0
       .  .  DO (L=1,18) PCOEF(I) = PCOEF(I) + E(L) * SI(L,I)
       .  .  PCOEF(I) = PHI * PCOEF(I) * (2.303/6.02E20) * SECDAY
       .  ...FIN
       ...FIN
       RETURN
C
1      FORMAT(I5,3F10.0)
2      FORMAT(1H0,13X,'NO PHOTOLYSIS DEGRADATION WILL BE COMPUTED')
3      FORMAT(1H0,48X,'PHOTOLYSIS TABLES AND COEFFICIENTS')
4      FORMAT(8F10.0/8F10.0/2F10.0)
5      FORMAT(1H0,56X,'PHOTOLYSIS TABLES'/39X,'ADSORBTION',
      1 23X,'SOLAR INTENSITIES'/23X,'LAMDA CENTER',
      2 2X,'COEFFICIENTS',5X,'SPRING',8X,'SUMMER',9X,'FALL',
      3 9X,'WINTER'/23X,6(12('-'),2X))
6      FORMAT(26X,F6.2,3X,5(2X,1PE12.4))
7      FORMAT(26X,I5,'...JULIAN STARTING DATE'/
      1 14X,1PE12.5,'...REACTION QUANTUM YIELD'/
      2 14X,1PE12.5,'...LIGHT EXTINCTION COEFFICIENT OF WATER'/
      3 14X,1PE12.5,'...LIGHT EXTINCTION COEFFICIENT OF SUSPENDED',
      4                      ' SOLIDS IN WATER')
C
       END

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      SUBROUTINE PROFIL(ALEN, AWID, DELZ, DEPTH, NELEM, Q,
     1                  USTAR, VOL, QH, EL, IFLAG, DELTA)
C
C   THIS ROUTINE ASSIGNS A LOGARITHMIC OR UNIFORM PROFILE FOR THE
C   BULK VOLUMETRIC FLOWS.
C
C       INPUT PARAMETERS:
C          ALEN    = SEGMENT LENGTH
C          AWID    = SEGMENT WIDTH
C          DELZ    = STANDARD ELEMENT THICKNESS
C          DEPTH   = FLOW DEPTH
C          NELEM   = NUMBER OF VERTICAL ELEMENTS IN THE SEGMENT
C          Q       = FLOW TO BE DISTRIBUTED
C          USTAR   = SHEAR VELOCITY
C          VOL     = SEGMENT VOLUME
C       OUTPUT PARAMETERS:
C          QH      = DISTRIBUTED FLOW
C
C       CALLED BY: HYDFLD, ICFLO
C
      INCLUDE 'ELMSIZ.PRM'
C
      DIMENSION QH(MXELEM), Z(MXELEM), Z1(MXELEM), AWID(MXELEM),
     1         EL(MXELEM)
      DATA XK/0.4/
      DATA G/9.81/
C
      DO (I = 1,MXELEM)
      .  QH(I) = 0.0
      ...FIN
      UBAR=Q / VOL * ALEN
C     Z0=DEPTH/(10.**(UBAR*XK/(2.3*USTAR) + 1./2.3))
      ICOUNT=0
      Z0=0.001
      C1=UBAR*XK/USTAR+1.0
      CON=DEPTH*(C1-2.303*ALOG10(DEPTH))
      REPEAT UNTIL(ABS(EPS).LT.0.01.OR.ICOUNT.GT.10)
      .  ICOUNT=ICOUNT+1
      .  FZO=CON-Z0*C1+2.303*DEPTH*ALOG10(Z0)
      .  FPZO=DEPTH/Z0-C1
      .  ZP=Z0-FZO/FPZO
      .  EPS=(ZP-Z0)/ZP
      .  Z0=ZP
      .  IF(Z0.LT.0.0)
      .  .  Z0=DEPTH/(10.**(UBAR*XK/(2.303*USTAR)+1./2.303))
      .  .  ICOUNT=11
      .  ...FIN
      ...FIN
C
      WHEN (Z0 .GT. DELZ/4.0.OR.NELEM.EQ.1)
C     .  *** DISTRIBUTE VELOCITY UNIFORMLY ***
      .  WHEN(IFLAG.EQ.0)
      .  .  DO (I=1,NELEM)
```

```
       .  .  .  QH(I)=UBAR*DELZ*AWID(I)
       .  .  ...FIN
       .  ...FIN
       .  ELSE
       .  .  DO (I=1,NELEM-1)
       .  .  .  QH(I)=UBAR*(EL(I+1)-EL(I))*AWID(I)
       .  .  ...FIN
       .  .  QH(NELEM)=UBAR*DELTA*AWID(NELEM)
       .  ...FIN
       ...FIN
       ELSE
C      .  *** DISTRIBUTE VELOCITY INTO A LOGARITHMIC PROFILE ***
       .  NUMB=NELEM+1
       .  Z(1)=Z0
       .  Z(NUMB)=DEPTH
       .  Z1(NUMB)=0.
C      .
       .  JX = 1
       .  J=NUMB
       .  REPEAT UNTIL (JX .EQ. NELEM .OR. Z(J) .LE. Z0)
       .  .  JX = JX + 1
       .  .  J=NELEM - JX + 2
       .  .  WHEN (IFLAG.EQ.0) Z1(J)=Z1(J+1)+DELZ
       .  .  ELSE
       .  .  .  WHEN (J.EQ.NELEM) Z1(J)=Z1(J+1)+DELTA
       .  .  .  ELSE Z1(J)=Z1(J+1)+EL(J+1)-EL(J)
       .  .  ...FIN
       .  .  Z(J)=DEPTH - Z1(J)
       .  ...FIN
       .  WHEN (Z(J) .GT. Z0) J = 1
       .  ELSE
       .  .  J1 = J-1
       .  .  DO (I=1,J1)
       .  .  .  QH(I)=0.
       .  .  ...FIN
       .  ...FIN
C      .
C      .
       .  A=2.303 * USTAR / XK
       .  SUM=0.
C      .  XLOGD=ALOG10(DEPTH)
C      .  DO (I=J,NELEM)
C      .  IP1=I+1
C      .  DLZ = Z(IP1) - Z(I)
C      .  T1=A*DLZ * XLOGD
C      .  T2 =A*(Z(IP1) * ALOG10(Z(IP1)) - Z(I) * ALOG10(Z(I))-DLZ)
C      .  QH(I)=(UBAR*DLZ-T1+T2)*AWID(I)
C      .  SUM = SUM + QH(I)
C      .  FIN
       .  T1=A/(DEPTH-Z0)*(Z0*ALOG10(Z0)-DEPTH*ALOG10(DEPTH))+UBAR
       .  DO (I=J,NELEM)
       .  .  IP1=I+1
       .  .  T2=A*(Z(IP1)*ALOG10(Z(IP1))-Z(I)*ALOG10(Z(I)))
       .  .  QH(I)=AWID(I)*(T2+(Z(IP1)-Z(I))*T1)
       .  .  SUM=SUM+QH(I)
       .  ...FIN
```

```
             .   DO (I=1,NELEM)
             .  .      QH(I)=QH(I)/SUM * Q
             .  ...    FIN
             ...FIN
             RETURN
             END

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                SUBROUTINE PUTERR(ID, NUMERR, HLDERR)
          C
          C     WHEN AN ERROR IS DETECTED IN THE INPUT STREAM ,
          C     THIS SUBROUTINE IS CALLED TO PLACE THE ERROR IDENTIFICATION
          C     CODE (ID) INTO THE HOLDING ARRAY (HLDERR) AND INCREMENTS
          C     THE NUMBER OF ERRORS (NUMERR).
          C
          C       CALLED BY: DIMDAT, INIDAT, TRBDAT, UPSDAT
          C
                BYTE HLDERR(100)
          C
                NUMERR=NUMERR+1
                HLDERR(NUMERR)=ID
                RETURN
                END

          (FLECS VERSION 22.46)

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               SUBROUTINE RADIUS ( ALEN, AREA, CROSEC, DEPTH, EL, HRAD)
        C
        C      THIS ROUTINE CALCULATES THE HYDRAULIC RADIUS OF A CROSS-SECTION.
        C
        C      INPUT PARAMETERS:
        C           ALEN   - SEGMENT LENGTH
        C           AREA   - SURFACE AREA AT NODAL DEPTHS
        C           DEPTH  - DEPTH OF CROSS-SECTION
        C           EL     - ELEVATION OF NODAL AREAS
        C      OUTPUT PARAMETERS:
        C           CROSEC - TOTAL CROSS-SECTIONAL AREA
        C           HRAD   - HYDRAULIC RADIUS
        C
        C      CALLED BY: HYDDAT, ICFLO
        C
               INCLUDE 'ELMSIZ.PRM'
               DIMENSION AREA(MXELEM), EL(MXELEM)
        C
               CROSEC = 0.
               BLEN = 1./ALEN
               WETPER = AREA(1)*BLEN
               ELBTM = EL(1)
               WBTM = AREA(1)*BLEN
        C
               DO (I=2,MXELEM)
               .  ELTOP = EL(I)
               .  WTOP = AREA(I)*BLEN
               .  IF (ELTOP.GE.DEPTH) GO TO 10
               .  CROSEC = (ELTOP - ELBTM)*(WTOP + WBTM)/2. + CROSEC
               .  WETPER = SQRT((ELTOP - ELBTM)**2 + ((WTOP - WBTM)/2.)**2) * 2.0
              1.             + WETPER
               .  ELBTM = ELTOP
               .  WBTM = WTOP
               ...FIN
               WRITE (6,1) CROSEC, WETPER, I
         1     FORMAT ('1', '   ERROR IN SUBROUTINE RADIUS'/
              1              '0  CROSEC = ', E12.4,'M**3'/
              2              '0  WETTED PERIMETER = ', E12.4,'M**2'/
              3        '0  ELEMENT= ', I3)
               GO TO 20
         10    WTOP = WBTM + (WTOP - WBTM) * (DEPTH - ELBTM)/(ELTOP - ELBTM)
               ELTOP = DEPTH
               CROSEC = CROSEC + (ELTOP - ELBTM) * (WTOP + WBTM)/2.
               WETPER = SQRT ((ELTOP - ELBTM)**2 + ((WTOP -WBTM)/2.)**2) * 2.0
              1          + WETPER
         20    HRAD = CROSEC / WETPER
               RETURN
               END

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        SUBROUTINE RDSFLO(ALEN, AREA, AWID,C, DELZ, DFZ, NELEM, NELEMP,
       1 PDELZ, PWID, PXSAR, VSET, XSAREA)
C
C    THIS SUBROUTINE IS CALLED EACH TIME STEP (EXCEPT THE FIRST) WHEN THE
C    DEPTH WITHIN THE SEGMENT HAS CHANGED. ITS TASK IS TO REDISTRIBUTE
C    THE CONCENTRATIONS.
C
C    FORMAL PARAMETERS:
C      AWID   - WIDTH @ CURRENT TIME STEP
C      C      - THE NELMPT+1 NODAL CONCENTRATIONS THAT ARE TO BE
C               REDISTRIBUTED
C      DELZ   - THE STANDARD ELEMENT THICKNESS FOR THE CURRENT TIME STEP
C      DFZ    - DIFFUSION-DISPERSION COEFFICIENT
C      NELEM  - THE NUMBER OF ELEMENTS FOR THE CURRENT TIME STEP
C      NELEMP - THE NUMBER OF ELEMENTS DURING THE PREVIOUS TIME STEP
C      PDELZ  - THE STANDARD ELEMENT THICKNESS USED DURING THE PREVIOUS
C               TIME STEP
C      PXSAR  - PRESS SECTION @ PREVIOUS TIME STEP
C      PWID   - WIDTH @ PREVIOUS TIME STEP
C      XSAREA - CROSS SECTION @ CURRENT TIME STEP
C      VSET   - SETTLING VELOCITY OF SEDIMENT
C
C    CALLED BY: SERATRA
C
        INCLUDE 'ELMSIZ.PRM'
C
        DIMENSION AREA(MXELEM), AWID(MXELEM), C(MXELEM,MAXCON),
       1CP(MXELEM,MAXCON), DFZ(4), PWID(MXELEM), PXSAR(MXELEM),
       2VSET(3), XSAREA(MXELEM), IELP(MXELEM), HEQXS(MXELEM), TMASS(7)
C
        PXS = 0.
        XS  = 0.
C
        DO (I=1,NELEM) XS = XS + XSAREA(I)
        DO (I=1,NELEMP) PXS = PXS + PXSAR(I)
        DO (I=1,NELEMP+1)
        .  DO (J=1,MAXCON)
        .  .  CP(I,J) = C(I,J)
        .  ...FIN
        ...FIN
        RATIO = PXS/XS
        CALL EQUPXS(PXSAR, PWID, PDELZ, XSAREA, NELEM, NELEMP, RATIO,
       1IELP, HEQXS)
        DO (K=1,MAXCON)
        .  TMASS(K)=0.
        .  CT=CP(2,K)
        .  CB=CP(1,K)
        .  NELMHT=1
        .  CMASAB=(CT+CB)/2.*PXSAR(1)
        .  CMASBB=0.
        .  DO(I=1,NELEM)
        .  .  NELMTP=IELP(I)
        .  .  NB=NELMTP
```

```
          .   .   NT=NB+1
          .   .   ET=NB*PDELZ
          .   .   EB=ET-PDELZ
          .   .   CT=CP(NT,K)
          .   .   CB=CP(NB,K)
          .   .   HEL=HEQXS(I)
          .   .   FAC1=(HEL-EB)/PDELZ
          .   .   FAC2=(ET-HEL)/PDELZ
          .   .   CTOP=CT*FAC1+CB*FAC2
          .   .   CMASAT=(CT+CTOP)/2.*PWID(NB)*(ET-HEL)
          .   .   CMASBT=(CTOP+CB)/2.*PWID(NB)*(HEL-EB)
          .   .   INDIC=NELMTP-NELMBT
          .   .   CMASS=0.
          .   .   IF(INDIC.EQ.0) CMASS=CMASBT-CMASBB
          .   .   IF(INDIC.GT.0) CMASS=CMASBT+CMASAB
          .   .   IF(INDIC.GT.1)
          .   .   .  DO(J=NELMBT+1,NELMTP-1)
          .   .   .  .  CT=CP(J+1,K)
          .   .   .  .  CB=CP(J,K)
          .   .   .  .  CMASS=CMASS+PXSAR(J)*(CT+CB)/2.
          .   .   .  ...FIN
          .   .   ...FIN
          .   .   TMASS(K)=TMASS(K)+CMASS
C         .   .   NODAL VALUE IN BOTTOM ELEMENT
          .   .   WHEN(I.EQ.1)
          .   .   .  WHEN(K.NE.7)
C         .   .   .  .
C         .   .   .  .  SAND SILT CLAY
C         .   .   .  .
          .   .   .  .  WHEN(K.LT.4)
          .   .   .  .  .  COEF =0.
          .   .   .  .  .  WS=VSET(K)*AREA(1)/(AWID(1)*ALEN)
          .   .   .  .  .  EZ=DFZ(K)
          .   .   .  .  ...FIN
C         .   .   .  .
C         .   .   .  .  POLLUTANT ASSOCIATED WITH SAND SILT CLAY
C         .   .   .  .
          .   .   .  .  ELSE
          .   .   .  .  .  COEF =0.
          .   .   .  .  .  WS=VSET(K-3)*AREA(1)/(AWID(1)*ALEN)
          .   .   .  .  .  EZ=DFZ(K-3)
          .   .   .  .  ...FIN
C         .   .   .  .
C         .   .   .  .  NOTE: CMASS IS IN (KG/M)
C         .   .   .  .
          .   .   .  .  C(1,K)=(2.*CMASS/XSAREA(1)-COEF*DELZ/EZ)/(2.-WS*DELZ/EZ)
          .   .   .  .  C(2,K)=2.*CMASS/XSAREA(1)-C(1,K)
          .   .   .  ...FIN
C         .   .   .
C         .   .   .  DISSOLVED POLLUTANT
C         .   .   .
          .   .   .  ELSE
          .   .   .  .  C(1,K)=CMASS/XSAREA(I)
          .   .   .  .  C(2,K)=C(1,K)
          .   .   .  ...FIN
          .   .   ...FIN
```

```
C      .  .  NODAL VALUES ABOVE BOTTOM ELEMENT
       .  .  ELSE C(I+1,K) = 2.*CMASS/XSAREA(I)-C(I,K)
       .  .  CMASAB=CMASAT
       .  .  CMASBB=CMASBT
       .  .  NELMBT=NELMTP
       .  ...FIN
       ...FIN
       RETURN
       END

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              SUBROUTINE RPTERR(NUMERR, HLDERR, FERROR)
          C
          C   THIS ROUTINE IS RESPONSIBLE FOR REPORTING ANY INPUT ERRORS
          C   UNCOVERED BY THE INPUT ROUTINES AND DETERMINING THEIR SEVERITY.
          C
          C     CALLED BY: SERATRA, STRTUP
          C
              BYTE HLDERR(100),BUFF(80,2)
          C
              LOGICAL*1 FERROR
          C
          C     CALLED BY: SERATRA
          C
              OPEN(UNIT=10,NAME='SERATERR.MSG',TYPE='OLD',ACCESS='DIRECT',
             1 FORM='FORMATTED',MAXREC=200,RECORDSIZE=80,
             2 ASSOCIATEVARIABLE=III,READONLY)
          C
              NUMW=0
              NUMF=0
              WRITE(6,4)
              DO (I=1,NUMERR)
              .  IND=(HLDERR(I)-1)*2+1
              .  READ(10'IND,1)(BUFF(K,1),K=1,80)
              .  IND=IND+1
              .  READ(10'IND,1)(BUFF(K,2),K=1,80)
              .  IF(BUFF(1,1).EQ.'W')NUMW=NUMW+1
              .  IF(BUFF(1,1).EQ.'F')NUMF=NUMF+1
              .  WRITE(6,2)((BUFF(K,J),K=1,80),J=1,2)
              ...FIN
              WRITE(6,3)NUMW,NUMF
              CLOSE(UNIT=10)
              IF (NUMF .GT. 0) FERROR = .TRUE.
              RETURN
          C
            1 FORMAT(80A1)
            2 FORMAT(1H0,A1,2X,3A1,3X,76A1/10X,80A1)
            3 FORMAT(//,10X,I5,' WARNING DIAGNOSTICS'/11X,I5,' FATAL ERROR(S)')
            4 FORMAT('/***** DIAGNOSTIC SUMMARY *****')
          C
              END

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            SUBROUTINE SAND(ABAR, ALEN, AREA, B, BDIV,  CCIN, DELTD, DELZ,
           1                 DENS, D50, HRAD, NBED, NELEM, POR, QHIN,
           2                 QHOUT, SCSHR, SLOPE, SMETH, STRESS, TEMPR,
           3                 VSET, VOL, XYSD, DEPO, ILAYR, SD, SR,
           4                 XNT, COLD, C, CROSEC, BWID, ECHO?, SCOUR)
      C
      C     THIS SUBROUTINE COMPUTES THE SOURCE/SINK TERMS REQUIRED FOR
      C     SCOUR/DEPOSITION OF SAND.  TRANSPORT CAPACITY IS CALCULATED
      C     ONCE PER SEGMENT.
      C
      C     INPUT PARAMETERS:
      C          ABAR   - AVERAGE VERTICAL PROJECTION AREA
      C          ALEN   - SEGMENT LENGTH
      C          AREA   - ELEMENT (REAL) VERTICAL PROJECTION AREA @ DATA NODES
      C          B      - BED CONDITIONS
      C          BDIV   - STANDARD BED LAYER THICKNESS
      C          BWID   - REAL WIDTH AT CROSS-SECTION BREAK POINTS
      C          C      - WATER CONDITIONS
      C          CCIN   - CONCENTRATION OF INFLOW
      C          CROSEC - TOTAL CROSS-SECTIONAL AREA, M**2
      C          DELTD  - TIME STEP (DAYS)
      C          DELZ   - STANDARD ELEMENT THICKNESS
      C          DELZT  - THICKNESS OF THE TOP ELEMENT
      C          DENS   - DENSITY
      C          D50    - MEDIAN BED SEDIMENT DIAMETER (METER)
      C          HRAD   - HYDRAULIC RADIUS
      C          NBED   - NUMBER OF BED LAYERS
      C          NELEM  - NUMBER OF ELEMENTS
      C          POR    - POROSITY
      C          QHIN   - INFLOW DISCHARGE
      C          QHOUT  - OUTFLOW DISCHARGE
      C          SCSHR  - CRITICAL SHEAR STRESS FOR SCOUR
      C          SLOPE  - ENERGY OR RIVER BED SLOPE
      C          SMETH  - METHOD TO BE USED WHEN COMPUTING SAND CAPACITY (BYTE
      C                   =T; TOFFALETTI'S METHOD
      C                   =C; COLBY'S METHOD
      C          STRESS - BED SHEAR STRESS
      C          TEMPR  - WATER TEMPERATURE
      C          VSET   - PARTICLE SETTLING VELOCITY
      C          VOL    - VOLUME
      C          XYSD   - THICKNESS OF TOP BED LAYER
      C       OUTPUT PARAMETERS:
      C          ILAYR  - NO. OF BED LAYERS AFFECTED BY SED. DEPOSITION AND ER
      C          SD     - DEPOSITION RATE, (KG(PC)/M**3/DAY)
      C          SR     - EROSION RATE, (KG(PC)/M**3/DAY)
      C          XNT    - WEIGHT OF TOP BED SEDIMENT LAYER, (KG/M**2)
      C       DEPO   - BED DEPOSITION RATE (KG(PC)/M2/DAY)
      C       SCOUR  - BED SCOUR RATE (KG(PC)/M2/DAY)
      C
      C       CALLED BY: TRANSP.
      C       CALLS: TOFFAL, COLBY
      C
            INCLUDE 'ELMSIZ.PRM'
```

```
C
          BYTE SMETH
C
          LOGICAL*1 FERROR, ECHO7
          REAL INFRAC
C
C
          DIMENSION ABAR(MXELEM), AREA(MXELEM), B(MAXLEV,MAXCON-1),
         1          COLD(MXELEM,MAXCON),CCIN(MXELEM,MAXCON), DENS(3),
         2          QHIN(MXELEM), QHOUT(MXELEM), SCSHR(3),
         3          SD(MXELEM,6), SR(6), VSET(3), XNT(3), EE(MXELEM),
         4          ILAYR(3), C(MXELEM,MAXCON), BWID(MXELEM),
         5          DEPO(6), SCOUR(6)
C
C
C         INITIALIZE SCALAR AND ARRAY VARIABLES
          ILAYR(1) = 0
          RS=0.0
          CS=0.0
          DEPO(1) =0.0
          DEPO(4) =0.0
          SRC = 0.0
          GSI = 0.0
          WTOT = 0.0
          SR(1)=0.0
          SR(4)=0.0
          SCOUR(1)= 0.0
          SCOUR(4)= 0.0
          RATE = 0.0
          VPCROS = ALEN * BWID(1)
          VOLUME = CROSEC * ALEN
          DO (K=1,NELEM)
          .  SD(K,1)=0.0
          .  SD(K,4)=0.0
          ...FIN
          XNT(1) = 0.
          IF(NBED.NE.0)
          .  XNT(1)=(1.0-POR)/(B(NBED,1)/DENS(1)+B(NBED,2)/DENS(2)+
         1.          B(NBED,3)/DENS(3))*XYSO*B(NBED,1)
          ...FIN
          IF (ECHO7)
C         .
C         .  CALCULATE ACTUAL SAND TRANSPORT WITHIN THE RIVER REACH, SRC(KG/DAY)
C         .
C         .      NOTE: CCIN IS A TIME AVERAGED QUANTITY, COLD IS NOT.   AN
C         .             ITERATIVE LOOP IS CALLED FOR WHERE SRC IS UPDATED UNTIL
C         .             RESULTS ARE UNCHANGED.
C         .
          .  DO (IX=1,NELEM)
          .  .  INFRAC=0.5*QHIN(IX)*DELTD/ABAR(IX)/DELZ
          .  .  EXFRAC=1.0-INFRAC
          .  .  SRC=SRC+INFRAC*QHIN(IX)*(CCIN(IX,1)+CCIN(IX+1,1))/2.
         1.  .        +EXFRAC*QHOUT(IX)*COLD(IX,1)
          .  .  QTOT=QTOT+INFRAC*QHIN(IX)+EXFRAC*QHOUT(IX)
          .  ...FIN
C         .
```

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C      .  IT IS IMPLICITLY ASSUMED THAT A DOWNSTREAM COURANT NUMBER
C      .  AT OR NEAR UNITY IS EMPLOYED IN THIS ANALYSIS
C      .
C      .
C      .  CALCULATIONS OF STREAM CAPACITY FOR SAND
       .  SELECT (SMETH)
       .  .  ('T')
C      .  .  .
C      .  .  .  THE TUFFALETI TECHNIQUE MAY NOT BE WELL SUITED FOR CHANNEL
C      .  .  .  CROSS-SECTIONS WHICH DIFFER MARKEDLY FROM RECTANGULAR,
C      .  .  .
       .  .  .  CALL TOFFAL(ALEN, D50, GSI, HRAD, QTOT, SLOPE, TEMPR, VOL, VSET,
      1.  .  .                GSU, GSM, GSL, GSB, YU, YM, YL)
       .  .  ...FIN
       .  .  ('C')
       .  .  .  CALL COLBY(ALEN, C, DELZ, D50, HRAD, NELEM, QTOT, TEMPR,
      1.  .  .                VOL, GSI, FERROR)
       .  .  .  IF(FERROR)
       .  .  .  .  CALL TUFFAL(ALEN, D50, GSI, HRAD, QTOT, SLOPE, TEMPR, VOL, VSET,
      1.  .  .  .                GSU, GSM, GSL, GSB, YU, YM, YL)
       .  .  .  .  FERROR = .FALSE.
       .  .  .  ...FIN
       .  .  ...FIN
       .  ...FIN
       .  GSI = GSI * BRID(NELEM + 1)
C      .
C      .  DETERMINE IF DEPOSITION, SCOUR, OR NEITHER OCCURS,
C      .
       .  DIF = GSI - SRC
       .  IF (DIF) 50, 100, 150
C      .
C      .  SAND WITHIN THE WATER COLUMN EXCEEDS CAPACITY - DEPOSITION OCCURS
C      .
50     .  DEPO(1) = -DIF/ AREA(1)
       .  RATE = -DIF/VOLUME
       .  ILAYR(1) = -1
       .  DO (K=1,NELEM)
       .  .  SD(K,1) = RATE
       .  .  VOLK = ABAR(K)*DELZ
       .  .  INFRAC=0.5*QHIN(K)*DELTD/VOLK
       .  .  EXFRAC=1.0-INFRAC
       .  .  SED=INFRAC*QHIN(K)*(CCIN(K,1)+CCIN(K+1,1))/2.
      1.  .   + EXFRAC*QHOUT(K)*COLD(K,1)
       .  .  CONT=INFRAC*QHIN(K)*(CCIN(K,4)+CCIN(K+1,4))/2.
      1.  .   + EXFRAC*QHOUT(K)*COLD(K,4)
       .  .  RATEK = RATE * VOLK
       .  .  SD(K,4) = RATEK/SED/VOLK*CONT
       .  .  DEPO(4) = DEPO(4)+SD(K,4)/AREA(1)*VOLK
       .  ...FIN
       .  RETURN
C      .
C      .  CAPACITY EQUALS LOAD - NOTHING EXCHANGES
C      .
100    .  RETURN
C      .
C      .  CAPACITY IS GREATER THAN LOAD - SCOUR OCCURS
```

```
C     .
C     .
C     .  DETERMINE WHICH (IF ANY)  BED LAYERS ARE SCOURED
C     .
150   .  TRSUSP = DIF * DELTD
      .  ILAYR(1) = 0
      .  IF (NBED.EQ.0) GO TO 200
      .  DO (K=1,NBED)
      .  .  NB = NBED - K + 1
      .  .  TDENS = (1.0 - POR) / (B(NB,1)/DENS(1) + B(NB,2)/DENS(2)
     1.  .                        + B(NB,3)/DENS(3))
      .  .  DEL = BDIV
      .  .  IF (NB.EQ.NBED) DEL = XYSO
      .  .  TINBED = TDENS * DEL * B(NB,1) * VPCROS
      .  .  WHEN (TRSUSP.GE.TINBED)
      .  .  .  RS = RS + TINBED
      .  .  .  CS = CS + TINBED * B(NB,4)
      .  .  .  TRSUSP = TRSUSP - TINBED
      .  .  .  TINBED = 0.0
      .  .  .  ILAYR(1) = ILAYR(1) + 1
      .  .  .  IF(ILAYR(1).EQ.NBED) GO TO 175
      .  .  ...FIN
      .  .  ELSE
      .  .  .  RS = RS + TRSUSP
      .  .  .  CS = CS + TRSUSP * B(NB,4)
      .  .  .  TINBED = TINBED - TRSUSP
      .  .  .  GO TO 175
      .  .  ...FIN
      .  ...FIN
175   .  SCOUR(1) = RS / DELTD/ AREA(1)
      .  SCOUR(4) = CS / DELTD/ AREA(1)
      .  XNT(1) = TINBED / VPCROS
      .  SR(1) = RS  /DELTD / VOLUME
      .  SR(4) = CS / DELTD / VOLUME
      ...FIN
200   RETURN
      END

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        SUBROUTINE SAVEIT(B, BDIV, BED, ELEV, C, DELZ,  NBED,
       1                  NELEM, NXEQ, RESELN, STRESS, XYSD,OLDC,
       2 ALEN,QHIN,QHOUT,CCIN,QV,AWID,BWID,VSET,DENS,DELTD,DFZ,
       3        POR, TBED)
  C
  C    THIS ROUTINE WRITES THE SIMULATION RESULTS TO THE RESULT FILE
  C    (LUN 5) THAT HAS BEEN OPENED BY SERATRA
  C
  C     FORMAL PARAMETERS:
  C        B       - BED CONCENTRATIONS
  C        BDIV    - STANDARD BED LAYER THICKNESS
  C        BED     - BED THICKNESS
  C        C       = WATER CONCENTRATIONS
  C        DELZ    - STANDARD ELEMENT THICKNESS
  C        ELEV    = SEGMENT ELEVATION (DATUM ELEVATION)
  C        NBED    - NUMBER OF BED LAYERS
  C        NELEM   - NUMBER OF ELEMENTS
  C        NXEQ    = CURRENT TIME STEP (I*4)
  C        RESELN - WATER SURFACE ELEVATION
  C        STRESS - SHEAR STRESS
  C        XYSD    - THICKNESS OF THE TOP BED LAYER
  C
  C        CALLED BY: SERATRA.
  C
        INCLUDE 'ELMSIZ.PRM'
  C
        INTEGER*4 NXEQ
  C
        DIMENSION B(MAXLEV,MAXCON-1),BAVG(MAXLEV), BEL(MAXLEV),
       1          C(MXELEM,MAXCON), CMASS(MXELEM), CVOLM(MXELEM),
       2          CTOTL(MXELEM), WELEV(MXELEM), D(MXELEM,MAXCON)
       3 ,QHIN(MXELEM),QHOUT(MXELEM),CCIN(MXELEM,MAXCON),
       4 QV(MXELEM),AWID(MXELEM),BWID(MXELEM),VSET(3),
       5 DENS(3),QCIN(MXELEM,MAXCON),QCOUT(MXELEM,MAXCON),
       6 CELAV(MXELEM,MAXCON),QVCEL(MXELEM,MAXCON),
       7 OLDC(MXELEM,MAXCON), DFZ(4), QVDIF(MXELEM,MAXCON),
       8       DTBED(MAXCON),TBED(MAXCON),BAL(MAXCON),DIF(MAXCON),
       9       DCELAV(MAXCON), TOTDIF(MAXCON)
        DATA EPSI/1.0E-30/
        NELMP1=NELEM+1
        NBEDP1 = NBED + 1
  C
  C     *** WATER CONCENTRATIONS ***
  C
        J = NELEM + 1
        WRITE(5) NXEQ,J,NBED,ELEV,DELZ,BDIV,XYSD,STRESS
        REPEAT UNTIL (J .EQ. 0)
        .  CMASS(J) = C(J,4) + C(J,5) + C(J,6)
        .  SUM = C(J,1) + C(J,2) + C(J,3)
        .  WHEN (SUM .GT. 0.0) CVOLM(J) = CMASS(J) / SUM
        .  ELSE CVOLM(J) = 0.0
        .  CTOTL(J) = CMASS(J) + C(J,7)
        .  SELECT (J)
```

```
      .  .  (NELEM+1) WELEV(NELEM+1) = RESELN
      .  .  (OTHERWISE) WELEV(J) = WELEV(J+1) - DELZ
      .  ...FIN
      .  J = J - 1
      ...FIN
      DO(K=1,MAXCON)
      .  DO(I=1,NELEM+1)
      .  .  WHEN (K .LE. 3 .OR. K .EQ. 7) D(I,K)=C(I,K)
      .  .  ELSE
      .  .  .  D(I,K)=0.
      .  .  .  IF (C(I,K-3) .GT. 1.0E-10) D(I,K)=C(I,K)/C(I,K-3)
      .  .  ...FIN
      .  ...FIN
      ...FIN
      WRITE(5) (WELEV(J),(C(J,K),K=1,MAXCON),CMASS(J),CVOLM(J),
     1          CTOTL(J),J=NELEM+1,1,-1)
      WRITE(5) ((D(J,K),K=4,6),J=NELEM+1,1,-1)
C
C     *** BED CONCENTRATIONS ***
C
      BELEV = (NBED-1) * BDIV + XYSO + ELEV
      J = NBED
      REPEAT UNTIL (J .EQ. 0)
      .  BAVG(J) = B(J,1)*B(J,4) + B(J,2)*B(J,5) + B(J,3)*B(J,6)
      .  SELECT (J)
      .  .  (NBED) BEL(NBED) = BELEV
      .  .  (NBED-1) BEL(NBED-1) = BELEV - XYSO
      .  .  (OTHERWISE) BEL(J) = BEL(J+1) - BDIV
      .  ...FIN
      .  J = J-1
      ...FIN
      WRITE(5) (BEL(J),(B(J,K),K=1,MAXCON-1),BAVG(J),J=NBED,1,-1)
C    *** ELEMENT MASS AND CONVECTED MASS ***
      DO (J=1,MAXCON)
      .  QCELAV(J) = 0.
      .  CELAV(NELMP1,J)=0
      .  QCIN(NELMP1,J)=0
      .  QCOUT(NELMP1,J)=0
      .  DO(I =1,NELEM)
      .  .  VOL=AWID(I)*DELZ*ALEN
      .  .  XS=AWID(I)*DELZ
      .  .  VPXS=AWID(I)*ALEN
      .  .  QCMEAN = (OLDC(I,J) + OLDC(I+1,J))/2.
      .  .  CMEAN=(C(I,J)+C(I+1,J))/2.
      .  .  CELAV(I,J)=VOL*CMEAN
      .  .  QCIN(I,J)=QHIN(I)*(CCIN(I,J)+CCIN(I+1,J))/2.*DELTD
      .  .  QCOUT(I,J)=QHOUT(I)*DELTD*(CMEAN+(OLDC(I,J)+OLDC(I+1,J))/2.)/2.
      .  .  CELAV(NELMP1,J)=CELAV(NELMP1,J)+CELAV(I,J)
      .  .  QCIN(NELMP1,J)=QCIN(NELMP1,J)+QCIN(I,J)
      .  .  QCOUT(NELMP1,J)=QCOUT(NELMP1,J)+QCOUT(I,J)
      .  .  QCELAV(J) = QCELAV(J) + QCMEAN*VOL
      .  .  K=J
      .  .  IF(J .GT. 3) K=J-3
      .  .  WHEN (K .EQ. 4) WS=0.
      .  .  ELSE WS=VSET(K)
      .  .  WHEN(I .EQ. 1) QVCBTM=QV(1)*(C(1,J)+OLDC(1,J))/2.
```

```
      .  .  ELSE QVCBTM=(QV(I)-WS*BWID(I)*ALEN)*(C(I,J)+OLDC(I,J))/2.
      .  .  WHEN (I .EQ. NELEM)
      .  .  .  QVCTOP=QV(NELEM+1)*(C(NELEM+1,J)+OLDC(NELEM+1,J))/2.
      .  .  ...FIN
      .  .  ELSE
      .  .  .  QVCTOP=(QV(I+1)-WS*BWID(I+1)*ALEN)*(C(I+1,J)+OLDC(I+1,J))/2.
      .  .  ...FIN
      .  .  QVCEL(I,J)=(QVCBTM-QVCTOP)*DELTD
      .  .  QVDIF(I,J)= DFZ(K)*DELTD*AWID(I)*ALEN*
     1.  .  (C(I+1,J)-C(I,J)+OLDC(I+1,J)-OLDC(I,J))/(2.*DELZ)
      .  ...FIN
      ...FIN
      VOLUME=0.0
      DO (J=1,NELEM) VOLUME=VOLUME+AWID(J)*DELZ*ALEN
      WRITE(5)VOLUME
      WRITE(5)((CELAV(J,K),K=1,MAXCON),J=NELMP1,1,-1)
      WRITE(5)((QCIN(J,K),K=1,MAXCON),J=NELMP1,1,-1)
      WRITE(5)((QCOUT(J,K),K=1,MAXCON),J=NELMP1,1,-1)
      WRITE(5)((QVCEL(J,K),K=1,MAXCON),J=NELEM,1,-1)
      WRITE(5)((QVDIF(J,K),K=1,MAXCON),J=NELEM,1,-1)
C
      DO (J=1,MAXCON)
      .  BAL(J) = QCIN(NELMP1,J)-QCOUT(NELMP1,J)+OCELAV(J)
      .  DIF(J) = CELAV(NELMP1,J)-BAL(J)
      ...FIN
      TBAL=0.
      TDIF=0.
      DO (J=4,MAXCON)
      .  TBAL = TBAL + BAL(J)
      .  TDIF = TDIF + DIF(J)
      ...FIN
      WRITE(5) (BAL(J),J=1,MAXCON),TBAL
      WRITE(5) (DIF(J),J=1,MAXCON),TDIF
C
C     *** BED SEDIMENT AND CONTAMINANT (KG, PC)/ELEMENT ***
C
      DO (J=1,MAXCON)
      .  OTBED(J) = TBED(J)
      .  TBED(J) = 0.
      ...FIN
      VPXS=BWID(1)*ALEN
      DO (J=1,MAXCON-1)
      .  DO (I=1,NBED)
      .  .  WHEN (J .LT. 4)
      .  .  .  DNSITY=(1.0-POR)/(B(I,1)/DENS(1)+B(I,2)/DENS(2)+B(I,3)/DENS(3))
      .  .  .  DEL=BDIV
      .  .  .  IF(I.EQ. NBED) DEL=XYSD
      .  .  .  VOL=DEL*VPXS
      .  .  .  CELAV(I,J)=B(I,J)*VOL*DNSITY
      .  .  ...FIN
      .  .  ELSE CELAV(I,J)=CELAV(I,J-3)*B(I,J)
      .  .  TBED(J) = TBED(J) + CELAV(I,J)
      .  ...FIN
      ...FIN
      WRITE(5) ((CELAV(J,K),K=1,MAXCON-1),J=NBED,1,-1)
      DO (J=4,MAXCON-1)
```

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          .  TBED(MAXCON) = TBED(MAXCON) + TBED(J)
          ...FIN
          WRITE(5) (TBED(J),J=1,MAXCON)
          DO (J=1,MAXCON-1)
          .  TOTDIF(J) =  TBED(J) - OTBED(J) + DIF(J)
          ...FIN
          TOTDIF(MAXCON) = TBED(MAXCON) - OTBED(MAXCON) + TDIF
          WRITE(5) (TOTDIF(J),J=1,MAXCON)
          RETURN
          END

      (FLECS VERSION 22,46)

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      ------------------------------------
       SUBROUTINE SEDDAT(DECAY, DENS, DFZ, DIAM, DSHR, D50, ECHO,
      1                  ERODE, HLDERR, NUMERR, SCSHR, SORBK, VSET,
      2     DSORB)
C
C   THIS SUBROUTINE IS RESPONSIBLE FOR READING AND PROCESSING THE
C   SEDIMENT CHARACTERISTICS.
C
C     FORMAL PARAMETERS:
C       DECAY  - DECAY PARAMETERS
C       DENS   - SPECIFIC WEIGHT
C       DFZ    - VERTICAL DIFFUSION COEFFICIENTS
C       DIAM   - PARTICLE DIAMETERS
C       DSHR   - CRITICAL SHEAR STRESS VALUE FOR DEPOSITION
C       D50    - MEDIAN BED SEDIMENT DIAMETER
C       ECHO   - LINE PRINTER ECHO CONTROL VARIABLE (L*1)
C       ERODE  - ERODABILITY
C       HLDERR - HOLDING ARRAY FOR ERROR NUMBERS (BYTE)
C       NUMERR - NUMBER OF INPUT ERRORS
C       SCSHR  - CRITICAL SHEAR STRESS VALUE FOR SCOUR
C       SORBK  - ADSORBTION VALUES
C     DSORB  - DESORPTION VALUES
C       VSET   - VERTICAL SETTLING VELOCITIES
C
C   CALLED BY:SERATRA
C   CALLES: PUTERR
C
       BYTE HLDERR(100)
C
       LOGICAL*1 ECHO
C
       DIMENSION DECAY(6),DENS(3),DFZ(4),DIAM(3),DSHR(3),ERODE(3),
      1          SCSHR(3),SORBK(9),DSORB(9),VSET(3)
C
C   ....PARTICLE SETTLINE VELOCITY (M/SEC)
C
C     COL.  1-10....VSET(1)....SAND SETTLING VELOCITY
C          11-20....VSET(2)....SILT SETTLING VELOCITY
C          21-30....VSET(3)....CLAY SETTLING VELOCITY
C
       READ(1,1) (VSET(I),I=1,3)
       IF(ECHO)
       .  WRITE(6,2)
       .  WRITE(6,12) (VSET(I),I=1,3)
       ...FIN
C
C   ....DENSITY (KG/M**3)
C
C     COL.  1-10....DENS(1)....DENSITY OF SAND
C          11-20....DENS(2)....DENSITY OF SILT
C          21-30....DENS(3)....DENSITY OF CLAY
C
       READ(1,1) (DENS(I),I=1,3)
       IF(ECHO)
```

```
      .  WRITE(6,3)
      .  WRITE(6,12) (DENS(I),I=1,3)
      ...FIN
      IF(DENS(1) .LE. 0.0) CALL PUTERR(17,NUMERR,HLDERR)
      IF(DENS(2) .LE. 0.0) CALL PUTERR(18,NUMERR,HLDERR)
      IF(DENS(3) .LE. 0.0) CALL PUTERR(19,NUMERR,HLDERR)
C
C   ....DIAMETER (METERS)
C
C     COL.  1-10....DIAM(1)....DIAMETER OF SAND
C          11-20....DIAM(2)....DIAMETER OF SILT
C          21-30....DIAM(3)....DIAMETER OF CLAY
C          31-40....D50........MEDIAN BED SEDIMENT DIAMETER
C
      READ(1,1) (DIAM(I),I=1,3),D50
      IF(ECHO)
      .  WRITE(6,4)
      .  WRITE(6,12) (DIAM(I),I=1,3)
      .  WRITE(6,13) D50
      ...FIN
      IF(DIAM(1) .LE. 0.0) CALL PUTERR(20,NUMERR,HLDERR)
      IF(DIAM(2) .LE. 0.0) CALL PUTERR(21,NUMERR,HLDERR)
      IF(DIAM(3) .LE. 0.0) CALL PUTERR(22,NUMERR,HLDERR)
C
C   ....CRITICAL SHEAR STRESS FOR SCOUR (KG/M**2)
C
C     COL.  1-10....SCSHR(1)....CRITICAL SHEAR STRESS FOR SAND
C          11-20....SCSHR(2)....CRITICAL SHEAR STRESS FOR SILT
C          21-30....SCSHR(3)....CRITICAL SHEAR STRESS FOR CLAY
C
      READ(1,1) (SCSHR(I),I=1,3)
      IF(ECHO)
      .  WRITE(6,5)
      .  WRITE(6,12) (SCSHR(I),I=1,3)
      ...FIN
      IF(SCSHR(1) .LE. 0.0) CALL PUTERR(26,NUMERR,HLDERR)
      IF(SCSHR(2) .LE. 0.0) CALL PUTERR(27,NUMERR,HLDERR)
      IF(SCSHR(3) .LE. 0.0) CALL PUTERR(28,NUMERR,HLDERR)
C
C   ....CRITICAL SHEAR STRESS FOR DEPOSITION (KG/M**2)
C
C     COL.  1-10....DSHR(1)....CRITICAL SHEAR STRESS FOR SAND
C          11-20....DSHR(2)....CRITICAL SHEAR STRESS FOR SILT
C          21-30....DSHR(3)....CRITICAL SHEAR STRESS FOR CLAY
C
      READ(1,1) (DSHR(I),I=1,3)
      IF(ECHO)
      .  WRITE(6,6)
      .  WRITE(6,12) (DSHR(I),I=1,3)
      ...FIN
      IF(DSHR(1) .LE. 0.0) CALL PUTERR(29,NUMERR,HLDERR)
      IF(DSHR(2) .LE. 0.0) CALL PUTERR(30,NUMERR,HLDERR)
      IF(DSHR(3) .LE. 0.0) CALL PUTERR(31,NUMERR,HLDERR)
C
C   ....ERODABILITY (KG/M**2/SEC)
C
```

```
C      COL.  1-10....ERODE(1)....ERODABILITY OF SAND
C           11-20....ERODE(2)....ERODABILITY OF SILT
C           21-30....ERODE(3)....ERODABILITY OF CLAY
C
       READ(1,1) (ERODE(I),I=1,3)
       IF(ECHO)
       .  WRITE(6,7)
       .  WRITE(6,12) (ERODE(I),I=1,3)
       ...FIN
       IF(ERODE(1) .LE. 0.0) CALL PUTERR(32,NUMERR,HLDERR)
       IF(ERODE(2) .LE. 0.0) CALL PUTERR(33,NUMERR,HLDERR)
       IF(ERODE(3) .LE. 0.0) CALL PUTERR(34,NUMERR,HLDERR)
C
C    ....VERTICAL DIFFUSION COEFFICIENTS (M**2/SEC)
C
C      COL.  1-10....DFZ(1)....COEFFICIENT FOR SAND
C           11-20....DFZ(2)....COEFFICIENT FOR SILT
C           21-30....DFZ(3)....COEFFICIENT FOR CLAY
C           31-40....DFZ(4)....COEFFICIENT FOR DISSOLVED CONTAMINANT
C
       READ(1,1) (DFZ(I),I=1,4)
       IF(ECHO)
       .  WRITE(6,8)
       .  WRITE(6,12) (DFZ(I),I=1,3)
       .  WRITE(6,14) DFZ(4)
       ...FIN
C
C    ....ADSORBTION VALUES (2 CARDS)
C
C      CARD #1
C        COL.  1-10....SORBK(1)....KD VALUE WITH SAND (M**3/KG)
C             11-20....SORBK(2)....KD VALUE WITH SILT (M**3/KG)
C             21-30....SORBK(3)....KD VALUE WITH CLAY (M**3/KG)
C             31-40....SORBK(4)....SUSPENDED SAND MASS TRANSFER RATE (1/S
C             41-50....SORBK(5)....SUSPENDED SILT MASS TRANSFER RATE (1/S
C             51-60....SORBK(6)....SUSPENDED CLAY MASS TRANSFER RATE (1/S
C             61-70....SORBK(7)....BED SAND MASS TRANSFER RATE (1/SEC)
C             71-80....SORBK(8)....BED SILT MASS TRANSFER RATE (1/SEC)
C      CARD #2
C        COL.  1-10....SORBK(9)....BED CLAY MASS TRANSFER RATE (1/SEC)
C
       READ(1,1) (SORBK(I),I=1,9)
C
C    ....DESORPTION VALUES (2 CARDS)
C
C      CARD #1
C        COL.  1-10....DSORB(1)....KD VALUE WITH SAND (M**3/KG)
C             11-20....DSORB(2)....KD VALUE WITH SILT (M**3/KG)
C             21-30....DSORB(3)....KD VALUE WITH CLAY (M**3/KG)
C             31-40....DSORB(4)....SUSPENDED SAND MASS TRANSFER RATE (1/S
C             41-50....DSORB(5)....SUSPENDED SILT MASS TRANSFER RATE (1/S
C             51-60....DSORB(6)....SUSPENDED CLAY MASS TRANSFER RATE (1/S
C             61-70....DSORB(7)....BED SAND MASS TRANSFER RATE (1/SEC)
C             71-80....DSORB(8)....BED SILT MASS TRANSFER RATE (1/SEC)
C      CARD #2
C        COL.  1-10....DSORB(9)....BED CLAY MASS TRANSFER RATE (1/SEC)
```

```
C
      READ(1,1) (DSORB(I),I=1,9)
      IF(ECHO)
      .  WRITE(6,9)
      .  WRITE(6,12) (SORBK(I),I=1,3)
      .  WRITE(6,15) (SORBK(I),I=4,9)
      .  WRITE(6,16)
      .  WRITE(6,12) (DSORB(I),I=1,3)
      .  WRITE(6,15) (DSORB(I),I=4,9)
      ...FIN
C
C    ....DECAY PARAMETERS (2 CARDS)
C
C     CARD #1
C       COL.  1-10....DECAY(1)....RADIONUCLIDE DECAY (1/SEC)
C            11-20....DECAY(2)....TOTAL DECAY, SUM OF ALL DECAY EXCEPT
C                                 FOR RADIONUCLIDE DECAY, IF GIVEN, THE
C                                 REMAINING PARAMETERS ARE NOT TO BE
C                                 SUPPLIED, PESTICIDE ONLY (1/SEC)
C            21-30....DECAY(6)....VOLATIZATION DEGRADATION RATE,
C                                 PESTICIDE ONLY (1/SEC)
C            31-40....PH..........DEGREE OF ACIDITY OF ALKALINITY
C            41-50....AKA.........SECOND ORDER ACID RATE CONSTANT
C                                 FOR HYDROLYSIS
C            51-60....AKB.........SECOND ORDER BASE RATE CONSTANT
C                                 FOR HYDROLYSIS
C            61-70....AKN.........SECOND ORDER RATE CONSTANT OF NEUTROL
C                                 REACTION WITH WATER
C            71-80....AKOX........SECOND ORDER RATE CONSTANT OF FREE
C                                 RADICAL OXYGEN FOR OXIDATION
C     CARD #2
C       COL   1-10....RO2.........CONCENTRATION OF FREE RADICAL OXYGEN
C            11-20....AKBIO.......SECOND ORDER RATE CONSTANT
C                                 BIODEGRADATION
C            21-30....BIOMAS......BIOMASS PER UNIT VOLUME
C
      READ(1,1) DECAY(1),DECAY(2),DECAY(6),PH,AKA,AKB,AKN,AKOX,RO2,
     1          AKBIO,BIOMAS
      DO (I=3,5) DECAY(I) = 0.0
      WHEN (DECAY(2) .NE. 0.0)
      .  IF(ECHO) WRITE(6,10) DECAY(1),DECAY(2)
      ...FIN
      ELSE
C     .  *** COMPUTE: DECAY(3) - CHEMICAL DEGRADATION DUE TO HYDROLYSIS
C     .               DECAY(4) - CHEMICAL DEGRADATION DUE TO OXIDATION
C     .               DECAY(5) - BIODEGRADATION  ***
      .  DECAY(3) = 10.0**(PH-14.0)*AKB + 10.0**(-PH)*AKA + AKN
      .  DECAY(4) = AKOX * RO2
      .  DECAY(5) = AKBIO * BIOMAS
      .  IF(ECHO)
      .  .  WRITE(6,11) DECAY(1),PH,AKA,AKB,AKN,DECAY(3),AKOX,RO2,DECAY(4),
     1.  .              AKBIO,BIOMAS,DECAY(5),DECAY(6)
      .  ...FIN
      ...FIN
C
      RETURN
```

```
C
1     FORMAT(8F10.0)
2     FORMAT(1H0,13X,'PARTICLE SETTLING VELOCITY (M/SEC)')
3     FORMAT(1H0,13X,'DENSITY (KG/M**3)')
4     FORMAT(1H0,13X,'DIAMETER (METERS)')
5     FORMAT(1H0,13X,'CRITICAL SHEAR STRESS FOR SCOUR (KG/M**2)')
6     FORMAT(1H0,13X,'CRITICAL SHEAR STRESS FOR DEPOSITION (KG/M**2)')
7     FORMAT(1H0,13X,'ERODABILITY (KG/M**2/SEC)')
8     FORMAT(1H0,13X,'VERTICAL DIFFUSION COEFFICIENTS (M**2/SEC)')
9     FORMAT(1H0,13X,'ADSORPTION KD VALUES')
10    FORMAT(1H0,13X,'DECAY PARAMETERS'/
     1  14X,1PE12.5,'...RADIONUCLIDE DECAY (1/SEC)'/
     2  14X,1PE12.5,'...TOTAL DECAY (EXCEPT RADIONUCLDE) = (1/SEC)')
11    FORMAT(1H0,13X,'DECAY PARAMETERS'/
     1  14X,1PE12.5,'...RADIONUCLIDE DECAY (1/SEC)'/
     2  14X,1PE12.5,'...PH = DEGREE OF ACIDITY OR ALKALINITY (PH)'/
     3  14X,1PE12.5,'...SECOND ORDER ACID RATE CONSTANT FOR HYDROLYSIS'
     4                            ' (AKA)'/
     5  14X,1PE12.5,'...SECOND ORDER BASE RATE CONSTANT FOR HYDROLYSIS'
     6                            ' (AKB)'/
     7  14X,1PE12.5,'...SECOND ORDER RATE CONSTANT OF NEUTROL REACTION'
     8                            ' WITH WATER (AKN)'/
     9  14X,1PE12.5,'...CHEMICAL DEGRADATION DUE TO HYDROLYSIS'/
     1  14X,1PE12.5,'...SECOND ORDER RATE CONSTANT OF FREE RADICAL'
     2                            ' OXYGEN (AKOX)'/
     3  14X,1PE12.5,'...CONCENTRATION OF FREE RADICAL OXYGEN (RO2)'/
     4  14X,1PE12.5,'...CHEMICAL DEGRADATION DUE TO OXIDATION'/
     5  14X,1PE12.5,'...SECOND ORDER RATE CONSTANT FOR BIODEGRADATION'
     6                            ' (AKBIO)'/
     7  14X,1PE12.5,'...BIOMASS PER UNIT VOLUME (BIOMAS)'/
     8  14X,1PE12.5,'...BIODEGRADATION'/
     9  14X,1PE12.5,'...VOLATILIZATION')
12    FORMAT(14X,1PE12.5,'...SAND'/
     1  14X,1PE12.5,'...SILT'/
     2  14X,1PE12.5,'...CLAY')
13    FORMAT(14X,1PE12.5,'...MEDIAN BED SEDIMENT DIAMETER')
14    FORMAT(14X,1PE12.5,'...DISSOLVED CONTAMINANT')
15    FORMAT(1H0,13X,'MASS TRANSFER RATES (1/SEC)'/
     1  14X,1PE12.5,'...SUSPENDED SAND'/
     2  14X,1PE12.5,'...SUSPENDED SILT'/
     3  14X,1PE12.5,'...SUSPENDED CLAY'/
     4  14X,1PE12.5,'...SAND ATTACHED TO THE BED'/
     5  14X,1PE12.5,'...SILT ATTACHED TO THE BED'/
     6  14X,1PE12.5,'...CLAY ATTACHED TO THE BED')
16    FORMAT(1H0,13X,'DESORPTION KD VALUES')
C
      END

(FLECS VERSION 22.46)

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      SUBROUTINE SEDIME(ABAR, ALEN, CCIN, DELTD, I, J, NELEM,
     1                 QHIN, QHOUT, QV, SD, SR, ALFA, BETA, VEL1,
     2                 VEL2, VSET,  DELZ, BWID, AWID,DEPTH,
     3                 BETA1, BETA2)
C
C    THIS ROUTINE CALCULATES COEFFICIENTS OF CONVECTION, DIFFUSION,
C    DECAY AND SOURCE TERMS IN THE SEDIMENT TRANSPORT CONVECTION
C    -DIFFUSION EQUATION
C
C      INPUT PARAMETERS:
C        ABAR    - AVERAGE AREA
C        CCIN    - CONCENTRATION OF INFLOW
C        DELTD   - TIME STEP IN DAYS
C        DEPTH   - DEPTH OF RIVER SEGMENT
C        I       - ELEMENT INDEX
C        J       - PARAMETER INDEX
C        NELEM   - NUMBER OF ELEMENTS
C        QHIN    - INFLOW DISCHARGE
C        QHOUT   - OUTFLOW DISCHARGE
C        QV      - VERTICAL DISCHARGE
C        SD      - SEDIMENT DEPOSITION RATE, (KG/M**3/DAY)
C        SR      - SEDIMENT EROSION RATE, (KG/M**3/DAY)
C      OUTPUT PARAMETERS:
C        ALFA    - DECAY TERM, (1/DAY)
C        BETA    - SOURCE OR SINK TERM, (KG/M**3/DAY)
C        BETA1   - INFLUENT SOURCE TERM FOR THE I-TH NODE, (KG/M**3/DAY)
C           BETA2  - INFLUENT SOURCE TERM FOR THE I+1-TH NODE, (KG/M**3/D
C        VEL1    - FIRST CONVECTIVE TERM, (M/DAY)
C        VEL2    - SECOND CONVECTIVE TERM, (M/DAY)
C
C      CALLED BY TRANSP.
C
       INCLUDE 'ELMSIZ.PRM'
C
       DIMENSION ABAR(MXELEM), AREA(MXELEM), CCIN(MXELEM,MAXCON),
     1           QHIN(MXELEM), QHOUT(MXELEM), QV(MXELEM), SD(MXELEM,6),
     2           SR(6), VSET(3), BWID(MXELEM), AWID(MXELEM)
C
C    CONVECTIVE TERM WITH CORRECTION FOR A CONTINUOUS SETTLING FLUX
C
       AQ = QV(I)
       VEL1=(AQ-VSET(J)*BWID(I)*ALEN)/ABAR(I)
C
       AQ = QV(I+1)
       VEL2=(AQ-VSET(J)*BWID(I+1)*ALEN)/ABAR(I)
C
C    DECAY TERM
C
       ALFA = QHOUT(I) / (ABAR(I) * DELZ)
C
C    SOURCE OR SINK TERM
C
       BETA=SR(J) - SD(I,J)
```

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             BETA1=QMIN(I)/(ABAR(I)*DELZ)*(CCIN(I,J)/3.+CCIN(I+1,J)/6.)
             BETA2=QMIN(I)/(ABAR(I)*DELZ)*(CCIN(I,J)/6.+CCIN(I+1,J)/3.)
             RETURN
             END

        (FLECS VERSION 22.46)

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C                                    [106,1]SERATRA.FLX
C*************************************************************************
C          VERSION: DRIED CHANNEL OPTION
C                   WITH SELECTION FOR IMPLICIT SETTLING VELOCITY SCHEME
C                      OR SUPERPOSITION OF SETTLING VELOCITY SCHEME
C*************************************************************************
C
C
C         THIS COMPUTER PROGRAM, SERATRA, IS AN UNSTEADY, TWO-
C         DIMENSIONAL (LONGITUDINAL AND VERTICAL) MODEL TO SIMULATE
C         SEDIMENT-CONTAMINANT TRANSPORT IN RIVERS AND RIVER-RUN
C         RESERVOIRS.
C
C         THE MODEL HAS GENERAL CONVECTION-DIFFUSION EQUATIONS
C         WITH DECAY AND SINK/SOURCE TERMS WITH APPROPRIATE BOUNDARY
C         CONDITIONS.
C
C         SERATRA UTILIZES THE FINITE ELEMENT COMPUTATION METHOD WITH
C         THE GALERKIN WEIGHTED RESIDUAL TECHNIQUE.
C
C         THE FOLLOWING REPORTS DESCRIBE SERATRA MODEL FORMULATION, USER'S
C         MANUAL AND SOME MODEL RESULTS:
C
C**
C 1 ONISHI,Y.,P.A.JOHANSON,R.G.BACA,ANDE.L.HILTY.1976.
C   "STUDIES OF COLUMBIA RIVER WATER QUALITY--DEVELOPMENT OF
C   MATHEMATICAL MODELS FOR SEDIMENT AND RADIONUCLIDE TRANSPORT
C   ANALYSIS." BNWL-B-452. BATTELLE, PACIFIC NORTHWEST
C   LABORATORIES, RICHLAND, WA.
C**
C 2 ONISHI,Y. 1977. "FINITE ELEMENT MODELS FOR SEDIMENT AND CONTAMINANT
C   TRANSPORT IN SURFACE WATERS--TRANSPORT OF SEDIMENT AND RADIONUCLIDES
C   IN THE CLINCH RIVER." BNWL-2227. BATTELLE, PACIFIC NORTHWEST
C   LABORATORIES, RICHLAND, WA.
C**
C 3 ONISHI,Y. 1977. "MATHEMATICAL SIMULATION OF SEDIMENT AND RADIO-
C   NUCLIDE TRANSPORT IN THE COLUMBIA RIVER." BNWL-2228. BATTELLE,
C   PACIFIC NORTHWEST LABORATORIES, RICHLAND, WA.
C**
C 4 ONISHI,Y., D.L. SCHREIBER AND R.B. CODELL. 1979. "MATHEMATICAL
C   SIMULATION OF SEDIMENT AND RADIONUCLIDE TRANSPORT IN THE CLINCH
C   RIVER, TENNESSEE."  PROCEEDINGS OF ACS/CSJ CHEMICAL CONGRESS,
C   HONOLULU, HAWAII, APRIL 1-6, 1979. "CONTAMINANTS AND SEDIMENTS",
C   R.A. BAKER (ED.), ANN ARBOR SCIENCE PUBLISHERS, INC., ANN ARBOR, MI.
C**
C 5 ONISHI,Y., B.M. BROWN, A.R. OLSEN, M.A. PARKHURST, S.E. WISE, AND
C   W.H. WALTERS. 1979. "METHODOLOGY FOR OVERLAND AND INSTREAM MIGRATION
C   AND RISK ASSESSMENT OF PESTICIDES," BATTELLE, PACIFIC NORTHWEST
C   LABORATORIES, RICHLAND, WA.
C**
C 6 ONISHI,Y. AND S.E. WISE. 1979. "MATHEMATICAL MODEL, SERATRA, FOR
C   SEDIMENT AND CONTAMINANT TRANSPORT IN RIVERS AND ITS APPLICATION TO
C   PESTICIDE TRANSPORT IN FOUR MILE AND WOLF CREEKS IN IOWA." BATTELLE,
```

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C    PACIFIC NORTHWEST LABORATORIES, RICHLAND, WA.
C**
C 7 ONISHI,Y. AND S.E. WISE. 1979. "USER'S MANUAL FOR THE INSTREAM
C    SEDIMENT-CONTAMINANT TRANSPORT MODEL, SERATRA," BATTELLE, PACIFIC
C    NORTHWEST LABORATORIES, RICHLAND, WA.
C
C
C    CALLS: BEDDAT, COLAPS. DIMDAT, FCODE, HYDDAT, HYDFLO, ICFLO, INIDAT,
C           ROBFLO, RPTERR, SAVEIT, SEDDAT, STRTUP, TRANSP, TRBDAT,
C           TRBFLO. UPSDAT. WTRDAT, PHOINP
C
       INCLUDE 'ELMSIZ.PRM'
C
       BYTE FNAME(29),BASE(5),FTYPE(3),DEV(3),GUIC(3),UUIC(3),
      1     HLDERR(100),NOW(8)
C
       LOGICAL*1 ECHO,ANALYS,NEWTRB,NEWIC,FERROR,NEWQI,RIVER,
      1          ECHO2,ECHO3,ECHO4,ECHO5,ECHO6,ECHO7,ECHO8,ECHO9,ECHO10,
      2          SAVECH
C
       INTEGER*2 OUTFLO,TRBOPT
C
       INTEGER*4 ETIME,ENDHYD,ENDIC,ENDTRB,SIMLEN,DUM2,
      1            NSTEPS,NXEQ,NFRST,DUM1,NSP,SECYR,JULSEC
C
C
       DIMENSION AWID(MXELEM), CLAST(MXELEM,MAXCON), CTRB(MXELEM,MAXCON),
      1            PTQAVG(MXELEM),ELMVOL(MXELEM),
      2QAVG(MXELEM),CTRIB(MAXCON),PCOEF(4),CNODE(MXELEM,MAXCON),
      3          EL(MXELEM), XSAREA(MXELEM), BWID(MXELEM), THABS(MAXCON),
      4 IELM(MXELEM),UWID(MXELEM),UEL(MXELEM),ABAR(MXELEM),PWID(MXELEM),
      5 PXBAR(MXELEM), OLOC(MXELEM,MAXCON), CDUMMY(MXELEM),
      6 TBED(MAXCON),  JSEG(5), SAVECH(10)
C
       INCLUDE 'TRANS.COM'
C
       DATA SECDAY/86400./
       DATA SECYR /31536000/
       DATA ECHO/.FALSE./
       DATA FERROR/.FALSE./
       DATA ZERO/1.0E-10/
       DATA SAVECH/.FALSE.,.FALSE.,.FALSE.,.FALSE.,.FALSE.,.FALSE.,.FALSE
      1.,.FALSE.,.FALSE.,.FALSE./
C
         IS1=1
         IS2=0
       CALL STRTUP(BASE, DEV, ECHO, FNAME, FTYPE, GUIC, INFLO, ISTRT,
      1              NFRST, OUTFLO, SMETH, UUIC,  SAVECH, JSEG,
      2        NSTEPS,ISEG,ITPRT,ANALYS,DELTH,ANALMT,DEPMIN,SIMLEN,
      3        PELEV)
C
C      *** READ INPUT DATA FOR BEGINNING SEGMENT ***
       NUMERR = 0
C
C      THIS IS THE RESTART OPTION.
C
```

```
    WHEN(ISTRT.NE.1)DELTO=DELTH/SECDAY
C
    ELSE
    . CALL INIDAT(ANALMT, ANALYS, DELTH, ECHO, HLDERR, IIPRT,
   1.             NSEG, NSTEPS, NUMERR, SIMLEN, DEPMIN)
    . DELTO=DELTH/SECDAY
    . IF(ECHO)
    . . CALL TIME(NOW)
    . . WRITE(6,3) ISTRT, NOW
    . ...FIN
    . CALL DIMDAT(ALEN, AREA, BDIV, BED, DLZSAV, ECHO, ELEV, HLDERR,
   1.             ISTRT, NBED, NELEM, NUMERR, PELEV, POR, RIVER,
   2.             XYSU,  EL)
    . CALL SEDDAT(DECAY, DENS, DFZ, DIAM, DSHR, D50, ECHO, ERODE,
   1.             HLDERR, NUMERR, SCSHR, SORBK, VSET, DSORB)
    . CALL PHOINP(ECHO,JULIAN,KAY1,KAY2,PCOEF)
    . CALL BEDDAT(B, ECHO, NBED,AREA,BDIV,DENS,POR,XYSD,TBED)
C   .
C   . READS INITIAL CONDITIONS FOR SEDIMENT AND CONTAMINANT
C   .
    . CALL WTRDAT(C, ECHO, NELEM)
C   .
C   . READS UPSTREAM BOUNDARY CONDITIONS FOR FIRST SEGMENT
C   .
    . CALL UPSDAT(ECHO, HLDERR, NUMERR, SIMLEN, UNID, UEL)
    . CALL TRBDAT(ECHO, HLDERR, NELEM, NTRIBS, NUMERR,
   1.             SIMLEN, TRBOPT)
    . CALL HYDDAT(ALEN, AREA, DELTH, DELZ, D50, ECHO, HLDERR, NSETS,
   1.             NUMERR, SIMLEN,DEPMIN, DLZSAV, EL)
C   .
    . IF (NUMERR .GT. 0)
    . . CALL RPTERR(NUMERR, HLDERR, FERROR)
    . . IF (FERROR) REPORT-FATAL-ERROR-AND-STOP
    . ...FIN
C   .
    ...FIN
C
    IF (ANALYS)
    . OPEN(UNIT=8,NAME='SY:TIMSERIES.DAT',TYPE='NEW',
   1.      FORM='UNFORMATTED')
    ...FIN
C***********************************
C   SEGMENT LOOP                   *
C***********************************
    DO (ISEG=ISTRT,NSEG)
    . CALL DIAG(ECHO2, ECHO3, ECHO4, ECHO5, ECHO6, ECHO7, ECHO8,
   1.           ECHO9, ECHO10, ISEG, JSEG, SAVECH)
3   . FORMAT('1',100X,'SEGMENT NO.',I3,1X,8A1)
    . RESET-DATA-TIME-CONTROLS
    . CAVGMX=0.0
    . JULSEC = JULIAN * SECDAY
C   .
    . UNLESS (ISEG .EQ. 1)
    . . IF (ECHO)
    . . . CALL TIME(NOW)
    . . . WRITE (6,3) ISEG,NOW
```

```
      .  .  ...FIN
      .  .  FERROR = .FALSE.
      .  .  NUMERR = 0
      .  .  CALL DIMDAT(ALEN, AREA, BDIV, BED, DLZSAV, ECHO, ELEV, HLDERR,
     1.  .              ISEG, NBED, NELEM, NUMERR, PELEV, POR, RIVER,
     2.  .              XYSO,  EL)
      .  .  CALL SEDDAT(DECAY, DENS, DFZ, DIAM, DSHR, D50, ECHO, ERODE,
     1.  .              HLDERR, NUMERR, SCSHR, SORBK, VSET, DSORB)
      .  .  CALL BEDDAT(B, ECHO, NBED,AREA,BDIV,DENS,POR,XYSO,TBED)
C     .  .
C     .  .  READS INITIAL CONDITIONS FOR SEDIMENT AND CONTAMINANT
C     .  .
      .  .  CALL WTRDAT(C, ECHO, NELEM)
      .  .  CALL TRBDAT(ECHO, HLDERR, NELEM, NTRIBS, NUMERR,
     1.  .              SIMLEN, TRBOPT)
      .  .  CALL HYDDAT(ALEN, AREA, DELTH, DELZ, D50, ECHO, HLDERR, NSETB.
     1.  .              NUMERR, SIMLEN, DEPMIN, DLZSAV, EL)
C     .  .
      .  .  IF (NUMERR .GT. 0)
      .  .  .  CALL RPTERR(NUMERR, HLDERR, FERROR)
      .  .  .  IF (FERROR) REPORT-FATAL-ERROR-AND-STOP
      .  .  ...FIN
      .  ...FIN
      .  NEBELN=ELEV+BED
C     .
C     .  *** READ THE HYDROLOGICAL DATA ***
      .  READ(4) DUM1,NELEM,DELZ,QI,QO,VOL,VEL,AWID,AREA,TEMPR,XSAREA,IELM,
     1.  DEPTH,BWID,ABAR,HRAD, CRUSEC
      .  REWIND 4
C     .
C     .  PROCESSING OF INITIAL DATA
C     .
      .  IF (NELEM .GT. 0)
      .  .  DO (K=1,MAXCON)
C     .  .  .  *** NELEM VALUES OF CLAST MUST BE CALUCLATED FROM NELEM+1
C     .  .  .      VALUES OF C ***
      .  .  .  IF (K .LE. 3 .OR. K .EQ. 7)
C     .  .  .  .
C     .  .  .  .  PROVIDES A CONSISTENT INITIAL CONDITION FOR THE DELZ DEFINED
C     .  .  .  .  IN HYDDAT - BOTH NODAL VALUES (CNODE=C), AND ELEMENT
C     .  .  .  .  AVERAGES (CLAST=COLD)
C     .  .  .  .
      .  .  .  .  CALL COLLAP(ALEN,AREA,C,DELZ,EL,IELM,K,NELEM,CLAST,TMASS,AWID,
     1.  .  .  .      VSET,DFZ,CNODE,XSAREA)
      .  .  .  ...FIN
      .  .  ...FIN
C     .  .
C     .  .  DIAGNOSTIC WRITES
C     .  .
      .  .  IF (ECHO5)
      .  .  .  WRITE(6,1500)
      .  .  .  WRITE(6,1510)
      .  .  .  WRITE(6,1520) (I,AREA(I),EL(I),ABAR(I),AWID(I),BWID(I),
     1.  .  .                XSAREA(I),TMASS(I), I=1,NELEM+1)
      .  .  .  WRITE(6,1530)
      .  .  .  WRITE(6,1520) (I,(C(I,J),J=1,MAXCON),I=1,MXELEM)
```

```
     .  .  .  WRITE(6,1540)
     .  .  .  WRITE(6,1520) (I,(CNODE(I,J),J=1,MAXCON),I=1,NELEM+1)
     .  .  .  WRITE(6,1550)
     .  .  .  WRITE(6,1520) (I,(CLAST(I,J),J=1,MAXCON),I=1,NELEM)
1500 .  .  .  FORMAT('0IMMEDIATELY FOLLOWING COLLAP, THE INITIAL CONDITION')
1510 .  .  .  FORMAT('0ELEMENT/NODE',5X,'AREA',10X,'EL',12X,'ABAR',
    1.  .  .        11X,'AMID',11X,'BMID',10X,'XSAREA',10X,'TMASS')
1520 .  .  .  FORMAT(2X,I5,3X,1P7E15.4)
1530 .  .  .  FORMAT('0NODAL CONCENTRATIONS PRIOR TO COLLAP')
1540 .  .  .  FORMAT('0NODAL CONCENTRATIONS FOLLOWING COLLAP')
1550 .  .  .  FORMAT('0ELEMENT AVERAGE CONCENTRATION FOLLOWING COLLAP')
     .  .  ...FIN
     .  .  DO (I=1,NELEM)
     .  .  .  DO (J=1,MAXCON)
     .  .  .  .  COLD(I,J)=CLAST(I,J)
     .  .  .  .  C(I,J)=CNODE(I,J)
     .  .  .  ...FIN
     .  .  ...FIN
     .  .  DO (J=1,MAXCON) C(NELEM+1,J)=CNODE(NELEM+1,J)
     .  .  DO (J=1,MAXCON) COLD(NELEM+1,J)=0.0
     .  .  IF(NELEM+1.LT.MXELEM)
     .  .  .  DO (I=NELEM+2,MXELEM)
     .  .  .  .  DO (J=1,MAXCON)
     .  .  .  .  .  COLD(I,J) = 0.0
     .  .  .  .  .  C(I,J) = 0.0
     .  .  .  .  ...FIN
     .  .  .  ...FIN
     .  .  ...FIN
     .  ...FIN
     .  CALL FCODE(FNAME, BASE, ISEG, FTYPE, DEV, GUIC, UUIC)
     .  OPEN(UNIT=5,NAME=FNAME,TYPE='NEW',FORM='UNFORMATTED')
     .  OPEN(UNIT=9,NAME='RSTRT.FIL',TYPE='NEW',FORM='UNFORMATTED')
     .  WRITE(5) ISEG
C    .
C    .  *** CONVERT INPUT VALUES TO THOSE UNITS USED BY MODEL ***
     .  DO (J=1,3) VSET(J)=VSET(J) * SECDAY
     .  DO (J=1,4) DFZ(J)=DFZ(J) * SECDAY
     .  DO (I=1,6) DECAY(I) = DECAY(I) * SECDAY
     .  DO (I=4,9) SORBK(I) = SORBK(I) * SECDAY
     .  DO (I=4,9) DSORB(I) = DSORB(I) * SECDAY
C**********************************************
C    .                 TIME STEP LOOP               *
C**********************************************
C    .
     .  NXEQ = NFRST
     .  IF (NXEQ.EQ.1)
     .  .  PTDPTH = DEPTH
     .  .  PTDELZ = DELZ
     .  .  NELMPT = NELEM
     .  ...FIN
     .  ETIME = NXEQ - 1
     .  ETIME = ETIME * DELTH
     .  UNTIL (NXEQ .GT. NSTEPS)
     .  .  IF (IS1 .EQ. 1) WRITE(11,4) ISEG,NXEQ
4    .  .  FORMAT(' SEGMENT #',I5,' TIME STEP',I10)
     .  .  ETIME = ETIME + DELTH
```

```
C      .  .  *** UPDATE THE FLOW AND CONCENTRATION ARRAYS ***
       .  .  CALL HYDFLO(ALEN, AREA, AWID, DELZ, DEPTH, D50, ELEV,
      1.  .              ENDHYD, ETIME, FERROR, HRAD, NELEM, NEWQI, PELEV,
      2.  .              QHIN, QHOUT, QV, RIVER, SLOPE, STRESS, TEMPR,
      3.  .              VEL, VOL, DEPMIN, XSAREA, BWID, ABAR, QI, CROSEC,
      4.  .              QO,IELM)
C      .  .
       .  .  IF (FERROR) REPORT-FATAL-ERROR-AND-STOP
       .  .  IF (NTRIBS .GT. 0)
       .  .  .  CALL TRBFLO(CTRB, CTRIB, ENDTRB, ETIME, FERROR, DEPTH, NELEM,
      1.  .  .                NEWQI, NEWTRB, QHIN, TRBOPT, DEPMIN)
       .  .  .  IF(ECHO3)
       .  .  .  .  WRITE(6,1100)
  1100 .  .  .  .  FORMAT('0AFTER TRBFLO, MASS FLUX VALUES OF CTRB')
       .  .  .  .  WRITE(6,1110)
  1110 .  .  .  .  FORMAT('0ELEMENT NO.',2X,3(3X,'CONC. OF',4X),3(1X,'CONC.'
      1.  .  .  .   'ASSOC.',2X),2X,'CONCAMINANT'/13X,'SUSPENDED SAND',1X,
      2.  .  .  .   'SUSPENDED SILT',1X,'SUSPENDED CLAY', 3X,'WITH SAND', 6X,
      3.  .  .  .   'WITH SILT', 6X,'WITH CLAY', 4X,'DISSOLVED CONC.')
       .  .  .  .  WRITE(6,1020)(I,(CTRB(I,K),K=1,MAXCON),I=1,NELEM)
       .  .  .  ...FIN
       .  .  .  IF (FERROR) REPORT-FATAL-ERROR-AND-STOP
       .  .  ...FIN
       .  .  CALL ICFLO(CCIN, DEPTH, DELZ, D50, ENDIC, ETIME, FERROR, INFLO,
      1.  .  ISEG,NELEM,NEWIC,QHIN,QI,DEPMIN,ALEN,
      2.  .             UEL, UWID, XSAREA, AREA, AWID, DFZ, VSET,
      3.  .        EL,ELEV,PELEV,RIVER,NEWQI,NEWTRB,
      4.  .              NM,PDEPTH,CNODE)
       .  .  IF (ECHO2) WRITE (6,9999)
   9999 .  .  FORMAT('*********** IN SERATRA TIME LOOP *********')
       .  .  IF(ECHO2) WRITE (6,4) ISEG, NXEQ
       .  .  IF (ECHO3)
       .  .  .  WRITE (6,1000)
  1000 .  .  .  FORMAT('0AFTER ICFLO, CCIN')
       .  .  .  WRITE (6,1010)
  1010 .  .  .  FORMAT('0',2X,'NODE NO.',2X,3(3X,'CONC. OF',4X),3(1X,'CONC.'
      1.  .  .     ' ASSOC.',2X),2X,'CONTAMINANT'/1X,'FROM BOTTOM',1X,
      2.  .  .  'SUSPENDED SAND',1X,'SUSPENDED SILT',1X,'SUSPENDED CLAY',
      3.  .  .  3X,'WITH SAND',6X,'WITH SILT',6X,'WITH CLAY',4X,'DISSOLVED',
      4.  .  .  ' CONC')
       .  .  .  WRITE(6,1020)(J,(CCIN(J,K),K=1,MAXCON),J=1,NELEM+1)
       .  .  .  IF (FERROR) REPORT-FATAL-ERROR-AND-STOP
       .  .  ...FIN
  1020 .  .    FORMAT(2X,I5,2X,1P7E15.5)
       .  .  IF (ECHO6)
       .  .  .  WRITE(6,1560)PTDPTH,NELMPT,PTDELZ,DEPTH,NELEM,DELZ
       .  .  .  WRITE(6,1570)
       .  .  .  WRITE(6,1010)
       .  .  .  WRITE(6,1020) (J,(C(J,K),K=1,MAXCON),J=1,NELMPT+1)
       .  .  .  WRITE(6,1580)
       .  .  .  WRITE(6,1110)
       .  .  .  WRITE(6,1020) (J,(COLD(J,K),K=1,MAXCON),J=1,NELMPT)
  1560 .  .  .  FORMAT('0IMMEDIATELY PRIOR TO RDSFLO, FOLLOWING ICFLO'/
      1.  .  .   '0PTDPTH =',E12.4,'  NELMPT =',I5,'  PTDELZ =',E12.4/
      2.  .  .   ' DEPTH  =',E12.4,'  NELEM  =',I5,'  DELZ   =',E12.4)
  1570 .  .  .  FORMAT('0NODAL CONCENTRATIONS PRIOR TO RDSFLO')
```

```
   1580 .  .  .  FORMAT('0ELEMENT AVERAGE CONCENTRATIONS PRIOR TO RDSFLO')
        .  .  ...FIN
        .  .  IF (DEPTH .GT. DEPMIN)
        .  .  .  T = ABS(PTDPTH/DEPTH-1.)
        .  .  .  IF (NXEQ .GT. 1 .AND. T .GT. ZERO)
        .  .  .  .  CALL RDSFLO(ALEN,AREA,AWID,C,DELZ,DFZ,NELEM,NELMPT,
      1.  .  .  .  PTDELZ,PWID,PXSAR,VSET,XSAREA)
        .  .  .  .  DO(J=1,MAXCON)
        .  .  .  .  .  DO(K=1,NELEM)
        .  .  .  .  .  .  COLD(I,J)=(C(I,J)+C(I+1,J))/2.
        .  .  .  .  .  ...FIN
        .  .  .  .  ...FIN
        .  .  .  .  IF (ECHO6)
        .  .  .  .  .  WRITE(6,1590)
        .  .  .  .  .  WRITE(6,1010)
        .  .  .  .  .  WRITE(6,1020) (J,(C(J,K),K=1,MAXCON),J=1,NELEM+1)
        .  .  .  .  .  WRITE(6,1600)
        .  .  .  .  .  WRITE(6,1110)
        .  .  .  .  .  WRITE(6,1020) (J,(COLD(J,K),K=1,MAXCON),J=1,NELEM)
   1590 .  .  .  .  .  FORMAT('0NODAL CONCENTRATIONS FOLLOWING RDSFLO')
   1600 .  .  .  .  .  FORMAT('0ELEMENT AVERAGE CONCENTRATIONS FOLLOWING RDSFLO')
        .  .  .  .  ...FIN
        .  .  .  ...FIN
        .  .  .  COMPUTE-BED-AND-WATER-SURFACE-ELEVATIONS
        .  .  ...FIN
C       .  .
C       .  .  *** AVERAGE THE INFLOW CONCENTRATIONS INTO THE SEGMENT BY TAKING
C       .  .         INTO ACCOUNT THE TRIBUTARY INPUT.
C       .  .
        .  .  IF (DEPTH .GT. DEPMIN)
        .  .  .  WHEN (NTRIBS .GT. 0)
        .  .  .  .  IF (NEWTRB .OR. NEWIC .OR. NEWQI)
        .  .  .  .  .  DO (K=1,MAXCON)
        .  .  .  .  .  .  DO (J=1,NELEM+1)
        .  .  .  .  .  .  .  CDUMMY(J) = CCIN(J,K)
        .  .  .  .  .  .  ...FIN
        .  .  .  .  .  .  DO (J=1,NELEM)
        .  .  .  .  .  .  .  CMASS=(CDUMMY(J)+CDUMMY(J+1))/2.*QWIN(J)
        .  .  .  .  .  .  .  CMASS=(CMASS+CTRB(J,K)*SECDAY)/QWIN(J)
C       .  .  .  .  .  .  .
C       .  .  .  .  .  .  .  NOTE: CMASS IS IN (KG/M**3)
C       .  .  .  .  .  .  .
        .  .  .  .  .  .  .  WHEN (J.EQ.1)
        .  .  .  .  .  .  .  .  WHEN (K.EQ.7)
        .  .  .  .  .  .  .  .  .  CCIN(1,K)=CMASS
        .  .  .  .  .  .  .  .  .  CCIN(2,K)=CMASS
        .  .  .  .  .  .  .  .  ...FIN
        .  .  .  .  .  .  .  .  ELSE
        .  .  .  .  .  .  .  .  .  KK=K
        .  .  .  .  .  .  .  .  .  IF(K.GT.3) KK=KK-3
        .  .  .  .  .  .  .  .  .  COEF=0.
        .  .  .  .  .  .  .  .  .  WS=VSET(KK)*AREA(1)/(AWID(1)*ALEN)
        .  .  .  .  .  .  .  .  .  EZ=DFZ(KK)
        .  .  .  .  .  .  .  .  .  CCIN(1,K)=(2.*CMASS-COEF*DELZ/EZ)/(2.-WS*DELZ/EZ)
        .  .  .  .  .  .  .  .  .  CCIN(2,K)=2.*CMASS - CCIN(1,K)
        .  .  .  .  .  .  .  .  ...FIN
```

```
           .  .  .  .  .  .  .  ...FIN
           .  .  .  .  .  .  .  ELSE
           .  .  .  .  .  .  .  .  CCIN(J+1,K)=2.*CMASS - CCIN(J,K)
           .  .  .  .  .  .  .  ...FIN
           .  .  .  .  .  .  ...FIN
           .  .  .  .  .  ...FIN
           .  .  .  .  ...FIN
           .  .  .  .  IF (ECHO3)
           .  .  .  .  .  WRITE(6,1300)
     1300  .  .  .  .  .  FORMAT('0AFTER TRIBUTARY INFLOW, CCIN AND QHIN')
           .  .  .  .  .  WRITE(6,1310)
     1310  .  .  .  .  .  FORMAT('0ELEMENT/NODE',3(3X,'CONC. OF',4X),3(1X,'CONC.'
          1.  .  .  .  .   ' ASSOC.',2X),2X,'CONTAMINANT',7X,'FLOW'/1X,'FROM BOTTOM',
          2.  .  .  .  .   2X,'SUSPENDED SAND SUSPENDED SILT SUSPENDED CLAY   WITH ',
          3.  .  .  .  .   'SAND',6X,'WITH SILT',6X,'WITH CLAY    DISSOLVED CONC.',
          4.  .  .  .  .   2X,'(M**3/SEC)')
           .  .  .  .  .  WRITE(6,1320)(J,(CCIN(J,K),K=1,MAXCON),QHIN(J),J=1,NELEM+1)
           .  .  .  .  ...FIN
     1320  .  .  .  .  FORMAT(2X,I5,4X,1P8E15.5)
           .  .  .  ...FIN
           .  .  .  ELSE
           .  .  .  .  DO (J=1,MXELEM)
           .  .  .  .  .  DO (K=1,MAXCON) CTRB(J,K)=0.0
           .  .  .  .  ...FIN
           .  .  .  .  QTR=0.0
           .  .  .  ...FIN
     C     .  .  .
     C     .  .  .  *** DETERMINE THE PROPER PHOTOLYSIS COEFFICIENT TO BE USED ***
           .  .  .  JULSEC = JULSEC + DELTH
           .  .  .  NSP = MOD(JULSEC,SECYR)
           .  .  .  CONDITIONAL
           .  .  .  .  (NSP .GE.        1 .AND. NSP .LE.  7948800) IPC = 1
           .  .  .  .  (NSP .GE.  7948801 .AND. NSP .LE. 15897600) IPC = 2
           .  .  .  .  (NSP .GE. 15897600 .AND. NSP .LE. 23760000) IPC = 3
           .  .  .  .  (NSP .GE. 23760001 .AND. NSP .LE. SECYR) IPC = 4
           .  .  .  .  (NSP .EQ. 0) IPC = 4
           .  .  .  ...FIN
           .  .  ...FIN
           .  .  WHEN (DEPTH .LE. DEPMIN)
           .  .  .  DO (L=1,MAXCON)
           .  .  .  .  DO (I=1,MXELEM)
           .  .  .  .  .  C(I,L)=0.
           .  .  .  .  .  COLD(I,L)=0.
           .  .  .  .  ...FIN
           .  .  .  ...FIN
           .  .  .  IF (DECAY(1) .GT. 0.0)
           .  .  .  .  CALL SEDDK(S, DECAY,DELTD,NSED)
           .  .  .  ...FIN
           .  .  ...FIN
           .  .  ELSE
           .  .  .  FERROR = .FALSE.
     C     .  .  .
           .  .  .  PCOEFF=PCOEF(IPC)
           .  .  .  IF (ECHO5)
           .  .  .  .  WRITE(6,1700)
           .  .  .  .  WRITE(6,1710)
```

```
       .  .  .  .  WRITE(6,1720) (I,AREA(I),ABAR(I),AWID(I),BWID(I),QV(I),QHIN(I),
      1.  .  .  .                 QHOUT(I),I=1,NELEM+1)
 1700  .  .  .  .  FORMAT('0GEOMETRY AND DISCHARGE INFO PRIOR TO TRANSP')
 1710  .  .  .  .  FORMAT('0ELEMENT/NODE',6X,'AREA',9X,'ABAR',11X,'AWID',11X,'BWID'-
      1.  .  .  .      12X,'QV',12X,'QHIN',11X,'QHOUT')
 1720  .  .  .  .  FORMAT(2X,I5,3X,1P7E15.4)
       .  .  .  ...FIN
C      .  .  .  WRITE(6,1111)NBED,NELEM,SHETH,FERROR,ECHO4,ECHO7,ECHO8,ECHO9,
C     1 PCOEFF,DEPTH,CROSEC,ALEN,BDIV,BED,DEPMIN,DELTH,DELZ,
C     2 D50,HRAD,KAY1,KAY2,POR,SLOPE,STRESS,TEMPR,VOL,XYSD
C      .  .  .  WRITE(6,2222)
C     3 ((OLDC(M,N),C(M,N),CCIN(M,N),COLD(M,N),N=1,7),
C     4 (B(M,N),N=1,6),BWID(M),AWID(M),ABAR(M),AREA(M),QHIN(M),
C     5 QHOUT(M),QV(M),M=1,10),(DECAY(M),M=1,6),(SORBK(M),
C     6 DSORB(M),M=1,9),(DFZ(M),M=1,4),(DENS(M),DIAM(M),DSHR(M),
C     7 ERODE(M),VSET(M),SCSHR(M),M=1,3)
 1111  .  .  .  FORMAT(5X'BEFORE TRANSP'2I3,A2,5L2/40(10E10.3/))
 2222  .  .  .  FORMAT(40(10E10.3/))
       .  .  .  CALL TRANSP(FERROR,PCOEFF,BWID,AWID,ABAR,DEPTH,OLDC.ECHO4,
      1.  .  .              CROSEC,ECHO7, ECHO8, ECHO9)
C      .  .  .  WRITE(6,1112)NBED,NELEM,SHETH,FERROR,ECHO4,ECHO7,ECHO8,ECHO9,
C     1 PCOEFF,DEPTH,CROSEC,ALEN,BDIV,BED,DEPMIN,DELTH,DELZ,
C     2 D50,HRAD,KAY1,KAY2,POR,SLOPE,STRESS,TEMPR,VOL,XYSD
C      .  .  .  WRITE(6,2222)
C     3 ((OLDC(M,N),C(M,N),CCIN(M,N),COLD(M,N),N=1,7),
C     4 (B(M,N),N=1,6),BWID(M),AWID(M),ABAR(M),AREA(M),QHIN(M),
C     5 QHOUT(M),QV(M),M=1,10),(DECAY(M),M=1,6),(SORBK(M),
C     6 DSORB(M),M=1,9),(DFZ(M),M=1,4),(DENS(M),DIAM(M),DSHR(M),
C     7 ERODE(M),VSET(M),SCSHR(M),M=1,3)
 1112  .  .  .  FORMAT(5X'AFTER TRANSP'2I3,A2,5L2/40(10E10.3/))
       .  .  .  IF(ECHO5)WRITE(6,2000)((C(I,J),J=1,MAXCON),I=1,NELEM+1)
 2000  .  .  .  FORMAT('0AFTER TRANSP'/50(1X,1P7E15.5/))
C      .  .  .
       .  .  .  IF (FERROR) REPORT-FATAL-ERROR-AND-STOP
C      .  .  .
       .  .  .  COMPUTE-BED-AND-WATER-SURFACE-ELEVATIONS
C      .  .  .
       .  .  ...FIN
C      .  .
C      .  .  *** SAVE THE RESULTS OF THIS TIME STEP, IT WILL BECOME INPUT TO
C      .  .     THE NEXT SEGMENT ***
       .  .  WRITE(OUTFLO) DEPTH,DELZ,NELEM,(QHOUT(K),XSAREA(K),AWID(K),
      1.  .              K=1,NELEM),((C(L,K),K=1,MAXCON),L=1,NELEM+1),
      2.  .              ((OLDC(L,K),K=1,MAXCON),L=1,NELEM+1)
C      .  .
       .  .  WRITE(9) DEPTH,DELZ,NELEM,(QHOUT(K),XSAREA(K),AWID(K),
      1.  .              K=1,NELEM),((C(L,K),K=1,MAXCON),L=1,NELEM+1),
      2.  .              ((OLDC(L,K),K=1,MAXCON),L=1,NELEM+1)
C      .  .
C      .  .
       .  .  IF (ANALYS) SAVE-THE-RESULTS-FOR-TIME-SERIES-ANALYSIS
C      .  .
       .  .  IF (MOD(NXEW,ITPRT) .EQ. 0)
C      .  .  .  *** SAVE THE RESULTS FOR PRINTING AND OTHER POST PROCESSING ***
       .  .  .  CALL SAVEIT(B, BDIV, BED, ELEV, C, DELZ,  NBED, NELEM.
      1.  .  .               NXEW, RESELN, STRESS, XYSD, OLDC,
```

```
             2.  .  .   ALEN,QHIN,QHOUT,CCIN,QV,AWID,BWID,VSET,DENS,DELTD,DFZ,
             3.  .  .         POW,THED)
                 .  .   ...FIN
        C        .  .
                 .  .   NELMPT=NELEM
                 .  .   PTOPTH=DEPTH
                 .  .   PTDELZ=DELZ
                 .  .   DO (I=1,NELEM)
                 .  .   .  PXSAR(I)=XSAREA(I)
                 .  .   .  PWID(I)=AWID(I)
                 .  .   ...FIN
        C        .  .
        C        .  .   *** CHECK SENSE SWITCH #2 TO SEE IF THE RUN IS TO BE STOPPED ***
                 .  .   IF (IS2.EQ.1)
                 .  .   .  CLOSE-THE-OPEN-FILES
                 .  .   .  OPEN(UNIT=1,NAME='TT:')
                 .  .   .  WRITE(1,2) NXEQ,ISEG
         2       .  .   .  FORMAT(//21X,'***** SERATRA *****'/
             1.  .  .   .   5X,'TERMINATED BY OPERATER AFTER TIME PLANE #',I10/
             2.  .  .   .   5X,'IN SEGMENT #',I5)
                 .  .   .  STOP
                 .  .   ...FIN
        C        .  .                  END OF TIME STEP LOOP
                 .  .   NXEQ = NXEQ + 1
                 .  ...FIN
        C        .                   END OF SEGMENT LOOP
                 .  PELEV = ELEV
                 .  NFRST = 1
                 .  LUNTMP=INFLO
                 .  INFLO=OUTFLO
                 .  OUTFLO=LUNTMP
                 .  REWIND INFLO
                 .  REWIND OUTFLO
                 .  CLOSE(UNIT=5)
                 .  CLOSE(UNIT=9)
                 ...FIN
                 CLOSE-THE-OPEN-FILES
                 STOP
        C

        ----------------------------------------

                 TO COMPUTE-BED-AND-WATER-SURFACE-ELEVATIONS
                 .  WELEV = ELEV + BED
                 .  RESELN = DEPTH + BELEV
                 ...FIN

        ----------------------------------------

                 TO CLOSE-THE-OPEN-FILES
                 .  CLOSE(UNIT=1)
                 .  CLOSE(UNIT=2)
                 .  CLOSE(UNIT=3)
                 .  CLOSE(UNIT=4)
                 .  CLOSE(UNIT=5)
                 .  CLOSE(UNIT=9)
```

```
                .  CLOSE(UNIT=6)
                .  CLOSE(UNIT=7)
                .  CLOSE(UNIT=8)
                ...FIN

        ----------------------------------------

                TO REPORT-FATAL-ERROR-AND-STOP
                .  CLOSE-THE-OPEN-FILES
                .  OPEN (UNIT=1,NAME='TT:')
                .  WRITE(1,1)
        1       .  FORMAT(//10X,'**** SERATRA -- FATAL ERROR *****'/
               1.   ' PRINT "SED.LST" FOR DETAILS')
        C       .  *** THE IF STATEMENT BELOW IS A CONCESSION TO THE COMPILER ***
                .  IF(FERROR) STOP
                ...FIN

        ----------------------------------------

                TO RESET-DATA-TIME-CONTROLS
                .  ENDIC = 0
                .  ENDHTO = 0
                .  ENDTRB = 0
                ...FIN

        ----------------------------------------

                TO SAVE-THE-RESULTS-FOR-TIME-SERIES-ANALYSIS
        C       .
        C       .  *** COMPUTE THE VOLUME OF EACH ELEMENT AND THE TOTAL VOLUME
        C       .       OF THE WATER COLUMN ***
        C       .
                .  AVOL=0.
                .  DO (I=1,NELEM)
                .  .  ELMVOL(I) = DELZ*ABAR(I)
                .  .  AVOL=AVOL+ELMVOL(I)
                .  ...FIN
        C       .
        C       .  *** AVERAGE DISSOLVED (KG/M**3) ***
                .  AVGDIS = 0.0
                .  DO(I=1,NELEM)AVGDIS=AVGDIS+(C(I,7)+C(I+1,7))*ELMVOL(I)/2.
                .  AVGDIS = AVGDIS / AVOL
                .  IF (AVGDIS .GT. ANALMT)
        C       .  .
        C       .  .  *** AVERAGE SEDIMENT (KG/M**3) ***
                .  .  AVGSED = 0.0
                .  .  DO(I=1,NELEM)
                .  .  .  AVGSED=AVGSED+(C(I,1)+C(I+1,1)+C(I,2)+C(I+1,2)+
               1.  .  .   C(I,3)+C(I+1,3))/2.
                .  .  ...FIN
                .  .  AVGSED = AVGSED / AVOL
        C       .  .
        C       .  .  **** AVERAGE (PARTICULATE (PC/KG)*SEDIMENT(KG/M**3))
                .  .  PARPCM = 0.0
                .  .  DO (I=1,NELEM)
                .  .  .  PARPCM = PARPCM +ELMVOL(I)*(C(I,4)+C(I,5)+C(I,6)
```

```
 00599         1.  .  .   +C(I+1,4)+C(I+1,5)+C(I+1,6))/2.
 00600           .  .  ...FIN
 00601           .  .  PARPCM = PARPCM / AVOL
 00602    C      .  .
 00603    C      .  .  *** AVERAGE PARTICULATE (PC/KG) ***
 00604           .  .  PARPCK = PARPCM / AVGSED
 00605    C      .  .
 00606           .  .  TOTKG = ( PARPCM + AVGDIS )*AVOL
 00607    C      .  .
 00608           .  .  CAVGMX = MAX(CAVGMX, AVGDIS)
 00609           .  .  TFLOW = 0.0
 00610           .  .  DO (I=1,NELEM) TFLOW = TFLOW + PTOAVG(I)
 00611           .  .  TFLOW = TFLOW / SECDAY
 00612           .  .  WRITE(8) ISEG,NXED,TFLOW,AVGSED,AVGDIS,PARPCM,PARPCK,TOTKG
 00613           .  ...FIN
 00614           ...FIN
 00615    C
 00616           END

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               PROCEDURE CROSS-REFERENCE TABLE

         00565 RESET-DATA-TIME-CONTROLS
               00158

         00570 SAVE-THE-RESULTS-FOR-TIME-SERIES-ANALYSIS
               00496

         00545 CLOSE-THE-OPEN-FILES
               00516  00538  00557

         00541 COMPUTE-BED-AND-WATER-SURFACE-ELEVATIONS
               00357  00481

         00556 REPORT-FATAL-ERROR-AND-STOP
               00142  00186  00285  00299  00319  00479

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              SUBROUTINE SETUP(II, DD, P, S, R, VEL, NELEM,ECHO4,WIDTH)
      C
      C       THIS SUBROUTINE SETS UP THE FINITE ELEMENT MATRICES
      C
      C       CALLED BY TRANSP.
      C
              LOGICAL*1 ECHO4
              REAL*8 SEL,P,R,S
              INCLUDE 'SY:ELMSIZ.PRM'
      C
              DIMENSION DD(10), P(MXELEM,3), PEL(2,2), R(MXELEM), S(MXELEM,3),
             *           SEL(2,2)
      C
      C
              PEL(1,1) = 1./3.
              PEL(1,2) = 1./6.
              PEL(2,1) = 1./6.
              PEL(2,2) = 1./3.
              SEL(1,1)= DD(1) + DD(3) + DD(7)/3.
              SEL(1,2)= -DD(1) + DD(4) + DD(7)/6.
              SEL(2,1)= -DD(1) - DD(5) + DD(7)/6.
              SEL(2,2)= DD(1) + DD(6) + DD(7)/3.
              IF(II.EQ.1) SEL(1,1)=SEL(1,1)+VEL
              IF(II.EQ.NELEM) SEL(2,2)=SEL(2,2)+VEL
      C
              DO (I=1,2)
              .  DO (J=1,2)
              .  .  PEL(I,J) = PEL(I,J) * WIDTH
              .  .  SEL(I,J) = SEL(I,J) * WIDTH
              .  ...FIN
              ...FIN
              DO (I=8,10,1) DD(I) = DD(I) * WIDTH
              DD2=DD(8)/2.0
              DO (J=1,2)
              .  NR=II + J - 1
              .  DO (K=1,2)
              .  .  MC=2+(II + K - 1) - NR
              .  .  P(NR,MC)= P(NR,MC) + PEL(J,K)
              .  .  S(NR,MC)= S(NR,MC) + SEL(J,K)
              .  ...FIN
              .  R(NR)= R(NR) + DD2 + DD(8+J)
              ...FIN
              IF (ECHO4)
              .  WRITE(6,999)
          999 .  FORMAT(' **************************IN SETUP')
              .  WRITE(6,1000)(I,(SEL(I,J),J=1,2),I=1,2)
              .  WRITE(6,1100)
              .  WRITE(6,1200)(I,(P(I,J),J=1,3),(S(I,J),J=1,3),R(I),I=1,NELEM+1)
         1000 .  FORMAT(' SEL(I,J), I=',I2,1X,' J=1,2 ',5X,1P2E14.4)
         1100 .  FORMAT('0NODE',7X,'P(I,1)',10X,'P(I,2)',10X,'P(I,3)',10X,
            1.   'S(I,1)',10X,'S(I,2)',10X,'S(I,3)',10X,'R(I)')
         1200 .  FORMAT(1X,I3,1P7E16.5)
              ...FIN
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 00054          RETURN
 00055          END

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                SUBROUTINE SHEARR(DEPTH, D50, STRESS, USTAR, VEL)
          C
          C   THIS SUBROUTINE CALCULATES BED SHEAR STRESS AND SHEAR VELOCITY FOR
          C   A SEDIMENT LADEN FLOW. METHOD IS APPLICABLE FOR RESERVOIRS.
          C   REF. HYDRAULICS OF SEDIMENT TRANSPORT BY W.H. GRAF, EQ 8.49
          C
          C   FORMAL PARAMETERS:
          C     DEPTH  - FLOW DEPTH (METERS)
          C     D50    - MEDIAN BED SEDIMENT DIAMETER (METERS)
          C     STRESS - BED SHEAR STRESS (KG/M**2)
          C     USTAR  - SHEAR VELOCITY (M/SEC)
          C     VEL    - AVERAGE VELOCITY (M/SEC)
          C
          C   CALLED BY: HYDFLO, ICFLO
          C
          C   RHO - WATER DENSITY (KG(FORCE)/M**3)
                DATA RHO /1000./
          C
          C   AKAPPA - KARMAN CONSTANT
                DATA AKAPPA /0.4/
          C
                USTAR=VEL/(17.66+(ALOG10(DEPTH/(96.5*D50)))*2.3/AKAPPA)
                STRESS=RHO*USTAR**2.0/9.8
                RETURN
                END

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      SUBROUTINE SHEARS(ALEN,ELEV, HRAD, PELEV,SLOPE,STRESS,USTAR)
C
C   THIS METHOD OF COMPUTING BED SHEAR STRESS AND SHEAR VELOCITY
C   IS APPLICABLE TO RIVERS AND STREAMS.
C
C   FORMAL PARAMETERS:
C     ALEN   - SEGMENT LENGTH
C     ELEV   - ELEVATION OF THE CURRENT SEGMENT
C     HRAD   - HYDRAULIC RADIUS OF THE SEGMENT
C     PELEV  - ELEVATION OF THE PREVIOUS SEGMENT
C     SLOPE  - BED SLOPE
C     STRESS - BED SHEAR STRESS
C     USTAR  - SHEAR VELOCITY
C
C   CALLED BY:HYDFLO
C
C     G   - GRAVITY (M/S**2)
C     RHO - DENSITY OF WATER (KG(FORCE)/M**3)
      DATA RHO/1000./
      DATA   G/9.801/
      SLOPE = (PELEV - ELEV) / ALEN
      STRESS = SLOPE * RHO * HRAD
      USTAR = SQRT(G * SLOPE * HRAD)
C
      RETURN
      END

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            SUBROUTINE SILCLA(ABAR, B, BDIV,  CCIN, DELTD, DELZ, DEPTH,
          1                  DENS, DSHR, ERODE, HRAD, J1, NBED, COLD,
          2                  NELEM, POR, QHIN, QHOUT, SCSHR, STRESS, VSET,
          3                  XYBD, DEPO, ILAYR, SD, SR, XNT,
          4                  CROSEC, BWID, ALEN, ECHO7, SCOUR)
      C
      C     THIS SUBROUTINE COMPUTES THE RATE AND SOURCE TERMS FOR THE
      C     TRANSPORT OF SILT (J1=2) AND CLAY (J1=3)
      C
      C     INPUT PARAMETERS:
      C        ABAR   - AVERAGE AREA
      C        B      - BED CONDITIONS
      C        BDIV   - STANDARD BED LAYER THICKNESS
      C        C      - WATER CONDITIONS
      C        CCIN   - CONCENTRATION OF INFLOW
      C        DELTD  - TIME STEP (DAYS)
      C        DELZ   - STANDARD ELEMENT THICKNESS
      C        DENS   - DENSITY
      C     DEPTH  - DEPTH OF FLOW
      C        DSHR   - CRITICAL SHEAR STRESS FOR DEPOSITION
      C        ERODE  - ERODABILITY, (KG/M**2/SEC)
      C        HRAD   - HYDRAULIC RADIUS
      C        J1     - =1: SILT      =2: CLAY
      C        NBED   - NUMBER OF BED LAYERS
      C        NELEM  - NUMBER OF ELEMENTS
      C        POR    - POROSITY
      C        QHIN   - INFLOW DISCHARGE
      C        QHOUT  - OUTFLOW DISCHARGE
      C        SCSHR  - CRITICAL SHEAR STRESS FOR SCOUR
      C        STRESS - BED SHEAR STRESS
      C        VSET   - PARTICLE SETTLING VELOCITY
      C        XYBD   - THICKNESS OF TOP BED LAYER
      C     OUTPUT PARAMETERS:
      C        ILAYR  - NO. OF BED LAYERS AFFECTED BY DEPOSITION AND EROSION
      C        SD     - DEPOSITION RATE, (KG(PC)/M**3/DAY)
      C        SR     - EROSION RATE, (KG(PC )/M**3/DAY)
      C        XNT    - WEIGHT OF TOP BED SEDIMENT LAYER, (KG/M**2)
      C     DEPO   - BED DEPOSITION RATE (KG(PC)/M2/DAY)
      C     SCOUR  - BED SCOUR RATE (KG(PC)/M2/DAY)
      C
      C     CALLED BY: TRANSP
      C     CALLS: DEPCAL
      C
            INCLUDE 'ELMSIZ.PRM'
      C
            REAL K4FUNC,K4,INFRAC
            LOGICAL*1 ECHO7
      C
            DIMENSION ABAR(MXELEM), B(MAXLEV,MAXCON+1),COLD(MXELEM,MAXCON),
          1           DENS(3), DSHR(3), ERODE(3), ILAYR(3),
          2           QHIN(MXELEM), QHOUT(MXELEM), SCSHR(3),
          3           SD(MXELEM,6), SR(6), VSET(3), XNT(3),
          4           CCIN(MXELEM,MAXCON), BWID(MXELEM), DEPO(6), SCOUR(6)
```

```
            DATA SECDAY/86400./
      C
            J2=J1+3
            XNT(J1)=0.
            IF (NBED.GT.0)
            .  XDTOP=(1.0-POR)/(B(NBED,1)/DENS(1)+B(NBED,2)/DENS(2) +
           1.            B(NBED,3)/DENS(3))
            .  XNT(J1) = XDTOP * B(NBED,J1) * XYBO
            ...FIN
            DEPO(J1) = 0.0
            DEPO(J2) = 0.0
            SR(J1) = 0.0
            SR(J2) = 0.0
            SCOUR(J1) = 0.0
            SCOUR(J2) = 0.0
            RS = 0.0
            CS = 0.0
            VOLUME = CROSEC * ALEN
            DO (IX = 1,NELEM)
            .  SD(IX,J1) = 0.0
            .  SD(IX,J2) = 0.0
            ...FIN
            ILAYR(J1) = 0
            IF(ECHO7)
            .  IF (STRESS .LT. DSHR(J1))
      C     .  .
      C    SEDIMENT DEPOSITION
      C     .  .
            .  .  ILAYR(J1) = -1
            .  .  AVGC = 0.0
            .  .  TOTQ = 0.0
            .  .  DO (IX = 1,NELEM)
      C     .  .  .
      C     .  .  .  IT IS IMPLICITLY ASSUMED THAT A DOWNSTREAM COURANT NUMBER
      C     .  .  .  AT OR NEAR UNITY IS EMPLOYED IN THIS ANALYSIS
      C     .  .  .
            .  .  .  INFRAC=0.5*QHIN(IX)*DELTD/ABAR(IX)/DELZ
            .  .  .  EXFRAC=1.0-INFRAC
            .  .  .  TOTQ = TOTQ + INFRAC*QHIN(IX)+EXFRAC*QHOUT(IX)
            .  .  .  AVGC=AVGC+INFRAC*QHIN(IX)*(CCIN(IX,J1)+CCIN(IX+1,J1))/2.
           1.  .  .          +EXFRAC*QHOUT(IX)*COLD(IX,J1)
            .  .  ...FIN
            .  .  AVGC = AVGC / TOTQ
            .  .  DEPO(J1) = VSET(J1) * AVGC * (1.0-(STRESS/DSHR(J1)))
            .  .  RATE = DEPO(J1) * BWID(1) * ALEN / VOLUME
            .  .  DO (K = 1,NELEM)
            .  .  .  SD(K,J1) = RATE
            .  .  .  VOLK = ABAR(K) * DELZ
            .  .  .  INFRAC=0.5*QHIN(K)*DELTD/VOLK
            .  .  .  EXFRAC=1.0-INFRAC
            .  .  .  SED=INFRAC*QHIN(K)*(CCIN(K,J1)+CCIN(K+1,J1))/2.
           1.  .  .   + EXFRAC*QHOUT(K)*COLD(K,J1)
            .  .  .  CONT=INFRAC*QHIN(K)*(CCIN(K,J2)+CCIN(K+1,J2))/2.
           1.  .  .   + EXFRAC*QHOUT(K)*COLD(K,J2)
      C     .  .  .
      C*************************************************************************
```

```
        .   .   .  RATEK = RATE * VOLK
        .   .   .  SD(K,J2) = RATEK / BED / VOLK * CONT
        .   .   .  DEPO(J2) = DEPO(J2) + SD(K,J2) / BWID(1) * VOLK
        .   .   ...FIN
        .   ...FIN
        .   IF (STRESS .GT. SCSHR(J1).AND. NBED. GT . 0)
C    SEDIMENT SCOURING
C       .   .
        .   .  RS = ERODE(J1) * SECDAY * (STRESS / SCSHR(J1) - 1.0)
        .   .  ILAYR(J1) = 0
C       .   .
C       .   .  COMPUTE AVAILABILITY OF COHESIVE SEDIMENT IN BED LAYERS.
C       .   .  MAXIMUM NUMBER OF LAYERS SCOURED IS RESTRICTED BY SAND SCOURING.
C       .   .
        .   .  RS = RS * DELTD
        .   .  WHEN (.NOT.(RS .GT. XNT(J1) .AND. ILAYR(1) .GT. 0) )
        .   .   .  RS = AMIN1(RS,XNT(J1))
        .   .   .  CS = RS * B(NBED,J2)
        .   .   .  XNT(J1) = XNT(J1)-RS
        .   .  ...FIN
        .   .  ELSE
        .   .   .  FAC=B(NBED,J2)
        .   .   .  RSUSP = RS
        .   .   .  RS = 0.
140     .   .   .  ILAYR(J1) = ILAYR(J1)+1
        .   .   .  NB = NBED-ILAYR(J1)
        .   .   .  RSUSP = RSUSP-XNT(J1)
        .   .   .  RS = RS+XNT(J1)
        .   .   .  CS = CS + FAC*XNT(J1)
        .   .   .  XNT(J1) = 0.0
        .   .   .  FAC = 0.0
        .   .   .  IF (NB.NE.0)
        .   .   .   .  XND=(1.0-POR)/(B(NB,1)/DENS(1)+B(NB,2)/DENS(2)+B(NB,3)/DENS(3))
        .   .   .   .  XNT(J1) = BDIV * B(NB,J1) * XND
        .   .   .   .  FAC = B(NB,J2)
        .   .   .  ...FIN
C       .   .   .
        .   .   .  IF (ILAYR(J1).EQ.ILAYR(1)) GO TO 155
        .   .   .  IF (RSUSP.GE.XNT(J1).AND.ILAYR(1).GT.ILAYR(J1))
        .   .   .   .  GO TO 140
        .   .   .  ...FIN
C       .   .   .
155     .   .   .  CONTINUE
        .   .   .  DEL = AMIN1(RSUSP,XNT(J1))
        .   .   .  RS = RS + DEL
        .   .   .  CS = CS + DEL * FAC
        .   .   .  XNT(J1) = XNT(J1) - DEL
        .   .   ...FIN
        .   ...FIN
        .   SCOUR(J1) = RS / DELTD
        .   SCOUR(J2) = CS / DELTD
        .   SR(J1) = RS / DELTD * BWID(1) * ALEN / VOLUME
        .   SR(J2) = CS / DELTD * BWID(1) * ALEN / VOLUME
C       .
        ...FIN
        RETURN
```

```
  00166          END
          (FLECS VERSION 22.46)
          ----------------------------------------
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C
C     [106,5]SPPR.FLX
C
C      SERATRA POST PROCESSING PROGRAM
C        -         -     --
C
C      THIS PROGRAM IS USED TO MANIPULATE THE RESULT FILES FROM THE
C      SEDIMENT TRANSPORT MODEL , SERATRA. LISTED BELOW ARE THE FUNCTIONS
C      THAT IT CAN PERFORM:
C
C        (1) LIST - READ THE SPECIFIED FILES AND PRINT PROPER MATRICES.
C
C      CALLS: GETSPC, LISTER
C
       BYTE FILNAM(30),BASE(5),EXT(3),DEV(3),GUIC(3),UUIC(3)
C
       INTEGER*2 BEGSEG,UNITS
       INTEGER*4 BEGTIM,LSTTIM
C
       LOGICAL*1 LIST,CHAIN
C
       DATA FILNAM(29),FILNAM(30)/2*' '/
C
       CALL GETSPC(BASE,BEGSEG,BEGTIM,CHAIN,EXT,DEV,FILNAM,GUIC,INTSEG,
     1           INTTIM,LSTSEG,LSTTIM,TSTEP,UNITS,UUIC)
C
       LIST = .TRUE.
       CALL LISTER(BASE,BEGSEG,BEGTIM,CHAIN,DEV,EXT,FILNAM,GUIC,INTSEG,
     1           INTTIM,LSTSEG,LSTTIM,TSTEP,UNITS,UUIC)
C
       STOP
       END

        (FLECS VERSION 22.46)

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      SUBROUTINE STRTUP(BASE, DEV, ECHO, FNAME, FTYPE, GUIC, INFLO,
     1                    ISTRT, NFRST, OUTFLO, SMETH, UUIC,
     2      SAVECH, JSEG, NSTEPS,NSEG,ITPRT,ANALYS,
     3      DELTH,ANALMT,DEPMIN,SIMLEN,PELEV)
C
C    THIS ROUTINE IS RESPONSIBLE FOR THE INTERACTIVE I/O AND OPENING THE
C    PROPER FILES,
C
C
C    FORMAL PARAMETERS:
C       BASE    - 5-CHARACTER BASE FILE NAME (BYTE)
C       DEV     - BASE OUTPUT FILE DEVICE (BYTE)
C       ECHO    -  LINE PRINTER ECHO CONTROL VARIABLE (L*1)
C       SAVECH(1)- ECHO CONTROL FOR SERATRA HEADINGS
C       SAVECH(2)- ECHO CONTROL FOR INFLUENT CONCENTRATIONS
C       SAVECH(3)-  ECHO CONTROL FOR SETUP OF ELEMENT MATRIX
C      SAVECH(4)=  ECHO CONTROL FOR GEOMETRY AND CONCENTRATIONS
C      SAVECH(5)-  ECHO CONTROL FOR RDSFLO, BEFORE AND AFTER
C      SAVECH(6)-  ECHO CONTROL FOR SEDIMENTATION
C      SAVECH(7)  -  ECHO CONTROL FOR DIAGNOSTICS WITHIN  SAND, SILCLA
C      SAVECH(8)-  ECHO CONTROL FOR PRINTOUT OF SCOUR/DEPOSITION DETAIL
C      SAVECH(9)=  ECHO CONTROL - UNDEFINED - TRANSFERS TO TRANSP
C       SAVECH(10)- ECHO CONTROL - UNDEFINED
C       FNAME   -  FILE DESCRIPTION FOR THE RESULT FILE (BYTE)
C       FTYPE   - BASE OUTPUT FILE EXTENSION (BYTE)
C       GUIC    - GROUP NUMBER FROM UIC OF BASE FILE NAME (BYTE)
C       INFLO   - LUN NUMBER TO THE DATA FROM THE PREVIOUS SEGMENT
C       ISTRT   - STARTING SEGMENT NUMBER
C       NFRST   - STARTING TIME PLANE NUMBER (I*4)
C       OUTFLO - LUN NUMBER TO THE FILE RECEIVING THE RESULTS OF THE
C                 CURRENT SEGMENT (I*2)
C       SMETH   - METHOD TO BE USED TO CALCULATE THE SAND CAPACITY (BYTE)
C       UUIC    - USER NUMBER FROM UIC OF BASE FILE NAME (BYTE)
C
C    CALLED BY: SERATRA
C    CALLS: FDCODE
C
C
      BYTE ANSWER,YES,R,FNAME(29),FTYPE(3),DEV(3),GUIC(3),UUIC(3),
     1     BASE(5),SMETH,INPFIL(30)
C
      INTEGER*2 OUTFLO
C
      INTEGER*4 NFRST,SIMLEN,NSTEPS
C
      LOGICAL*1 ECHO, SAVECH, WRTSEG, ANALYS
C
      DIMENSION JSEG(9), SAVECH(10)
C
      DATA R/'R'/
      DATA YES/'Y'/
      DATA WRTSEG/.FALSE./
C
```

```
          WRITE(8,1)
          READ(8,2) NCHR,(INPFIL(I),I=1,NCHR)
          INPFIL(NCHR+1) = 0
          OPEN(UNIT=1,NAME=INPFIL,TYPE='OLD',READONLY)
    C
          WRITE(8,3)
          READ(8,4)ANSWER
          IF (ANSWER .EQ. YES) ECHO = .TRUE.
    C
          WRITE(8,6)
          READ(8,4)(FNAME(I),I=1,29)
          CALL FDCODE(FNAME,BASE,JSEG,FTYPE,DEV,GUIC,UUIC)
    C
          WRITE(8,7)
          READ(8,4) SMETH
    C
          WRITE(8,8)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(1) = .TRUE.
    C
          WRITE(8,9)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(2) = .TRUE.
    C
          WRITE(8,10)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(3) = .TRUE.
    C
          WRITE(8,11)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(4) = .TRUE.
    C
          WRITE (8,12)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(5) = .TRUE.
    C
          WRITE (8,13)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(6) = .TRUE.
    C
          WRITE (8,14)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) SAVECH(7) = .TRUE.
    C
          WRITE (8,15)
          READ(8,4) ANSWER
          IF (ANSWER.EQ.YES) WRTSEG = .TRUE.
          WHEN (WRTSEG) JSEG(1) = 0
          ELSE
          .  WRITE (8,16)
          .  READ(8,17)  (JSEG(J),J=1,5)
          ...FIN
          WRITE(8,18)
          READ(8,4) ANSWER
    C
          WHEN(ANSWER.EQ.YES)
```

```
                 .  WRITE(8,19)
                 .  READ(8,2) NCHR,(INPFIL(I),I=1,NCHR)
                 .  INPFIL(NCHR+1) = 0
                 .  OPEN(UNIT=2,NAME=INPFIL,TYPE='OLD',FORM='UNFORMATTED')
C                .
                 .
                 .  WRITE(8,20)
                 .  READ(8,17)ISTRT
C                .
                 .  WRITE(8,21)
                 .  READ(8,17)NSEG
C                .
                 .  WRITE(8,22)
                 .  READ(8,17)NFRST
C                .
                 .  WRITE(8,23)
                 .  READ(8,17)NSTEPS
C                .
                 .  WRITE(8,24)
                 .  READ(8,17)ITPRT
C                .
                 .  WRITE(8,25)
                 .  READ(8,4)ANSWER
                 .  IF(ANSWER.EQ.YES)ANALYS=.TRUE.
C                .
                 .  WRITE(8,26)
                 .  READ(8,27)DELTH
                 .  SIMLEN = DELTH * NSTEPS
C                .
                 .  WRITE(8,28)
                 .  READ(8,27)ANALMT
C                .
                 .  WRITE(8,29)
                 .  READ(8,27)DEPMIN
C                .
                 .  WRITE(8,30)
                 .  READ(8,27)PELEV
C                .
                 ...FIN
                 ELSE
                 .  NFRST = 1
                 .  ISTRT=1
                 .  OPEN(UNIT=2,NAME='DUMMY.DT1',TYPE='NEW',FORM='UNFORMATTED')
                 ...FIN
                 CLOSE(UNIT=8)
                 INFLO=2
                 OUTFLO=3
                 OPEN(UNIT=3,NAME='DUMMY.DT2',TYPE='NEW',FORM='UNFORMATTED')
                 OPEN(UNIT=4,NAME='HYDROLOGY.TMP',TYPE='NEW',FORM='UNFORMATTED')
                 OPEN(UNIT=7,NAME='TRIBUTARY.TMP',TYPE='NEW',FORM='UNFORMATTED')
                 OPEN(UNIT=6,NAME='SED.LST',TYPE='NEW')
                 RETURN
C
C                ** FORMATS **
           1     FORMAT('$ENTER NAME OF INPUT FILE>')
           2     FORMAT(Q,30A1)
```

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        3  FORMAT('$DO YOU WANT THE INPUT FILE ECHOED (Y OR N)>')
        4  FORMAT(29A1)
        6  FORMAT('$ENTER BASE FILE NAME>')
        7  FORMAT(' WHICH SAND CAPACITY METHOD IS TO BE USED?'/
          & '$ENTER T (TOFFALETTI) OR C (COLBY)>')
        8    FORMAT('$DO YOU WANT SERATRA HEADINGS ECHOED (Y OR N)?')
        9    FORMAT('$DO YOU WANT INFLUENT CONCENTRATIONS ECHOED (Y OR N)?')
       10    FORMAT('$DO YOU WANT ELEMENT MATRICES ECHOED (Y OR N)?')
   11      FORMAT('$DO YOU WANT GEOMETRY AND CONCENTRATIONS ECHOED (Y OR N)',
          &        '?')
   12      FORMAT('$DO YOU WANT CONCENTRATION ECHOED BEFORE AND AFTER RDSFLO'
          &        ,' (Y OR N)?')
   13      FORMAT('$DO YOU WANT SCOUR/DEPOSITION TO OCCUR? (Y OR N)')
   14      FORMAT('$DO YOU WANT COMPLETE SCOUR/DEPOSITION INFORMATION',
          1' RECORDED? (Y OR N)')
   15      FORMAT('$DO YOU WANT COMPLETE ECHO INFORMATION FOR ALL',
          1' SEGMENTS? (Y OR N)')
   16      FORMAT('$FOR WHICH SEGMENTS DO YOU WANT COMPLETE ECHO',
          1' INFORMATION? (MAXIMUM OF 5)')
   17      FORMAT(5I5)
   18      FORMAT('$IS THIS TO BE A RESTART OF A PREVIOUS RUN (Y OR N)?>')
   19      FORMAT('$ENTER NAME OF RESTART FILE>')
   20      FORMAT('$ENTER THE BEGINNING SEGMENT NUMBER>')
   21      FORMAT('$ENTER THE ENDING SEGMENT NUMBER>')
   22      FORMAT('$ENTER THE BEGINNING TIME PLANE NUMBER>')
   23      FORMAT('$ENTER THE ENDING TIME PLANE NUMBER>')
   24      FORMAT('$ENTER THE PRINT FREQUENCY>')
   25      FORMAT('$DO YOU WANT THE TIME SERIES ANALYSIS? (Y OR N)>')
   26      FORMAT('$ENTER THE TIME INCREMENT>')
   27      FORMAT(F10.0)
   28      FORMAT('$ENTER THE MINIMUM CONCENTRATION LIMIT>')
   29      FORMAT('$ENTER THE MINIMUM DEPTH LIMIT>')
   30      FORMAT('$ENTER THE UPSTREAM ELEVATION>')
   C
           END

   (FLECS VERSION 22.46)

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        SUBROUTINE TOFFAL(ALEN, D50, GSI, HRAD, QTOT, SLOPE, TEMPR, VOL,
       1                  VSET, GSU, GSM, GSL, GSB, YU, YM, YL)
C
C     THIS SUBROUTINE USES TOFFALETTI'S METHOD TO CALCULATE THE CAPACITY
C     OF THE FLOW TO TRANSPORT SAND.  A SUMMARY OF THIS METHOD CAN BE
C       FOUND IN THE ASCE 1975 EDITION OF "SEDIMENTATION ENGINEERING"
C       PAGES 209 - 213.
C
C       FORMAL PARAMETERS:
C         ALEN  - SEGMENT LENGTH
C         D50   - MEDIAN BED SEDIMENT DIAMETER (METERS)
C         GSI   - TOTAL CAPACITY OF THE SEGMENT (KG/DAY/M)
C         HRAD  - HYDRAULIC RADIUS
C         QTOT  - TOTAL FLOW WITHIN THE SEGMENT
C         SLOPE - ENERGY OR RIVER BED SLOPE
C         TEMPR - WATER TEMPERATURE
C         VOL   - VOLUME
C         VSET  - SETTLING VELOCITY
C
C     CALLED BY: SAND
C
        REAL K4FUNC,K4
C
        DIMENSION VSET(3)
C
        CONST1 = 3.7975E-5
        CONST2 = 5.60249E+22
        CONST3 = 2.976328E+3
        FDIAM=D50 * 3.280833
        TMPR=TEMPR * 1.80 + 32.0
        V=(QTOT * ALEN / (VOL)) * CONST1
        FHRAD=HRAD * 3.280833
C
C     FOR WATER TEMPERATURES GREATER THAN 32F AND LESS THAN 100F
C     THE KINEMATIC VISCOSITY CAN BE WRITTEN AS THE FOLLOWING:
C
        VIS=4.106E-4 * (TMPR ** -0.864)
C
C     ASSUMING THE D50 GRAIN SIZE (DIAM) IS APPROXIMATELY
C     EQUAL TO THE GEOMETRIC MEAN GRAIN SIZE AND SIGMA-G = 1.5,
C     THE D65 GRAIN SIZE CAN BE DETERMINED TO BE 1.17 * D50.
C
        D65=1.17 * FDIAM
        CNV=0.1198 + 0.00048 * TMPR
        CZ=260.67 - 0.667 * TMPR
        TT=1.10 * (0.051 + 0.00009 * TMPR)
        ZI=VSET(1) * CONST1 * V / (CZ * FHRAD * SLOPE)
        IF(ZI.LT.CNV) ZI=1.5 * CNV
C
C     THE MANNING-STRICKLER EQUATION IS USED HERE TO
C     DETERMINE THE HYDRAULIC RADIUS COMPONENT DUE TO
C     GRAIN ROUGHNESS (R'), TAKEN FROM THE 1975 ASCE
C     "SEDIMENTATION ENGINEERING",PG. 128.
```

```
C
C     SUBSTITUTIONS ARE MADE IN EQUATION 2.141 FOR SHEAR VELOCITY
C     AND K(SUB)S.  THE FORMER IS REPLACED BY EQUATION 2.142, AND
C     THE LATTER BY D(SUB)65.
C
      RPRIME=((V**1.5) * (D65 **0.25) / (SLOPE ** 0.75)) * 0.00349
      USTAR=(RPRIME * SLOPE * 32.2) ** 0.5
      AFUNC=(VIS * 1.0E5) ** 0.333 / (10.0 * USTAR)
      CONDITIONAL
      .  (AFUNC .LE. 0.500)  AC = (AFUNC/4.89)** -1.45
      .  (AFUNC .LE. 0.660)  AC = (AFUNC/0.0036)**0.67
      .  (AFUNC .LE. 0.720)  AC = (AFUNC/0.29)**4.17
      .  (AFUNC .LE. 1.25)   AC = 48.0
      .  (AFUNC .GT. 1.25)   AC = (AFUNC/0.304)**2.74
      ...FIN
C
      K4FUNC=AFUNC * SLOPE * D65 * 1.0E5
      CONDITIONAL
      .  (K4FUNC.LE.0.25)  K4 = 1.0
      .  (K4FUNC.LE.0.35)  K4 = (K4FUNC**1.10) * 4.81
      .  (K4FUNC.GT.0.35)  K4 = (K4FUNC** -1.05) * 0.89
      ...FIN
C
      ACK4=AC * K4
      IF (ACK4 .LT. 16.0)
      .  ACK4=16.0
      .  K4=16.0 / AC
      ...FIN
      OCZU=1.0 + CNV - 1.5 * ZI
      OCZM=1.0 + CNV - ZI
      OCZL=1.0 + CNV - 0.756 * ZI
      ZINV=CNV - 0.756 * ZI
      ZM=-ZINV
      ZN=1.0 + ZINV
      ZO=-0.756 * ZI
      ZP=0.244 * ZI
      ZQ=0.5 * ZI
C
C   CLI HAS BEEN MULTIPLIED BY 1.0E30 TO KEEP IT FROM
C   EXCEEDING THE COMPUTER OVERFLOW LIMIT
C
      WHEN((OCZL*ALOG10(2.0*FDIAM)-20.0).GT.38.)CLI=0.0
      ELSE
      .  CLI=(1.0E-20)*CONST2 * OCZL * (V ** 2.333) / FHRAD ** (ZM) /
     1.        ((TT * AC * K4 * FDIAM) ** 1.667) / (1.0 + CNV) /
     2.        ((FHRAD / 11.24) ** (ZN-20./ALOG10(FHRAD/11.24)) -
     3.        ((2.0*FDIAM)**(OCZL-20./ALOG10(2.0*FDIAM))))
      ...FIN
      WHEN(CLI.EQ.0.0)CZD=0.0
      ELSE
      .  CZD=CLI*(2.0*FDIAM/FHRAD)**(ZO-30./ALOG10(2.0*FDIAM/FHRAD))
      ...FIN
C
C   CHECK TO SEE IF THE CALCULATED VALUE IS REASONABLE
C   (< 100.0), AND ADJUST IT IF IT IS NOT.
C
```

```
      IF(C2D.GT.100.0) CLI=CLI*100.0/C2D
C
C   CMI HAS BEEN MULTIPLIED BY 1.0E30 TO KEEP IT FROM
C   EXCEEDING THE COMPUTER OVERFLOW LIMIT
C
C     P(SUB)I APPEARING IN EQUATIONS 2.236H, J, K, L, M, AND
C       N IS THE WEIGHT FRACTION OF TOTAL SAND THAT THE I-TH
C       SIZE FRACTION CONTAINS.  SINCE WE ARE MODELING ALL
C       SAND AS A SINGLE SIZE FRACTION -- P(SUB)I = 1.0, AND
C       HENCE DOES NOT APPEAR IN THE MODEL EQUATIONS.
C
      WHEN(CLI.EQ.0.0) CHI=0.0
      ELSE
      .  CMI=43.2 * CLI * (1.0 + CNV) * V * (FHRAD ** (ZM))
      ...FIN
C
      WHEN(CMI.EQ.0.0)
      .  GSU=0.0
      .  GSM=0.0
      .  GSL=0.0
      .  GSB=0.0
      ...FIN
      ELSE
C     .
C   CALCULATE TRANSPORT CAPACITY OF THE UPPER LAYER
C     .
      .  FD11=FHRAD / 11.24
      .  FD25=FHRAD / 2.5
      .  GSU=(CMI * (FD11 ** (ZP)) * (FD25 ** (ZQ)) *
     1.        (FHRAD ** (OCZU) - (FD25 ** (OCZU)))) / (OCZU * 1.0 E+30)
C     .
C   CALCULATE THE CAPACITY OF THE MIDDLE LAYER.
C     .
      .  GSM=(CMI * (FD11 ** (ZP)) * ((FD25 **(OCZM)) -
     1.        (FD11 ** (OCZM)))) / (OCZM * 1.0E+30)
C     .
C   CALCULATE THE CAPACITY OF THE LOWER LAYER
C     .
      .  GSL=CMI*(FD11**(ZN-30./ALOG10(FD11))-(2.0*FDIAM)**(OCZL-
     1.        30./ALOG10(2.0*FDIAM)))/OCZL
C   CALCULATE THE CAPACITY OF THE BED LAYER
C     .
      .  GSB=CMI*(2.0*FDIAM)**(ZN-30./ALOG10(2.0*FDIAM))
      ...FIN
C
C*********************************************************************
C   TOTAL CAPACITY OF THE SEGMENT (GSI HAS UNITS OF TONS/DAY/FT)
C
      GSI=GSU + GSM + GSL + GSB
C
C   CONVERTING  TO KG/DAY/M
C
      GSU = GSU * CONST3
      GSM = GSM * CONST3
      GSL = GSL * CONST3
      GSB = GSB * CONST3
```

```
 00166          YU = HRAD / 2.5
 00167          YM = HRAD / 11.24
 00168          YL = 2.0 * D50
 00169          GSI=GSI * CONST3
 00170    C
 00171          RETURN
 00172          END

          (FLECS VERSION 22.46)

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****************************************

      SUBROUTINE TRANSP(FERROR,PCOEF,BWID,AMID,ABAR,DEPTH,OLDC,ECHO4,
     1                 CROSEC,ECHO7, ECHO8, ECHO9)
C
C   THIS ROUTINE SOLVES THE MASS TRANPORT EQUATIONS BY AN IMPLICIT
C   FINITE-ELEMENT METHOD.  A CRANK-NICHOLSON METHOD IS USED TO
C   APPROXIMATE THE SOLUTION THROUGH TIME.
C
C   VARIABLE DEFINITIONS:
C     ALEN   - SEGMENT LENGTH
C     AREA   - ELEMENT AREAS
C     B      - BED CONDITIONS
C     BDIV   - STANDARD BED LAYER THICKNESS
C     BED    - BED THICKNESS
C     C      - WATER CONDITIONS
C     CCIN   - CONCENTRATION OF INFLOW
C     COLD   - CELL-CENTERED CONCENTRATION
C     CROSEC - TOTAL CROSS-SECTIONAL AREA, M**2
C     DECAY  - FIRST ORDER DECAY
C     DELTH  - TIME STEP (SECONDS)
C     DELZ   - STANDARD ELEMENT THICKNESS
C     DENS   - DENSITY
C     DFZ    - DIFFUSION COEFFICIENT
C     DIAM   - DIAMETER
C     DSHR   - CRITICAL SHEAR STRESS FOR DEPOSITION
C     D50    - MEDIAN BED SEDIMENT DIAMETER (M)
C     ERODE  - ERODABILITY
C     FERROR - FATAL ERROR FLAG (L*1)
C     HRAD   - HYDRAULIC RADIUS
C     KAY1   - LIGHT EXTINCTION COEFFICIENT OF WATER
C     KAY2   - LIGHT EXTINCTION OF SUSPENDED SEDIMENT IN WATER
C     NBED   - NUMBER OF BED LAYERS
C     NELEM  - NUMBER OF ELEMENTS
C     PCOEF  - FIRST TERM OF THE PHOTOLYSIS RATE OF CHANGE EQUATION
C     POR    - POROSITY
C     QHIN   - INFLOW DISCHARGE
C     QHOUT  - OUTFLOW DISCHARGE
C     QV     - VERTICAL DISCHARGE
C     SCSHR  - CRITICAL SHEAR STRESS FOR SCOUR
C     SLOPE  - ENERGY OR RIVER BED SLOPE
C     SMETH  - CONTROL VARIABLE TO SELECT THE METHOD TO BE USED
C              WHEN COMPUTING THE SAND CARRYING CAPACITY. (BYTE)
C     SR     - SEDIMENT EROSION RATE
C     STRESS - BED SHEAR STRESS
C     TEMPR  - WATER TEMPERATURE
C     VOL    - VOLUME
C     VSET   - PARTICLE SETTLING VELOCITY
C     XYSO   - THICKNESS OF TOP BED LAYER
C
C   CALLED BY: SERATRA
C   CALLS: BEDDK, BEDHIS, COLAPS, COMB, DISOLV, FALL, PARTIC, SAND,
C          SEDIME, SETUP, SILCAL, TRISOL
C
      INCLUDE 'ELMSIZ.PRM'
```

```
C
          LOGICAL*1 FERROR, ECHO4, ECHO7, ECHO8, ECHO9
          REAL*8 PBAR,P,R,S
C
C
          DIMENSION A(MXELEM), ABAR(MXELEM), DD(10), ILAYR(3), P(MXELEM,3),
         1          R(MXELEM), S(MXELEM,3), SD(MXELEM,6),
         2          SR(6), XNT(3), Z(MXELEM), BWID(MXELEM), AWID(MXELEM)
         3   ,DLOC(MXELEM,MAXCON), DEPO(6), SCOUR(6), SEDSD(3)
C
          INCLUDE 'TRANS.COM'
C
C
          DATA EPSI/1.0E-30/
C
          MP1 = NELEM + 1
          ML1 = NELEM - 1
C
C         *** PERFORM CALCULATIONS OVER THE TIME STEP DELTD ***
C
          DELTD = DELTH / 86400.
          DO (J=1,MAXCON)
          .  DO (L = 1,MP1)
          .  .  R(L) = 0.0
          .  .  DO (N = 1,3)
          .  .  .  S(L,N) = 0.0
          .  .  .  P(L,N) = 0.0
          .  .  ...FIN
          .  ...FIN
C         .
C         .
          .  DO (I=1,NELEM)
          .  .  RCDZ = 0.0
          .  .  IF (I .EQ. 1)
          .  .  .  SELECT(J)
          .  .  .  .  (1)
C         .  .  .  .  .  WRITE(6,1119)NBED,NELEM,(ILAYR(N),N=1,3),ECHO7,SMETH,ALEN,BDIV,
C        1 DELTD,DELZ,D50,HRAD,POR,SLOPE,STRESS,TEMPR,VOL,XYSD,
C        2 CROSEC,((B(M,N),SD(M,N),N=1,6),(CCIN(M,N),COLD(M,N),
C        3 C(M,N),N=1,7),M=1,10),(DENS(N),SCSHR(N),VSET(N),XNT(N),
C        4 N=1,3),(DEPO(N),SCOUR(N),N=1,6)
1119      .  .  .  .  .  FORMAT(5X'BEFORE SAND'5I3,L2,A2/20(10E10.3/))
          .  .  .  .  .  CALL SAND (ABAR, ALEN, AREA, B, BDIV, CCIN, DELTD, DELZ,
         1.  .  .  .  .              DENS, D50, HRAD, NBED, NELEM, POR, QMIN, QMOUT,
         2.  .  .  .  .              SCSHR, SLOPE, SMETH, STRESS, TEMPR, VSET,VOL, XYSD,
         3.  .  .  .  .              DEPO,ILAYR, SD, SR, XNT, COLD, C,
         4.  .  .  .  .              CROSEC,BWID,ECHO7, SCOUR)
C         .  .  .  .  .  WRITE(6,1120)NBED,NELEM,(ILAYR(N),N=1,3),ECHO7,SMETH,ALEN,BDIV,
C        1 DELTD,DELZ,D50,HRAD,POR,SLOPE,STRESS,TEMPR,VOL,XYSD,
C        2 CROSEC,((B(M,N),SD(M,N),N=1,6),(CCIN(M,N),COLD(M,N),
C        3 C(M,N),N=1,7),M=1,10),(DENS(N),SCSHR(N),VSET(N),XNT(N),
C        4 N=1,3),(DEPO(N),SCOUR(N),N=1,6)
1120      .  .  .  .  .  FORMAT(5X'AFTER SAND'5I3,L2,A2/20(10E10.3/))
          .  .  .  .  .  IF(ECHO8)
          .  .  .  .  .  .  WRITE(6,1000)
          .  .  .  .  .  .  WHEN(ILAYR(1).LT.0)
```

```
              .  .  .  .  .  .  .  .  WRITE(6,1010) J,ILAYR(1),DEPO(1),DEPO(4),SD(1,1),XNT(1),
           1. .  .  .  .  .  .  .  .                  (SD(II,4),II=1,NELEM)
              .  .  .  .  .  .  .  ...FIN
              .  .  .  .  .  .  .  ELSE
              .  .  .  .  .  .  .  .  WRITE(6,1015) J,ILAYR(1),SCOUR(1),SR(1),XNT(1),SCOUR(4),SR(4)
              .  .  .  .  .  .  .  ...FIN
      1010    .  .  .  .  .  .  .   FORMAT(' J=',I2,'  ILAYR=',I2,'  DEPO=',E15.7,'  DEPO(+3)=',
           1. .  .  .  .  .  .  .  E15.7,'  SD=',E15.7,'  XNT=',E15.7,5X,'SD(I,+3)='/
           2. .  .  .  .  .  .  .  (5X,8E15.7))
      1015    .  .  .  .  .  .  .  FORMAT(' J=',I2,'  ILAYR=',I2,'  SCOUR=',E15.7,'  SR=',E15.7,
           1. .  .  .  .  .  .  .  '  XNT=',E15.7,'  SCOUR(+3)=',E15.7,'  SR(+3)=',E15.7)
              .  .  .  .  .  .  ...FIN
      1000    .  .  .  .  .  .  FORMAT('0IN TRANSP FOLLOWING SAND')
              .  .  .  .  .  ...FIN
              .  .  .  .  .  (2)
              .  .  .  .  .  .  CALL SILCLA(ABAR, B, BDIV, CCIN, DELTD, DELZ, DEPTH, DENS,
           1. .  .  .  .  .  .                 DSHR, ERODE, HRAD, 2, NBED,COLD,NELEM, POR, QHIN,
           2. .  .  .  .  .  .                 QHOUT, SCSHR, STRESS, VSET, XYSD, DEPO, ILAYR,
           3. .  .  .  .  .  .                 SD, SR, XNT, CROSEC, BWID, ALEN, ECHO7, SCOUR)
              .  .  .  .  .  .  IF(ECHO8)
              .  .  .  .  .  .  .  WRITE(6,1020)
              .  .  .  .  .  .  .  WHEN(ILAYR(2).LT.0)
              .  .  .  .  .  .  .  .  WRITE(6,1010) J,ILAYR(2),DEPO(2),DEPO(5),SD(1,2),XNT(2),
           1. .  .  .  .  .  .  .  .                  (SD(II,5),II=1,NELEM)
              .  .  .  .  .  .  .  ...FIN
              .  .  .  .  .  .  .  ELSE
              .  .  .  .  .  .  .  .  WRITE(6,1015) J,ILAYR(2),SCOUR(2),SR(2),XNT(2),SCOUR(5),SR(5)
              .  .  .  .  .  .  .  ...FIN
              .  .  .  .  .  .  ...FIN
      1020    .  .  .  .  .  .  FORMAT('0IN TRANSP FOLLOWING SILT')
              .  .  .  .  .  ...FIN
              .  .  .  .  .  (3)
              .  .  .  .  .  .  CALL SILCLA(ABAR, B, BDIV, CCIN, DELTD, DELZ, DEPTH, DENS,
           1. .  .  .  .  .  .                 DSHR, ERODE, HRAD, 3, NBED,COLD,NELEM, POR, QHIN,
           2. .  .  .  .  .  .                 QHOUT, SCSHR, STRESS, VSET, XYSD, DEPO, ILAYR,
           3. .  .  .  .  .  .                 SD, SR, XNT, CROSEC, BWID, ALEN, ECHO7, SCOUR)
              .  .  .  .  .  .  IF(ECHO8)
              .  .  .  .  .  .  .  WRITE(6,1030)
              .  .  .  .  .  .  .  WHEN(ILAYR(3).LT.0)
              .  .  .  .  .  .  .  .  WRITE(6,1010) J,ILAYR(3),DEPO(3),DEPO(6),SD(1,3),XNT(3),
           1. .  .  .  .  .  .  .  .                  (SD(II,6),II=1,NELEM)
              .  .  .  .  .  .  .  ...FIN
              .  .  .  .  .  .  .  ELSE
              .  .  .  .  .  .  .  .  WRITE(6,1015) J,ILAYR(3),SCOUR(3),SR(3),XNT(3),SCOUR(6),SR(6)
              .  .  .  .  .  .  .  ...FIN
              .  .  .  .  .  .  ...FIN
      1030    .  .  .  .  .  .  FORMAT('0IN TRANSP FOLLOWING (SILT) CLAY')
              .  .  .  .  .  ...FIN
              .  .  .  .  ...FIN
              .  .  .  ...FIN
              .  .  CONDITIONAL
              .  .  .  (J .LE. 3)
      C       .  .  .  .  .  WRITE(6,1117)T,J,NELEM,ALEN,DELTD,ALFA,BETA,VEL1,VEL2,
      C    1 DELZ,DEPTH,BETA1,BETA2,((CCIN(M,N),N=1,7),(SD(M,N),
      C    2 N=1,6),ABAR(M),QHIN(M),QHOUT(M),QV(M),BWID(M),AWID(M),
      C    3 M=1,10),(SR(M),M=1,6),(VSET(M),M=1,3)
```

```
 1117  .   .   .   .  FORMAT(5X'BEFORE SEDIME'3I3/20(10E10.3/))
       .   .   .   .  CALL SEDIME(ABAR, ALEN, CCIN, DELTD, I, J, NELEM, QHIN,
     1.    .   .   .                      QHOUT, QV, SD, SR, ALFA, BETA, VEL1, VEL2,VSET,
     2.    .   .   .                DELZ, BWID, AWID, DEPTH, BETA1, BETA2)
 C     .   .   .   .  WRITE(6,1118)I,J,NELEM,ALEN,DELTD,ALFA,BETA,VEL1,VEL2,
 C     1 DELZ,DEPTH,BETA1,BETA2,((CCIN(M,N),M=1,7),(SD(M,N),
 C     2 N=1,6),ABAR(M),QHIN(M),QHOUT(M),QV(M),BWID(M),AWID(M),
 C     3 M=1,10),(SR(M),M=1,6),(VSET(M),M=1,3)
 1118  .   .   .   .  FORMAT(5X'AFTER SEDIME'3I3/20(10E10.3/))
       .   .   .   .  IF(ECHO8) WRITE(6,1500)
 1500  .   .   .   .  FORMAT('0IN TRANSP FOLLOWING SEDIME')
       .   .   .   ...FIN
       .   .   .   (J .GE. 4 .AND. J .LE. 6)
       .   .   .   .  CALL PARTIC(ABAR, ALEN, B, C, CCIN, COLD, DECAY, DELTD, DFZ,
     1.    .   .   .    I, J, NBED, NELEM, QHOUT, QHIN, QV, SORBK, SD, SR, ALFA, BETA,
     2.    .   .   .                      VEL1, VEL2,VSET, DELZ, DEPTH,BWID,AWID,
     3.    .   .   .                      BETA1, BETA2, DSORB, OLOC)
       .   .   .   .  IF(ECHO8) WRITE(6,1510)
 1510  .   .   .   .  FORMAT('0IN TRANSP FOLLOWING PARTIC')
       .   .   .   ...FIN
       .   .   .   (J .EQ. 7)
       .   .   .   .  CALL DISOLV(ABAR,  B, BDIV, C, CCIN, COLD, DECAY, DELZ,
     1.    .   .   .                      DELTD, DENS, DIAM,  I, KAY1, KAY2, NELEM,NBED,
     2.    .   .   .                      PCOEF, POR, QHIN, QHOUT, QV, SORBK, ALFA, BETA, VEL1,
     3.    .   .   .                      VEL2, BETA1, BETA2, DEPO, SCOUR, BEDSD, XYSD, AREA,
     4.    .   .   .              DSORB, OLOC)
       .   .   .   .  IF(ECHO8) WRITE(6,1520) (BEDSD(II),II=1,3)
 1520  .   .   .   .  FORMAT('0IN TRANSP FOLLOWING DISOLV        BEDSD(1-3) =',3E18.7)
       .   .   .   ...FIN
       .   .   ...FIN
       .   .   IF(ECHO8) WRITE(6,1530) VEL1,VEL2
 1530  .   .   FORMAT('  VEL1 =',E15.7,10X,'VEL2 =',E15.7)
 C     .   .
 C     .   .   *** CONSTRUCT THE FINITE ELEMENT MATRICES FOR EACH LAYER ***
       .   .   WHEN (J.LE.3) DIFUSE = DFZ(J)
       .   .   ELSE DIFUSE = DFZ(J-3)
       .   .   DD(1) = DIFUSE/(DELZ*DELZ)
       .   .   DD(2) = 6.0 * DELZ
       .   .   DD(3) = (VEL2 - 4. * VEL1) / DD(2)
       .   .   DD(4) = (VEL1 + 2. * VEL2) / DD(2)
       .   .   DD(5) = (2. * VEL1 + VEL2) / DD(2)
       .   .   DD(6) = (4. * VEL2 - VEL1) / DD(2)
       .   .   DD(7) = ALFA
       .   .   DD(8) = BETA
       .   .   DD(9) = BETA1
       .   .   DD(10) = BETA2
       .   .   IF (ECHO4)
       .   .   .  WRITE(6,2500)
  2500 .   .   .  FORMAT('0  I',1X,'J',6X,'DD(1)',7X,'DD(2)',7X,'DD(3)',7X,'DD(4)',7
     1.    .   .  X,'DD(5)',7X,'DD(6)',7X,'DD(7)',7X,'DD(8)',7X,'DD(9)',7X,'DD(10)')
       .   .   .  WRITE(6,2000)I,J,(DD(K),K=1,10)
  2000 .   .   .  FORMAT(1X,I3,1X,I1,1X,10(1PE12.4))
       .   .   ...FIN
 C     .   .
       .   .   VEL = VEL1/DELZ
       .   .   IF(I.EQ.NELEM) VEL=-VEL2/DELZ
```

```
          .  .  WIDTH = AWID(I)
          .  .  CALL SETUP(I, DO, P, S, R, VEL,NELEM,ECHO4,WIDTH)
          .  ...FIN
C         .
          .  HALFD = DELTD / 2.0
          .  DO (L = 1,MP1)
          .  .  R(L) = R(L) * DELTD
          .  .  Z(L) = C(L,J)
          .  .  DO (N = 1,3)
          .  .  .  P1 = S(L,N)*HALFD
          .  .  .  PBAR = P(L,N) + P1
          .  .  .  S(L,N) = P(L,N) - P1
          .  .  .  P(L,N) = PBAR
          .  .  ...FIN
          .  ...FIN
C         .
          .  IF (ECHO4)
          .  .  WRITE(6,5760)
  5760    .  .  FORMAT(' BEFORE COMB***************BEFORE COMB**')
          .  .  WRITE(6,5761)
 5761     .  .  FORMAT('0NODE',6X,'P(I,1)',10X,'P(I,2)',10X,'P(I,3)',10X,
         1.  .  'S(I,1)',10X,'S(I,2)',10X,'S(I,3)',11X,'Z(I)',12X,'R(I)')
          .  .  WRITE(6,5762)(I,(P(I,K),K=1,3),(S(I,K),K=1,3),Z(I),R(I),
         1.  .                  I=1,MP1)
 5762     .  .  FORMAT(1X,I2,1P8E16.5)
          .  ...FIN
C         .  WRITE(6,1113)MP1,((S(M,N),N=1,3),Z(M),R(M),M=1,10)
 1113     .  FORMAT(5X'BEFORE COMB'I3/10(10E10.3/))
          .  CALL COMB(MP1, S, Z, R)
C         .  WRITE(6,1114)MP1,((S(M,N),N=1,3),Z(M),R(M),M=1,10)
 1114     .  FORMAT(5X'AFTER COMB'I3/10(10E10.3/))
          .  IF (ECHO4) WRITE(6,6000)(R(L),L=1,MP1)
  6000    .  FORMAT(' R  AFTER COMB',8(1PE12.4,2X))
C         .
C         .  *** SOLVE THE SYSTEM OF EQUATIONS BY GAUSSIAN ELIMINATION ***
C         .
C         .  WRITE(6,1111)MP1,P(2,1),P(1,2),P(1,3),(R(M),M=1,10)
 1111     .  FORMAT(5X'BEFORE TRISOL'I3/10(10E10.3/))
          .  CALL TRISOL(MP1,P(2,1), P(1,2), P(1,3),R)
C         .  WRITE(6,1112)MP1,P(2,1),P(1,2),P(1,3),(R(M),M=1,10)
 1112     .  FORMAT(5X'AFTER TRISOL'I3/10(10E10.3/))
C         .
          .  DO (I=1,MP1)
          .  .  OLDC(I,J)=C(I,J)
          .  .  C(I,J)=R(I)
          .  ...FIN
          .  COMPUTE-CELL-CENTERED-VALUES
C         .
          ...FIN
          CALL SEDHIS(S, SDIV, SED, COLD, DELTD, DELZ,  DENS,
         1            FERROR, ILAYR, NBED, NELEM, POR, XNI, XYBO,
         2            DEPO, SCOUR, SEDBD)
          IF(DECAY(1).GT.0.0) CALL SEDDK(S,DECAY,DELTD,NBED)
          RETURN

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 00276               TO COMPUTE-CELL-CENTERED-VALUES
 00277    C          .
 00278    C          .   *** COLLAPSE THE NODAL VALUES OF C INTO CELL CENTERED VALUES
 00279    C          .       IN COLD ***
 00280    C          .
 00281               .   DO (I=1,NELEM)
 00282               .   .  COLD(I,J) = (C(I,J) + C(I+1,J))/2.
 00283               .   ...FIN
 00284     6200 .   FORMAT(' C IN PROCEDURE I=',I2,2X,1P7E14.4)
 00285               .   IF (ECHO4)
 00286               .   .  IF(J.EQ.MAXCON)
 00287               .   .  .  WRITE(6,6200)(I,(C(I,JJ),JJ=1,MAXCON),I=1,MP1)
 00288               .   .  .  WRITE(6,6300)(I,(COLD(I,JJ),JJ=1,MAXCON),I=1,NELEM)
 00289               .   .  ...FIN
 00290               .   ...FIN
 00291     6300 .   FORMAT(' COLD IN PROCEDRE I=',I2,2X,1P7E14.4)
 00292               ...FIN
 00293               END

         ----------------------------------------

               PROCEDURE CROSS-REFERENCE TABLE

         00276 COMPUTE-CELL-CENTERED-VALUES
               00288


         (FLECS VERSION 22.46)

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      SUBROUTINE TRBDAT(ECHO, HLDERR, NELEM, NTRIBS, NUMERR,
     1                     SIMLEN, TRBOPT)
C
C   THIS ROUTINE IS RESPONSIBLE FOR READING AND PROCESSING THE
C   TRIBUTARY INFLOW MASS FLUX DATA.  THE DATA IS READ FROM
C   THE INPUT STREAM (LUN 1) AND WRITTEN TO "TRIBUTARY.TMP" (LUN 7)
C   FOR USE DURING THE SIMULATION.
C
C     FORMAL PARAMETERS:
C       ECHO   - LINE PRINTER ECHO OPTION CONTROL VARIABLE (L*1)
C       HLDERR - HOLDING ARRAY FOR ERROR NUMBERS (BYTE)
C       NELEM  - NUMBER OF VERTICAL ELEMENTS
C              NOTE: NELEM IS LATER REDEFINED IN HYDDAT
C       NTRIBS - NUMBER OF TRIBUTARIES (0 OR 1)
C       NUMERR - NUMBER OF INPUT ERRORS
C       SIMLEN - SIMULATION LENGTH (SECONDS - I*4)
C       TRBOPT - TRIBUTARY INPUT CONTROL VARIABLE
C
C   CALLED BY: SERATRA
C   CALLS: PUTERR
C
      INCLUDE 'ELMSIZ.PRM'
C
      BYTE HLDERR(100)
C
      INTEGER*2 TRBOPT
C
      INTEGER*4 ENDTIM,PRETIM,SIMLEN
C
      LOGICAL*1 ECHO
C
      DIMENSION CTRB(MXELEM,MAXCON)
C
C   ....TRIBUTARY INFLOW MASS FLUX
C
C       FIRST RECORD.....
C
C          COL.  1- 5...NTRIBS....NUMBER OF TRIBUTARIES (0 OR 1)
C                6-10...TRBOPT....TRIBUTARY INPUT OPTION
C                                =0; THE USER WANTS THE MODEL TO
C                                    DISTRIBUTE THE MASS FLUX THRU
C                                    THE ELEMENTS.
C                                =1; THE USER WILL SUPPLY THE
C                                    MASS FLUX VALUES FOR EACH ELEMENT
C
      REWIND 7
C
      READ(1,2) NTRIBS,TRBOPT
C
      IF (ECHO) WRITE(6,3) NTRIBS,TRBOPT
C
      IF (NTRIBS .GT. 0)
      .  IF(ECHO) WRITE(6,4)
```

```
      .  REPEAT UNTIL (ENDTIM .EQ. -9999)
C     .  .
C     .  .  CARD 11-B
C     .  .  COL.  1-10...ENDTIM....ENDING TIME FOR THE DATA THAT FOLLOWS.
C     .  .                     A VALUE OF -9999 TERMINATES THE DATA
C     .  .                        (SECONDS).
C     .  .
      .  .  READ(1,6) ENDTIM
C     .  .
      .  .  UNLESS (ENDTIM .EQ. -9999)
C     .  .  .
C     .  .  .  RECORD TWO.......TRIBUTARY MASS FLUX AND DEPTH
C     .  .  .            *********** CAUTION ***********
C     .  .  .            THE MASS FLUX UNITS ARE DIFFERENT FROM THOSE OF
C     .  .  .            INITIAL WATER AND UPSTREAM WATER CONCENTRATIONS.
C     .  .  .            RADIONUCLIDE IS PC/SEC, PESTICIDE IS KG/SEC,
C     .  .  .            SEDIMENT IS KG/SEC
C     .  .  .            *********** CAUTION ***********
C     .  .  .
C     .  .  .  COL.  1-10...CTRB(1,1)...MASS FLUX OF SAND (KG/M**3)*(M**3/SEC)
C     .  .  .         11-20...CTRB(1,2)...MASS FLUX OF SILT
C     .  .  .         21-30...CTRB(1,3)...MASS FLUX OF CLAY
C     .  .  .         31-40...CTRB(J,4)...MASS FLUX OF CONTAMINANT ASSOCIATED
C     .  .  .                             WITH SAND (PC/KG)*(KG/M**3)*(M**3/SEC)
C     .  .  .         41-50...CTRB(J,5)...MASS FLUX OF CONTAMINANT ASSOCIATED
C     .  .  .                             WITH SILT
C     .  .  .         51-60...CTRB(J,6)...MASS FLUX OF CONTAMINANT ASSOCIATED
C     .  .  .                             WITH CLAY
C     .  .  .         61-70...CTRB(J,7)...MASS FLUX OF DISSOLVED CONTAMINANT
C     .  .  .                          (PC/M**3)*(M**3/SEC)
C     .  .  .
      .  .  .  WHEN (TRBOPT .EQ. 0) N = 1
      .  .  .  ELSE N = NELEM
      .  .  .  DO (J=1,N)
      .  .  .  .  READ(1,1) (CTRB(J,I),I=1,MAXCON)
      .  .  .  .  IF (ECHO)
      .  .  .  .  .  WRITE(6,5) ENDTIM,(CTRB(J,I),I=1,MAXCON)
      .  .  .  .  ...FIN
      .  .  .  ...FIN
      .  .  .  WRITE(7) ENDTIM,((CTRB(J,I),I=1,7),J=1,N)
      .  .  .  PRETIM = ENDTIM
      .  .  ...FIN
      .  ...FIN
      .  REWIND 7
      .  IF (PRETIM .LT. SIMLEN) CALL PUTERR(23, NUMERR, HLDERR)
      ...FIN
C
      RETURN
C
  1   FORMAT(7F10.0)
 2    FORMAT(2I5)
 3    FORMAT(1H0,4X,'TRIBUTARY DATA'/14X,I5,'...NUMBER OF TRIBUTARIES'
     1  /14X,I5,'...TRIBUTARY INPUT CONTROL VARIABLE')
 4    FORMAT(1H0,'ENDING TIME',1X,3(3X,'CONC. OF',4X),3(1X,'CONC.',
     1  ' ASSOC.',2X),2X,'CONTAMINANT',7X,'FLOW'/13X,'SUSPENDED SAND'
     2  ,1X, 'SUSPENDED SILT',1X,'SUSPENDED CLAY',3X,'WITH SAND',6X,
```

```
           3  'WITH SILT',6X,'WITH CLAY',4X,'DISSOLVED CONC',2X,
           4  '(M**3/SEC)')
       5      FORMAT(2X,I10,2X,7(1PE12.5,3X),1PE12.5)
       6      FORMAT(I10)
      C
              END

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      SUBROUTINE TRBFLO(CTRB, CTRIB, ENDTRB, ETIME, FERROR, DEPTH,
     1                  NELEM, NEWQI, NEWTRB, QHIN, TRBOPT, DEPMIN)
C
C       WHEN THERE IS A TRIBUTARY TO THE SEGMENT THIS SUBROUTINE IS
C       CALLED EACH TIME STEP TO READ THE DATA FROM LUN 7
C       WHICH WAS WRITTEN BY SUBROUTINE TRBDAT.
C
C       FORMAL PARAMETERS:
C          CTRB   - REDISTRIBUTED CONCENTRATIONS
C          CTRIB  - ORIGINAL TRIBUTARY MASS FLUX
C          ENDTRB - ENDING TIME OF THE CURRENT TRIBUTARY DATA (I*4)
C          ETIME  - ELAPSED TIME OF THE SIMULATION (I*4)
C          FERROR - FATAL ERROR FLAG
C          NELEM  - NUMBER OF ELEMENTS
C                CAUTION: NELEM HAS BEEN REDEFINED IN HYDDAT
C                SINCE ITS USE IN TRBDAT
C          NEWQI  - NEW QHIN DATA FLAG (L*1)
C          NEWTRB - NEW TRIBUTARY DATA FLAG (L*1)
C          QHIN   - INFLOW TO CURRENT SEGMENT
C          TRBOPT - TRIBUTARY INPUT OPTION CONTROL VARIABLE (I*2)
C
C       CALLED BY: SERATRA
C
      INCLUDE 'SY:ELMSIZ.PRM'
C
      INTEGER*2 TRBOPT
C
      INTEGER*4 ENDTRB,ETIME
C
      LOGICAL*1 NEWTRB,NEWQI,FERROR
C
      DIMENSION CTRB(MXELEM,MAXCON), CTRIB(MAXCON), QHIN(MXELEM)
C
      NEWTRB = .FALSE.
      IF (ETIME .GT. ENDTRB)
      .  NEWTRB = .TRUE.
      .  REPEAT UNTIL(ETIME .LE. ENDTRB)
  100 .  .  CONTINUE
      .  .  WHEN (TRBOPT .EQ. 0)
      .  .  .  READ(7,END=200) ENDTRB, (CTRIB(J),J=1,MAXCON)
      .  .  ...FIN
      .  .  ELSE READ(7,END=200) ENDTRB,((CTRB(I,J),J=1,MAXCON),I=1,NELEM)
      .  ...FIN
      ...FIN
      IF (DEPTH .LE. DEPMIN) RETURN
      IF (TRBOPT .EQ. 0 .AND. (NEWTRB .OR. NEWQI))
      .  QHTOT = 0.0
      .  DO (I=1,NELEM) QHTOT = QHTOT + QHIN(I)
C     .  *** DISTRIBUTE THE MASS FLUX THROUGHOUT THE ELEMENTS ***
C     .   NOTE: UNITS ARE
C     .                 SEDIMENT KG/SEC
C     .                 PARTICULATE  PC/SEC OR KG/SEC
C     .                 DISSOLVED    PC/SEC
```

```
      .  DO (K=1,MAXCON)
      .  .  DO (I=1,NELEM)
      .  .  .  CTRB(I,K) = CTRIB(K) * QHIN(I) / QHTOT
      .  .  ...FIN
      .  ...FIN
      ...FIN
      RETURN
C
 200  CONTINUE
      FERROR = .TRUE.
      WRITE(6,1)
1     FORMAT(10X,'FATAL ERROR - TRIBUTARY DATA EXHAUSTED')
      RETURN
C
      END

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                SUBROUTINE TRISOL(MP1,D1,D,D2,R)
          C     CALLED BY TRANSP.
          C     USED IN ORIGINAL VERSION OF SERATRA
                INCLUDE 'ELMSIZ.PRM'
          C
                REAL*8 D,R,D1,D2
                DIMENSION D(MXELEM), D1(MXELEM), D2(MXELEM), R(MXELEM)
          C
                N=MP1
                N1=N-1
          C
          C     FORWARD ELIMINATION
          C
                DO(I=1,N1)
                .  D10=D1(I)/D(I)
                .  D(I+1)=D(I+1)-D2(I)*D10
                .  R(I+1)=R(I+1)-R(I)*D10
                ...FIN
          C
          C     BACKWARD SUBSTITUTION
          C
                R(N)=R(N)/D(N)
                DO (I=1,N1)
                .  K=N-I
                .  R(K)=(R(K)-D2(K)*R(K+1))/D(K)
                ...FIN
          C
                RETURN
                END

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         SUBROUTINE TRNPOS(ABAR,AREA,AWID,ALEN,BWID,DELZ,EL,
        1          IELM,NELEM,XSAREA,VOL)
   C
   C     THIS SUBROUTINE CONSERVE THE GROSS CROSS-SECTINAL AREA  AS A FUNCTION
   C     OF DEPTH DURING THE CONVERSION OF THE REAL CROSS-SECTION TO ITS
   C     IDEALIZED RECTILINEAR SHAPE.
   C
         INCLUDE 'SY:ELMSIZ.PRM'
   C
         DIMENSION ABAR(MXELEM), AREA(MXELEM), AWID(MXELEM),
        1         BWID(MXELEM), EL(MXELEM), IELM(MXELEM),
        2         XSAREA(MXELEM)
   C
   C
         BLEN=1./ALEN
         ELTOP=DELZ
         WB=AREA(1)*BLEN
         BWID(1)=WB
         ARAB=(WB+AREA(2)*BLEN)*(EL(2)-EL(1))/2.
         ARBB=0.
         NB=1
   C
   C     DETERMINE LOCATION OF TOP NODE WITH RESPECT TO ORIGINAL DATA
   C
         DO(I=1,NELEM)
         .  DO(J=1,MXELEM-1)
         .  .  IF(ELTOP .GE. EL(J) .AND. ELTOP .LE. EL(J+1))
         .  .  .  EB=EL(J)
         .  .  .  ET=EL(J+1)
         .  .  .  WB=AREA(J)*BLEN
         .  .  .  WT=AREA(J+1)*BLEN
         .  .  .  NT=J
         .  .  .  IELM(I)=J
         .  .  .  GO TO 10
         .  .  ...FIN
         .  ...FIN
    10   .  CONTINUE
   C     .
   C     .  LINEARLY INTERPOLATE WIDTH AT ELEMENT'S TOP NODE
   C     .
         .  WTOP=WB + (ELTOP-EB)*(WT-WB)/(ET-EB)
   C     .
   C     .  ASSUME TRAPZOIDAL SHAPES TO FIND CROSS-SECTIONAL AREAS
   C     .
         .  ARAT=(WT+WTOP)*(ET-ELTOP)/2.
         .  ARBT=(WTOP+WB)*(ELTOP-EB)/2.
   C     .
   C     .  DETERMINE IF NEW ELEMENT SURFACES HAVE BEEN FOUND TO
   C     .  (A) LIE WITHIN A SINGLE DATA SET
   C     .  (B) LIE IN SEQUENTIAL DATA SETS, OR
   C     .  (C) BE SEPARATED BY ONE OR MORE DATA SETS
   C     .  FINALLY, FORM THE CROSS-SECTIONAL AREA
   C     .
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             .  INDIC=NT-NB
             .  IF(INDIC .EQ. 0) XSAREA(I)=ARBT-ARBB
             .  IF (INDIC .GE. 1) XSAREA(I)=ARBT+ARAB
             .  IF (INDIC .GE. 2)
             .  .  XBAR=0.
             .  .  DO(II=NB+1,NT-1)
             .  .  .  XBAR=XBAR+(AREA(II)+AREA(II+1))*(EL(II+1)-EL(II))*BLEN/2.
             .  .  ...FIN
             .  .  XSAREA(I)=XSAREA(I)+XBAR
             .  ...FIN
       C     .
       C     .  DETERMINE AVERAGE VERTICAL PROJECTION, AVERAGE WIDTH, REAL WIDTH,VOLUM
       C     .
             .  AWID(I)=XSAREA(I)/DELZ
             .  ABAR(I)=AWID(I)*ALEN
             .  BWID(I+1)=WTOP
             .  VOL=VOL+XSAREA(I)*ALEN
       C     .
       C     .  OVERWRITE INITIAL INFORMATION FOR NEXT ELEMENT
       C     .
             .  ELTOP=ELTOP+DELZ
             .  ARAB=ARAT
             .  ARBB=ARBT
             .  NB=NT
             ...FIN
             RETURN
             END

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      SUBROUTINE UPSDAT(ECHO, HLDERR, NUMERR, SIMLEN,UWID,UEL)
C
C   THIS ROUTINE IS RESPONSIBLE FOR READING THE UPSTREAM INFLOW
C   CONDITIONS TO SEGMENT 1. THE DATA IS READ FROM THE INPUT STREAM
C   (LUN 1) AND THEN WRITTEN TO "DUMMY.DT1' (LUN 2) FOR SUBSEQUENT
C   USE DURING THE SIMULATION.
C
C     FORMAL PARAMETERS:
C       ECHO   - LINE PRINTER ECHO OPTION CONTROL VARIABLE (L*1)
C       HLDERR - HOLDING ARRAY FOR ERROR NUMBERS (BYTE)
C       NUMERR - NUMBER OF INPUT ERRORS
C       SIMLEN - SIMULATION LENGTH (SECONDS - I*4)
C
C   CALLED BY: SERATRA
C   CALLS: PUTERR
C
      INCLUDE 'ELMSIZ.PRM'
C
      BYTE HLDERR(100)
C
      INTEGER*4 ENDTIM,PRETIM,SIMLEN
C
      LOGICAL*1 ECHO
C
      DIMENSION CCIN(MXELEM,MAXCON), UWID(MXELEM), UEL(MXELEM)
C
      REWIND 2
C
      IF (ECHO) WRITE(6,6)
C
C     .....UPSTREAM INFLOW CONDITIONS TO SEGMENT 1
C
      REPEAT UNTIL (ENDTIM .EQ. -9999)
C     .
C     .    RECORD ONE.....
C     . .    COL.  1-10...ENDTIM....ENDING TIME FOR DATA THAT FOLLOWS.
C     .                             A VALUE OF -9999 TERMINATES THE DATA.
C     .                             (SECONDS)
C     .          11-15...NM........NUMBER OF ELEMENTS
C     .       16-25...UDEPTH...ELEVATION OF FREE SURFACE ABOVE BED
C     .
      .  READ(1,5) ENDTIM, NM, UDEPTH
C     .
      .  IF(ENDTIM .NE. -9999)
C     .  .
C     .  .  RECORD TWO......WATER CONDITIONS. ONE CARD IS READ FOR EACH NODE.
C     .  .                 THE UNITS OF THE CONTAMINANT CONCENTRATIONS DEPEND
C     .  .                 UPON THE TYPE OF CONTAMINANT (RADIONUCLIDE..PC/KG
C     .  .                 OR PESTICIDE..KG/KG). THE PARAMETERS ARE READ IN
C     .  .                 THE FOLOWING ORDER:
C     .  .
C     .  .     PARAMETER 1...CONCENTRATION OF SAND (KG/M**3)
C     .  .               2...CONCENTRATION OF SILT (KG/M**3)
```

```
C     .  .              3...CONCENTRATION OF CLAY (KG/M**3)
C     .  .              4...CONCENTRATION OF CONTAMINANT ASSOCIATED WITH
C     .  .                  SAND
C     .  .              5...CONCENTRATION OF CONTAMINANT ASSOCIATED WITH
C     .  .                  SILT
C     .  .              6...CONCENTRATION OF CONTAMINANT ASSOCIATED WITH
C     .  .                  CLAY
C     .  .              7...CONCENTRATION OF DISSOLVED CONTAMINANT
C     .  .
      .  .  WHEN(NM .GT. 0)
      .  .  .  DO (I=1,NM)
      .  .  .  .  READ (1,1) (CCIN(I,K), K=1, MAXCON)
      .  .  .  ...FIN
      .  .  ...FIN
      .  .  ELSE
      .  .  .  NM=MXELEM
      .  .  .  READ (1,1) (CCIN(1,K), K=1, MAXCON)
      .  .  .  DO (I=2,NM)
      .  .  .  .  DO (K=1, MAXCON) CCIN(I,K)=CCIN(1,K)
      .  .  .  ...FIN
      .  .  ...FIN
      .  .  IF (ECHO)
      .  .  .  WRITE(6,4) ENDTIM
      .  .  .  WRITE(6,3)
      .  .  .  DO (I=1,NM)
      .  .  .  .  WRITE(6,2) I,(CCIN(I,K),K=1,MAXCON)
      .  .  .  ...FIN
      .  .  ...FIN
C     .  .
      .  .  WRITE(2) ENDTIM,NM,UDEPTH,((CCIN(I,K),K=1,MAXCON),I=1,NM)
      .  .  PRETIM = ENDTIM
      .  ...FIN
      ...FIN
      IF (PRETIM .LT. SIMLEN) CALL PUTERR(24, NUMERR, HLDERR)
C
      REWIND 2
C     RECORD THREE.....CHANNEL CROSS-SECTION DATA
C         .....UWID -- WIDTH OF SEGMENT AT NODES
C         .....UEL  -- ELEVATION OF NODE ABOVE BOTTOM
C*****************************************************************
C
C     CAUTION!
C     IF CONCENTRATIONS ARE INPUT AT VARIOUS DEPTHS,
C     THE CHANNEL CROSS-SECTIONAL DATA MUST BE INPUT
C     AT THOSE SAME DEPTHS.
C
C****************************************************************
      READ(1,7) NWID, UWIDTH, DEL
      WHEN (NWID.EQ.0)
      .  E=0.
      .  DO (I=1,MXELEM)
      .  .  UWID(I)=UWIDTH
      .  .  UEL(I)=E
      .  .  E=E+DEL
      .  ...FIN
      ...FIN
```

```
           ELSE
           .  READ(1,1) (UWID(I),I=1,NWID)
           .  READ(1,1) ( UEL(I),I=1,NWID)
           .  IF(NWID.LT.MXELEM)
           .  .  DO (I = NWID + 1,MXELEM)
           .  .  .  UWID(I) = UWIDTH
           .  .  .  UEL(I) = UEL(I-1) + DEL
           .  .  ...FIN
           .  ...FIN
           ...FIN
           IF(ECHO)
           .  WRITE(6,8) (I,UWID(I),I=1,MXELEM)
           .  WRITE(6,9) (I, UEL(I),I=1,MXELEM)
           ...FIN
     C
           RETURN
     C
         1 FORMAT(8F10.0)
        2  FORMAT(2X,I3,1X,6(3X,1PE12.5),4X,1PE12.5)
        3  FORMAT(1H0,'ELEMENT',1X,
          1  3(3X,'CONC. OF',4X),3(1X,'CONC. ASSOC.',2X),2X,'CONTAMINANT'/
          2  9X,'SUSPENDED SAND',1X,'SUSPENDED SILT',1X,'SUSPENDED CLAY',
          3  3X,'WITH SAND',6X,'WITH SILT',6X,'WITH CLAY',4X,'DISSOLVED '
          4  'CONC.')
        4  FORMAT(1H0,8X,I10,'...DATA SET ENDING TIME')
        5  FORMAT(I10,I5,F10.0)
        6  FORMAT(1H0,48X,'UPSTREAM INFLOW WATER CONDITIONS')
     7     FORMAT (I5,2F10.0)
     8     FORMAT (1H0,58X,'X-SECTION WIDTHS'/4(27X,5(I3,1PE12.5)/))
     9     FORMAT (1H0,58X,'X-SECTION ELEVATIONS'/4(27X,5(I3,1PE12.5)/))
     C
           END

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      SUBROUTINE WTRDAT(C, ECHO, NELEM)
C
C   THIS ROUTINE IS RESPONSIBLE FOR READING THE INITAL WATER CONDITIONS.
C
C     FORMAL PARAMETERS:
C       C     = INITIAL WATER CONDITIONS
C       ECHO  = LINE PRINT ECHO OPTION CONTROL VARIABLE (L*1)
C       NELEM = NUMBER OF VERTICAL ELEMENTS
C
C   CALLED BY: SERATRA
C
      INCLUDE 'ELMSIZ.PRM'
      LOGICAL*1 ECHO
        INTEGER SWITCH
C
      DIMENSION C(MXELEM,MAXCON)
C
C   ....INITAL WATER CONDITIONS
C
C     A SET OF INITIAL WATER CONDITIONS ARE READ FOR EACH NODE
C     OF THE SEGMENT (ELEMENTS ARE NUMBERED BEGINNING AT THE BOTTOM,
C     (ELEMENT 1), AND ENDING WITH THE SURFACE ELEMENT, (ELEMENT #NELEM)
C
C     IF THERE IS NO VERTICAL VARIATION, COLUMNS 1-5 CONTAIN A NEGATIVE
C     VALUE AND COLUMNS 6-15 CONTAIN THE CONSTANT VALUE. WHEN THE DATA
C     DOES VARY WITH DEPTH, A VALUE IS READ FOR EACH ELEMENT. THE UNITS
C     OF THE CONTAMINANT CONCENTRATIONS DEPEND UPON THE TYPE OF CONTAMIN
C     (RADIONUCLIDE..PC/KG OR PESTICIDE..KG/KG).
C
C                     THE UNITS OF THE CONTAMINANT CONCENTRATIONS DEPEND
C                     UPON THE TYPE OF CONTAMINANT (RADIONUCLIDE..PC/KG
C                     OR PESTICIDE..KG/KG). THE PARAMETERS ARE READ IN
C                     THE FOLOWING ORDER:
C
C        PARAMETER 1...CONCENTRATION OF SAND (KG/M**3)
C                  2...CONCENTRATION OF SILT (KG/M**3)
C                  3...CONCENTRATION OF CLAY (KG/M**3)
C                  4...CONCENTRATION OF CONTAMINANT ASSOCIATED WITH
C                      SAND
C                  5...CONCENTRATION OF CONTAMINANT ASSOCIATED WITH
C                      SILT
C                  6...CONCENTRATION OF CONTAMINANT ASSOCIATED WITH
C                      CLAY
C                  7...CONCENTRATION OF DISSOLVED CONTAMINANT
      DO(K=1,MAXCON)
      .  DO(J=1,MXELEM) C(J,K)=0.0
      ...FIN
C
C
      DO (K=1,MAXCON)
      .  READ(1,2) SWITCH,VALUE
      .  WHEN(SWITCH .LT. 0)
C     .  .  *** PARAMETER DOES NOT VARY VERTICALLY ***
```

```
           .  .  DO (J=1,MXELEM) C(J,K) = VALUE
           .  ...FIN
           .  ELSE
C          .  .  *** PARAMETER VARIES VERTICALLY ***
           .  .  READ(1,1) (C(J,K),J=1,NELEM+1)
           .  ...FIN
           ...FIN
           IF (ECHO)
           .  WRITE(6,3)
           .  WRITE(6,5)
           .  DO (J=1,NELEM+1)
           .  .  WRITE(6,4)J,(C(J,K),K=1,MAXCON)
           .  ...FIN
           ...FIN
C
           RETURN
C
1          FORMAT(8F10.0)
2          FORMAT(I5,F10.0)
3          FORMAT(1H0,52X,'INITIAL WATER CONDITIONS')
4          FORMAT(3X,I2,1X,6(3X,1PE12.5),4X,1PE12.5)
5          FORMAT(1H0,'ELEMENT',1X,
          1  3(3X,'CONC. OF',4X),3(1X,'CONC. ASSOC.',2X),2X,'CONTAMINANT'/
          2  9X,'SUSPENDED SAND',1X,'SUSPENDED SILT',1X,'SUSPENDED CLAY',
          3  3X,'WITH SAND',6X,'WITH SILT',6X,'WITH CLAY',4X,'DISSOLVED '
          4  'CONC.')
C
           END

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APPENDIX C

SAMPLE INPUT AND OUTPUT FOR SERATRA

INPUT

```
                 3 SEGMENTS             5 TIMESTEPS
            5     3     1FALSE3600.          0.0          0.0
6,4,1.0,0.1,0.36,4350.0,120.5,0.5,121.0,                                SEGMENT 1 PARAMETERS
7,1.67E+6,1.22                                                          CROSS-SECTIONAL GEOMETRY
2.32E+5,7.03E+5,9.68E+5,1.16E+6,1.35E+6,1.51E+6,1.67E+6
0.0,1.22,2.44,3.66,4.88,6.10,7.32
1.0E-3,1.0E-5,1.0E-6,                                                   FALL VELOCITY
2650.0,2650.0,2650.0                                                    PARTICLE DENSITY
1.0E-3,3.0E-5,2.0E-6,2.5E-3,                                            PARTICLE DIAMETER
1.0,2.0,3.0                                                             CRITICAL SCOUR SHEAR STRESS
0.50,0.10,0.01                                                          CRITICAL DEPOSITION SHEAR STRESS
1.74E-6,1.74E-6,1.74E-6,
6.0E-3,6.0E-3,6.0E-3,6.0E-3
0.25,1.25,2.50,1.16E-5,1.16E-5,1.16E-5,0.0,0.0,
0.0,
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OUTPUT

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RIVER SEGMENT NUMBER:                         1
TIME STEP NUMBER:                             1
ELAPSED TIME:                           3600,00
DATUM:                                 120,5000
NUMBER OF ELEMENTS:                           5
STANDARD ELEMENT THICKNESS:      1,1880000E+00
NUMBER OF BED LAYERS:                         4
STANDARD BED LAYER THICKNESS:    1,0000000E-01
TOP LAYER THICKNESS:             5,9991665E-02
SHEAR STRESS VALUE:              4,5688120E-01


                                                      WATER CONCENTRATIONS


            SUSPENDED    SUSPENDED    SUSPENDED     DISSOLVED    CONTAMINANT CONTAMINANT CONTAMINANT     TOTAL        TOTAL
ELEVATION     SAND         SILT         CLAY       CONTAMINANT    WITH SAND   WITH SILT   WITH CLAY    PARTICULATE     CONC.
(METERS)    KG/M**3      KG/M**3      KG/M**3       KG/M**3       KG/M**3     KG/M**3     KG/M**3       KG/M**3      KG/M**3
 126,8000  1,2116E-03  5,9570E-03  1,9960E-03  1,4203E-06  3,4577E-09  1,0543E-07  7,0654E-08  1,7954E-07  1,5999E-06
 125,6120  1,5810E-03  5,9446E-03  1,9874E-03  1,4140E-06  4,6067E-09  1,0521E-07  7,0346E-08  1,8016E-07  1,5942E-06
 124,4240  2,3599E-03  6,0093E-03  2,0020E-03  1,4242E-06  7,2072E-09  1,0636E-07  7,0863E-08  1,8443E-07  1,6087E-06
 123,2360  2,7776E-03  6,0100E-03  1,9990E-03  1,4222E-06  8,5087E-09  1,0637E-07  7,0759E-08  1,8563E-07  1,6078E-06
 122,0480  3,7909E-03  6,0918E-03  2,0193E-03  1,4363E-06  1,1872E-08  1,0782E-07  7,1470E-08  1,9117E-07  1,6274E-06
 120,8600  4,6585E-03  6,1447E-03  2,0326E-03  1,4455E-06  1,4647E-08  1,0875E-07  7,1950E-08  1,9535E-07  1,6408E-06


                                                       BED CONCENTRATIONS


              SAND WEIGHT      SILT WEIGHT      CLAY WEIGHT      CONTAMINANT      CONTAMINANT      CONTAMINANT        AVERAGE
ELEVATION      FRACTION         FRACTION         FRACTION         WITH SAND        WITH SILT        WITH CLAY          CONC.
(METERS)                                                            KG/KG            KG/KG            KG/KG            KG/KG
 120,8600   8,5998058E-01    1,2001666E-01    2,0002777E-02    0,0000000E-01    0,0000000E-01    0,0000000E-01    0,0000000E-01
 120,8000   8,6000001E-01    1,2000000E-01    2,0000000E-02    0,0000000E-01    0,0000000E-01    0,0000000E-01    0,0000000E-01
 120,7000   8,6000001E-01    1,2000000E-01    2,0000000E-02    0,0000000E-01    0,0000000E-01    0,0000000E-01    0,0000000E-01
 120,6000   8,6000001E-01    1,2000000E-01    2,0000000E-02    0,0000000E-01    0,0000000E-01    0,0000000E-01    0,0000000E-01


                                             CONTAMINANT ASSOCIATED WITH SEDIMENT


                               CONTAMINANT CONTAMINANT CONTAMINANT    AVERAGE
                     ELEVATION  WITH SAND   WITH SILT   WITH CLAY      CONC.
                     (METERS)     KG/KG       KG/KG       KG/KG        KG/KG
                      126,8000  2,8533E-06  1,7699E-05  3,5397E-05  1,9590E-05
                      125,6120  2,9138E-06  1,7698E-05  3,5397E-05  1,8939E-05
                      124,4240  3,0541E-06  1,7698E-05  3,5397E-05  1,7783E-05
                      123,2360  3,0634E-06  1,7698E-05  3,5397E-05  1,7210E-05
                      122,0480  3,1316E-06  1,7699E-05  3,5397E-05  1,6062E-05
                      120,8600  3,1442E-06  1,7699E-05  3,5397E-05  1,5219E-05
```

```
                    INTEGRATED VALUES OF TOTAL MASS OR CONTAMINANT IN EACH ELEMENT

         SUSPENDED    SUSPENDED    SUSPENDED    CONTAMINANT CONTAMINANT CONTAMINANT   DISSOLVED
ELEMENT    SAND         SILT         CLAY        WITH SAND   WITH SILT   WITH CLAY   CONTAMINANT
            KG           KG           KG            KG          KG          KG           KG
   0     1.3980E+04   3.5552E+04   1.1849E+04   4.2512E-02  6.2921E-01  4.1942E-01  8.4299E+00
   1     2.3407E+03   9.9748E+03   3.3365E+03   6.7588E-03  1.7654E-01  1.1817E-01  2.3755E+00
   2     2.4969E+03   8.7674E+03   2.9326E+03   8.6849E-03  1.5552E-01  1.0380E-01  2.0864E+00
   3     3.2082E+03   7.5057E+03   2.4985E+03   9.8142E-03  1.3284E-01  8.8440E-02  1.7775E+00
   4     3.2189E+03   5.9305E+03   1.9692E+03   9.9874E-03  1.0496E-01  6.9704E-02  1.4008E+00
   5     2.5153E+03   3.3531E+03   1.1103E+03   7.2669E-03  5.9345E-02  3.9303E-02  7.8967E-01

                      FLUX OF SEDIMENT MASS OR CONTAMINANT INFLUENT TO ELEMENT

         SUSPENDED    SUSPENDED    SUSPENDED    CONTAMINANT CONTAMINANT CONTAMINANT   DISSOLVED
ELEMENT    SAND         SILT         CLAY        WITH SAND   WITH SILT   WITH CLAY   CONTAMINANT
            KG           KG           KG            KG          KG          KG           KG
   0     7.3397E+03   2.2019E+04   7.3397E+03   2.5982E-02  3.8974E-01  2.5982E-01  5.2112E+00
   1     2.2909E+03   6.8727E+03   2.2909E+03   6.1098E-03  1.2165E-01  8.1098E-02  1.6265E+00
   2     1.9277E+03   5.7832E+03   1.9277E+03   6.8242E-03  1.0236E-01  6.8242E-02  1.3687E+00
   3     1.5345E+03   4.6036E+03   1.5345E+03   5.4322E-03  8.1483E-02  5.4322E-02  1.0895E+00
   4     1.0517E+03   3.1550E+03   1.0517E+03   3.7229E-03  5.5844E-02  3.7229E-02  7.4669E-01
   5     5.3485E+02   1.6045E+03   5.3445E+02   1.8930E-03  2.8400E-02  1.8934E-02  3.7974E-01

                      FLUX OF SEDIMENT MASS OR CONTAMINANT EFFLUENT FROM ELEMENT

         SUSPENDED    SUSPENDED    SUSPENDED    CONTAMINANT CONTAMINANT CONTAMINANT   DISSOLVED
ELEMENT    SAND         SILT         CLAY        WITH SAND   WITH SILT   WITH CLAY   CONTAMINANT
            KG           KG           KG            KG          KG          KG           KG
   0     7.7682E+03   2.2009E+04   7.3376E+03   2.5402E-02  3.8954E-01  2.5974E-01  5.2150E+00
   1     1.9874E+03   6.9928E+03   2.3357E+03   6.5021E-03  1.2377E-01  8.2679E-02  1.6601E+00
   2     1.9414E+03   5.8562E+03   1.9532E+03   6.3500E-03  1.0365E-01  6.9141E-02  1.3882E+00
   3     1.7710E+03   4.6554E+03   1.5508E+03   5.7906E-03  8.2398E-02  5.4895E-02  1.1022E+00
   4     1.4304E+03   3.2621E+03   1.0853E+03   4.6749E-03  5.7736E-02  3.8416E-02  7.7127E-01
   5     6.3801E+02   1.2421E+03   4.1265E+02   2.0847E-03  2.1988E-02  1.4607E-02  2.9323E-01
```

```
                         INTEGRATED VALUES OF TOTAL MASS OR CONTAMINANT IN THE BED

        ELEMENT     SAND WEIGHT     SILT WEIGHT     CLAY WEIGHT     CONTAMINANT     CONTAMINANT     CONTAMINANT
                                                                     WITH SAND       WITH SILT       WITH CLAY
                        KG              KG              KG              KG              KG              KG
           1       1.3859277E+07   2.2132798E+06   3.6887991E+05   0.0000000E-01   0.0000000E-01   0.0000000E-01
           2       2.6436398E+07   3.6887997E+06   6.1479994E+05   0.0000000E-01   0.0000000E-01   0.0000000E-01
           3       2.6436398E+07   3.6887997E+06   6.1479994E+05   0.0000000E-01   0.0000000E-01   0.0000000E-01
           4       2.6436398E+07   3.6887997E+06   6.1479994E+05   0.0000000E-01   0.0000000E-01   0.0000000E-01

(1)  OLDC + INFLUENT - EFFLUENT
(2)  NEWC - (1)
(3)  NEWBED = SUMMATION (W(I,J)*VOLUME*DENSITY)
(4)  NEWBED - OLDBED + (2)

        SAND            SILT            CLAY           W/SAND          W/SILT          W/CLAY         DISSOLVED   TOTAL CONTAMINANT
         KG              KG              KG              KG              KG              KG              KG              KG
   1.1418569E+04   3.5551523E+04   1.1649160E+04   4.2518605E-02   6.2927920E-01   4.1947168E-01   8.4075775E+00   9.4988470E+00
   2.5614961E+03   1.5625000E-02  -3.9062500E-03  -6.8135560E-06  -7.2240829E-05  -4.8364169E-05   2.2356311E-02   2.2222688E-02
   9.9168472E+07   1.3279679E+07   2.2132798E+06   0.0000000E-01   0.0000000E-01   0.0000000E-01                   0.0000000E-01
   1.4560547E+00   1.5625000E-02  -2.5390625E-01  -6.8135560E-06  -7.2240829E-05  -4.8364169E-05                   2.2222888E-02
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16. ABSTRACT *(200 words or less)*

SERATRA, a transient, two-dimensional (laterally-averaged) computer model of sediment-contaminant transport in rivers, satisfactorily resolved the distribution of sediment and radionuclide concentrations in the Cattaraugus Creek stream system in New York. By modeling the physical processes of advection, diffusion, erosion, deposition, and bed armoring, SERATRA routed three sediment size fractions, including cohesive soils, to simulate three dynamic flow events. In conjunction with the sediment transport, SERATRA computed radionuclide levels in dissolved suspended sediment, and bed sediment forms for four radionuclides (^{137}Cs, ^{90}Sr, ^{239,240}Pu, and ^{3}H). By accounting for time dependent sediment-radionuclide interaction in the water column and bed, SERATRA is a physically explicit model of radionuclide fate and migration. Sediment and radionuclide concentrations calculated by SERATRA in the Cattaraugus Creek stream system are in reasonable agreement with measured values.

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