COMPUTER SIMULATION PROGNOSIS FOR THE DEGRADATION OF THE MISSOURI RIVER BETWEEN GAVINS POINT DAM AND IOWA'S SOUTHERN BORDER

by

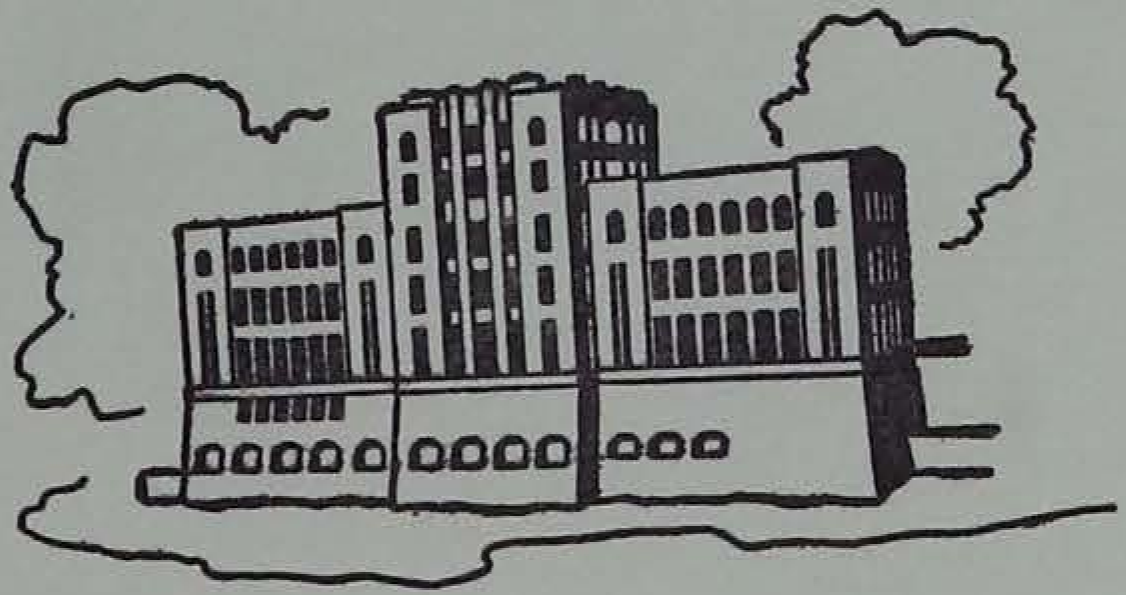
F. M. Holly Jr. and M. F. Karim

Sponsored by
Iowa State Water Resources Research Institute
355 Town Engineering Building
Ames, Iowa 50011

Office of Water Resources Technology
Project No. C-001-IA
Agreement No. 14-34-0001-2117

ISWRRI-135

IIHR Report No. 267



Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa 52242

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Executive Summary

The bed of the Missouri River between Gavins Point Dam and Omaha has undergone extensive bed degradation since 1950. This scouring has had severe consequences, including potential undermining of structures, loss of wildlife habitat, and lowering of the water table with associated increased pumping costs and dropping of water levels in oxbow lakes used for recreation.

River bed degradation is a complex process which, before the advent of the computer and associated computational-hydraulics techniques, was not subject to rational, deterministic analysis. However, now that such techniques are available, it has become possible to simulate long term river bed evolution in response to changed river geometry, hydrologic regime, and sediment supply. The IALLUVIAL computer program, developed in 1981-82 at the Iowa Institute of Hydraulic Research, has been applied in previous studies to simulation of the past twenty years of Missouri River bed degradation.

The success of IALLUVIAL in reproducing past bed degradation laid the groundwork for the present study, whose goals included modification of IALLUVIAL to treat more realistic river conditions, including tributaries, bank erosion, and vertical nonhomogeneity of bed sediments, and then use of the improved version of IALLUVIAL to simulate bed degradation over the next twenty years, 1980-2000. These prognosis simulations, performed for various hypothetical scenarios of river management, showed the sensitivity of Missouri River bed degradation to geometric, hydrologic, and sediment variables, and furnished indications of the expected pattern of future degradation.

The simulations of this study suggest that the worst of the degradation is over. An additional three to four feet might be expected, but the rate of degradation is decreasing, as the river approaches a new equilibrium between

sediment supply and transport capacity. Prognosis runs assuming a wider channel suggest that it is primarily the channelization of the Missouri, rather than the shut-off of sediment supply at Gavins Point Dam, which is responsible for the severe degradation. Other runs suggest that further modulation of Gavins Point Dam water releases could reduce ultimate degradation by about one foot.

Application of IALLUVIAL to this prototype problem has made it possible to identify several areas of the methodology which need further development and refinement. The simulations have also clearly demonstrated the importance of collecting bed sediment size distribution data which includes as much detail as possible on the coarser size fractions, as these fractions play a critical role in limiting the rate and ultimate extent of degradation.

ACKNOWLEDGEMENTS

This study was performed under a grant from the Iowa State Water Resources Research Institute (ISWRRI), Office of Water Resources Technology Project No. C-001-IA, Agreement No. 14-34-0001-2117. Grateful acknowledgement is extended to Dr. A. Austin, Director of ISWRRI, and to the ISWRRI Council, for having selected this project for support.

Appreciation is expressed to the members of the Advisory Panel for this study, who provided helpful suggestions and guidance in data acquisition and the formulation of prognosis scenarios. The Panel, whose members are listed below, met at the Insitute of Hydraulic Research on 23 September 1982, 11 January 1983, and 19 April 1983; in addition, Panel members received draft copies of this report for review.

Much of the data used in this study were obtained with the help of the U.S. Army Corps of Engineers, Omaha District. Mr. Wayne Dorough and his staff have been particularly helpful in this respect.

The IALLUVIAL computer program was originally developed with the support of the National Science Foundation and the Omaha District, U.S. Army Corps of Engineers. The Omaha District has continued to support the refinement of IALLUVIAL; the addition of tributaries, bank erosion, and vertical variation of bed material composition, described in Sections II.G and II.H of this report, was jointly supported by this study and the Omaha District. Messrs. Wayne Dorough, Ken Murnan, and John LaRandeau of the Omaha District, and Messrs. Warren Mellema and Tsong Wei of the Missouri River Division, Corps of Engineers, have been most helpful in reviewing the development of IALLUVIAL and providing technical input.

Mr. Inmula Prasad, graduate student at The University of Iowa, handled most of the data reduction and computer operations. The Graduate College of The University of Iowa provided a portion of the computer funds used.

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TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

Page

LIST OF TABLES

I. INTRODUCTION

The history of the channel changes which have been experienced by Iowa's reach of the Missouri River since the closure of Gavins Point Dam, in 1955, is so well known that it is not necessary to recount it here. The interested reader can obtain an overview of the channel changes and their consequences from Chapters 2 and 3 of Reference 6. The problems attendant to river degradation that have emerged to date include, among others, loss of wildlife habitat, loss of public lands, difficulty in diverting water during low flows, falling ground-water levels, shrinking ox-bow lakes, and loss of foundation support for bridge piers and shoreline structures. It is to be expected that after a major alteration of the hydraulic, hydrologic, and sedimentary regimes of a river, such as resulted from navigation channel narrowing and the closure of Gavins Point Dam, the affected river channel eventually will reach a new equilibrium. However, the time scale of the approach to equilibrium is not known, and therefore considerable uncertainty surrounds the future of Missouri River channel changes. Has equilibrium been nearly attained? Or is the degradation in its early or intermediate stages? The economic, environmental, and other consequences of further degradation are enormous, and therefore an accurate prediction of the future rates, amounts, and spatial distribution of channel degradation would be invaluable in planning the future utilization and management of the Missouri River.

The responses of a river to major alterations in its hydraulic and hydrologic regime and virtually complete curtailment of its sediment supply involve so many complex factors that accurate prediction of the morphology of disturbed streams cannot be approached by means of classical mathematical analysis. Moreover, the time periods (typically decades) involved are so great and the affected channel reaches so long (often hundred of miles) that recourse to physical, laboratory modelling is out of the question. As a result, prediction of channel changes downstream from reservoirs heretofore have generally been made on the basis of either highly simplified analyses or "engineering judgment". Neither has been particularly reliable, and the resultant misleading predictions have given rise in numerous instances to extremely expensive problems. Furthermore, because of the highly individualistic character of each river, experience gained with others has not been particularly helpful. The recent development of computer-based numerical-simulation techniques, which permit faithful mathematical modelling of the numerous, complex, interrelated factors constituent to river-channel changes is making it possible to produce surprisingly accurate predictions of long-term river-channel changes. The Institute of Hydraulic Research recently completed development of such a model, named IALLUVIAL, which was especially designed for the Missouri River. Funding for development of IALLUVIAL was provided by the National Science Foundation and the U.S. Army Corps of Engineers' Omaha District. In the course of its development, an extensive study was made of the sediment-transport and friction-factor characteristics of the Missouri River, and a new, analytically based, predictive formulation for these key elements of any flow- and sediment-routing model was incorporated into IALLUVIAL. These features are described in References 4 and 5. Reference 5 in particular documents the agreement that has been achieved between observed and predicted Missouri River water-surface changes during the 20-year period following closure of Gavins Point Dam.

The Corps of Engineers Contract under which IALLUVIAL was produced called for development of its constituent components (sediment-discharge predictor by size fraction, friction-factor predictor, bed-armoring model, and flow- and sediment-routing subroutines); their synthesis into a skeletal computer program which could be used to make preliminary evaluations of the capability and reliability of the program; and for conduct of a few "postdictive" computer runs to demonstrate that even the skeletal model could reproduce, at least qualitatively, the changes that have been observed.

The primary objectives of the present research project were refinement of IALLUVIAL to incorporate channel and flow features not included in its development under the Corps contract; further verification of its predictive capabilities, and calibration of its key constituent parts against field data; and, most important, utilization of the refined version of IALLUVIAL to obtain predictions of the anticipated future degradation of the Missouri River upstream from Iowa's southern border. These aspects are described in greater detail below.

1. Refinement of IALLUVIAL. The first version of IALLUVIAL did not include detailed variations of channel width, bed-material size, and river slope along the study reach. Instead, because of limited time and funding, the study reach was broken down into four separate reaches, each of which was treated as having uniform width, initial bed material size, and slope. It is likely that no river reach of comparable length has been studied more intensively that the Missouri River along Iowa's boundary, and a wealth of data has been accumulated and is on file at the Institute of Hydraulic Research. Additional detail incorporated into IALLUVIAL would permit it to more faithfully reproduce observed and expected river behavior. More detail concerning channel width and historical streamwise and vertical (subsurface) sediment-size distributions would be used.

2. Sediment Inputs. In its original form, IALLUVIAL did not include sediment contributions from bank erosion or from tributaries. The capability to do so had been programmed, but time and funding limitations did not permit the extensive data analysis required to include the sediment inflows and their effects. It was judged to be important to include these features, because they represent the major sources of fine sediment entering the Missouri River below Gavins Point Dam.

3. Improvement of Coding. It is invariably the case that in the course of developing a complex computer program, changes are made and additions are incorporated on an as-needed basis. There comes a time when it is in order to reprogram much of the code, with extensive commenting, to facilitate future use of the program and to reduce computer-time and memory requirements. IALLUVIAL had reached that stage, and this activity was pursued under the present project.

4. Predictive Simulations. The principal activity to be pursued under this project was the conduct of a number of predictive, simulation runs to provide a prognosis for the future course of Missouri River channel changes along Iowa's border. The first runs were to be directed toward determining the expected time scale of the process, to answer questions concerning the length of time required for the river to reach its new equilibrium. Other detailed simulation runs were to be made to and beyond this date to provide predictions of the temporal and spatial distributions of future Missouri River changes for different hydrologic and river-management scenarios. The results of these computer simulations were to provide projections of the future temporal and spatial changes in river-bed elevation, water-surface elevation for different discharges, bed-material-size distribution, and degree of bed armoring. Additionally, simulation runs were to be made to examine the effectiveness of any proposed (by the State of Iowa, the Corps of Engineers, or others) measures which might be taken to retard degradation, as suggested by the Advisory Panel for the study (see Acknowledgements).

The goal of this project was to develop a reliable predictive tool which could be updated in the future and used to examine the consequences to the river's channel and flow regime of practically any proposed modifications to its inputs or geometry.

II. IALLUVIAL COMPUTER PROGRAM

II.A. General Remarks. IALLUVIAL is a computer-based flow- and sediment-routing model for simulation of the long-term bed evolution of alluvial streams. It treats the flow as one-dimensional and quasi-steady, solving the following governing equations:

1. Equation of motion of water flow;
2. Equation of continuity for water flow;
3. A friction-fractor equation that takes into account the variable roughness of sediment-transporting streams;
4. Equation for sediment discharge;
5. Equation of continuity for sediment.

A river reach is divided into subreaches, and the computations for each are performed for successive, discrete time intervals. In each time interval, IALLUVIAL solves the governing equations in two steps: the relations in 1 through 4 above are solved in the first "backwater" step to obtain water-surface elevation, depth, velocity, and sediment discharge at each computational point; in the second step, the sediment continuity equation is solved to yield depths of degradation/aggradation, changes in bed-material composition, and changes in armoring of the bed surface. The initial and boundary conditions required for a solution are: known initial bed elevation and sediment size distribution at all computation points; known water and sediment discharge hydrographs at the upstream limit of the model; and a known stage (water-surface elevation) hydrograph, or discharge-stage relationship, at the downstream limit of the model.

For a detailed description of the principal features of IALLUVIAL, reference is made to the IIHR (Iowa Institute of Hydraulic Research) Report No. 250 prepared in August, 1982 under the sponsorship of the U.S. Army Corps of Engineers, Omaha District (5). A brief review of these features, plus the modifications and additions to the original porgram incorporated under the scope of the present study, are presented in the following sections.

II.B. Sediment-discharge and friction-factor predictors.

The Total-Load Transport Model (TLTM) developed by Karim and Kennedy (4) is used for the sediment-discharge and friction-factor predictors. The formulation of TLTM takes into account the well-known fact that the friction factors of alluvial streams are heavily dependent on their sediment discharges, and avoids the need to specify a fixed hydraulic roughness, such as Manning's coefficient, *a priori*. In keeping with this concept, the friction-factor relation includes sediment discharge as one of the independent variables, and an iteration scheme is used to calculate sediment discharge and friction factor from the following pair of simultaneous relations:

Sediment-discharge predictor

$$\mathrm{Log}\left(\frac{q_s}{\sqrt{g(s-1)\,D_{50}^3}}\right) = -2.2786 + 2.9719\ \mathrm{Log}\ V_1 + 1.0600\ \mathrm{Log}\ V_1\ \mathrm{Log}\ V_6$$

$$+ 0.2989\ \mathrm{Log}\ V_2\ \mathrm{Log}\ V_6 \qquad (1)$$

Friction-factor predictor

$$\text{Log}\left(\frac{U}{\sqrt{g\,(s-1)\,D_{50}}}\right) = 0.9045 + 0.1665\ \text{Log}\ V_7$$

$$+\ 0.0831\ \text{Log}\ V_4\ \text{Log}\ V_5\ \text{Log}\ V_7 + 0.2166\ \text{Log}\ V_4\ \text{Log}\ V_5$$

$$-\ 0.0411\ \text{Log}\ V_2\ \text{Log}\ V_3\ \text{Log}\ V_4 \qquad (2)$$

where

$$V_1 = \frac{U}{\sqrt{g\,(s-1)\,D_{50}}},\ V_2 = \frac{d}{D_{50}},\ V_3 = S \cdot 10^3,\ V_4 = \frac{u_*}{w}$$

$$V_5 = \frac{wD_{50}}{\nu},\ V_6 = \frac{u_* - u_{*c}}{\sqrt{g\,(s-1)\,D_{50}}},\ V_7 = \frac{q_s}{\sqrt{g\,(s-1)\,D_{50}^3}}$$

q_s = volumetric bed-material discharge/unit width

U = mean flow velocity

d = mean flow depth

D_{50} = median size of bed material

S = energy slope

w = fall velocity of sediment particles

ν = kinematic viscosity of water

s = specific gravity of sediment particles

u_* = bed shear velocity = $\sqrt{gdS}$

u_{*c} = critical shear velocity obtained from Shields' diagram

The numerical coefficients of Eqs. (1) and (2) were obtained through nonlinear regression analysis of extensive field and laboratory data (4).

II.C. **Water-surface-profile calculations.** Computations for sediment discharge and water surface profile in one time interval proceed simultaneously, because of the interdependence between friction factor and sediment discharge incorporated in Eqs. (1) and (2). Starting from a known or specified water-surface elevation at the downstream end, the calculation scheme solves simultaneously Eqs. (1), (2), and the steady-state continuity and energy equations of flow, by an iteration scheme analogous to the standard step method for backwater computations. This procedure calculates depth, velocity, energy slope, and sediment discharge at successive upstream sections in a single computational sweep, downstream to upstream.

II.D. **Change in bed elevation.** The depth of degradation or aggradation in a subreach of length Δx during a time interval Δt is calculated by applying the sediment-continuity equation between the two bounding computation points,

$$(1-p)\frac{\partial z}{\partial t} + \frac{\partial q_s}{\partial x} = 0 \tag{3}$$

where p = porosity, and z = bed elevation. Equation (3) may be discretized to calculate the change in bed elevation for a reach, Δz, from

$$\Delta z = \frac{(q_s)_i - (q_s)_{i+1}}{(1-p)} \frac{\Delta t}{\Delta x} \tag{4}$$

in which $(q_s)_i$ and $(q_s)_{i+1}$ are sediment-transport capacities per unit width at downstream and upstream ends of the subreach respectively. A positive value of Δz indicates degradation when $(q_s)_i > (q_s)_{i+1}$, i.e., a deficit in sediment-transport capacities exists between the downstream and upstream sections of the subreach. When $(q_s)_i < (q_s)_{i+1}$, Δz is negative, and its absolute value gives the depth of aggradation in the subreach. In the present version of IALLUVIAL, the entire wetted perimeter is shifted up or down by Δz.

II.E. **Changes in bed-material composition.** The composition of an alluvial river bed undergoes continuous change in response to degradation or aggradation occurring due to imbalance in sediment transport capacities at the two ends of a reach. The depths (or volumes) of sediments of each size fraction scoured from or deposited in a reach are determined by applying the sediment continuity equation by size fraction. The fraction of sediment discharge in size interval k and reach i, $P_{di,k}$, is calculated from the relation given by Karim and Kennedy (4):

$$P_{di,k} = \frac{P_{i,k} \left(\frac{D_{50i}}{D_k}\right)^x}{\sum_{k=1}^{m} P_{i,k}\left(\frac{D_{50}}{D_k}\right)^x} \tag{5}$$

where $P_{i,k}$ = fraction of size interval k in bed material of reach i; D_{50i} = median bed-material size in subreach i; D_k = geometric mean size of fraction k; m = total number of sediment size intervals; and x is given by

$$x = 0.0316 \left(\frac{d_i}{D_{50i}}\right)^{0.5} \tag{6}$$

where d_i = average flow depth in subreach i.

The size distribution of the bed sediments is updated at the end of each time interval by taking out the calculated depths of degradation from, or adding the deposited volumes to, the mixed layer, and then accounting for the proportionate change in each sediment size interval. The horizon of bed material immediately below the bed surface undergoing continual mixing due to agitation, overturning, bed-form migration, etc. is referred to herein as the mixed layer, and is assumed to have a thickness equal to the average bed-form (or dune) height and to be homogeneous in size distribution at any given time. The dune height H_d, is estimated from the following relation (1):

$$H_d = d\left[b_o + b_1 \left(\frac{\theta}{3}\right) + b_2\left(\frac{\theta}{3}\right)^2 + b_3 \left(\frac{\theta}{3}\right)^3 + b_4 \left(\frac{\theta}{3}\right)^4\right] \tag{7}$$

where θ = non-dimensional bed-shear stress; b_o = 0.079865, b_1 = 2.23897, b_2 = -18.1264, b_3 = 70.9001, and b_4 = - 88.3293. This relation accounts for both the growth and decay of bed-form heights with variation in bed-shear stresses.

II.F. **Bed armoring.** In a degrading river, the finer sediment particles are transported preferentially from the bed, resulting in gradual coarsening of the bed surface. If the bed material contains sediments which are sufficiently large that they cannot be transported by the flow, then coarser particles gradually accumulate on the bed surface forming an "armor coat" which protects the underlying finer sediments which would otherwise be transported. The fraction of the bed surface, A_f, covered by these immobile sediment particles is expressed by the following relation, developed from volumetric considerations:

$$A_f(t) = C_1\,(1-p)\,d_s(t) \sum_{k=l}^{m} \frac{P_k}{D_k} \tag{8}$$

where p = porosity; $d_s(t)$ = depth of degradation to time t; P_k = fraction of bed material with size D_k; l = sediment-size interval containing the smallest size which remains immobile on the bed; and C_1 = constant determined by the shape of the particles and their array on the bed. C_1 = 1.90 for ellipsoidal particles of shape factor 0.70 laying flat in a one-diameter-thick armor layer.

Bed armoring plays an important role in restoring balance between the sediment-transport capacity of the flow and the reduced sediment-supply rate into a reach. Armoring assists the river in seeking a new equilibrium by reducing sediment discharge and also by changing the hydraulic roughness. It is assumed in the present study that sediment discharge is reduced in direct proportion to the fraction of the bed surface that is armored (A_f). Similarly, the friction factor is taken equal to a weighted average of the fixed-bed roughness for the armored portion (A_f) and the movable bed roughness ($1 - A_f$). The thickness of the mixed layer is assumed to decrease linearly with increasing armoring of the bed surface.

II.G. **Variation of bed material with depth.** For a river degrading into its alluvium, the rate of degradation and its ultimate value are greatly influenced by the composition of underlying materials encountered by the degrading river bed. Underlying coarser materials result in increased coarsening of bed material and armoring of the bed surface, reducing both the time scale of evolution and the final depth of degradation; the reverse is true in the case of underlying finer materials. Variation in the composition of subsurface materials has been accounted for in IALLUVIAL as part of this study, by defining different layers of subsurface sediments (each layer defined by its thickness and sediment size distribution) below the initial bed elevation at the start of the simulation, as shown in Figure II.1. The thickness of each layer, (t_L), and size distribution of each layer $P_{i,k,L}$ are

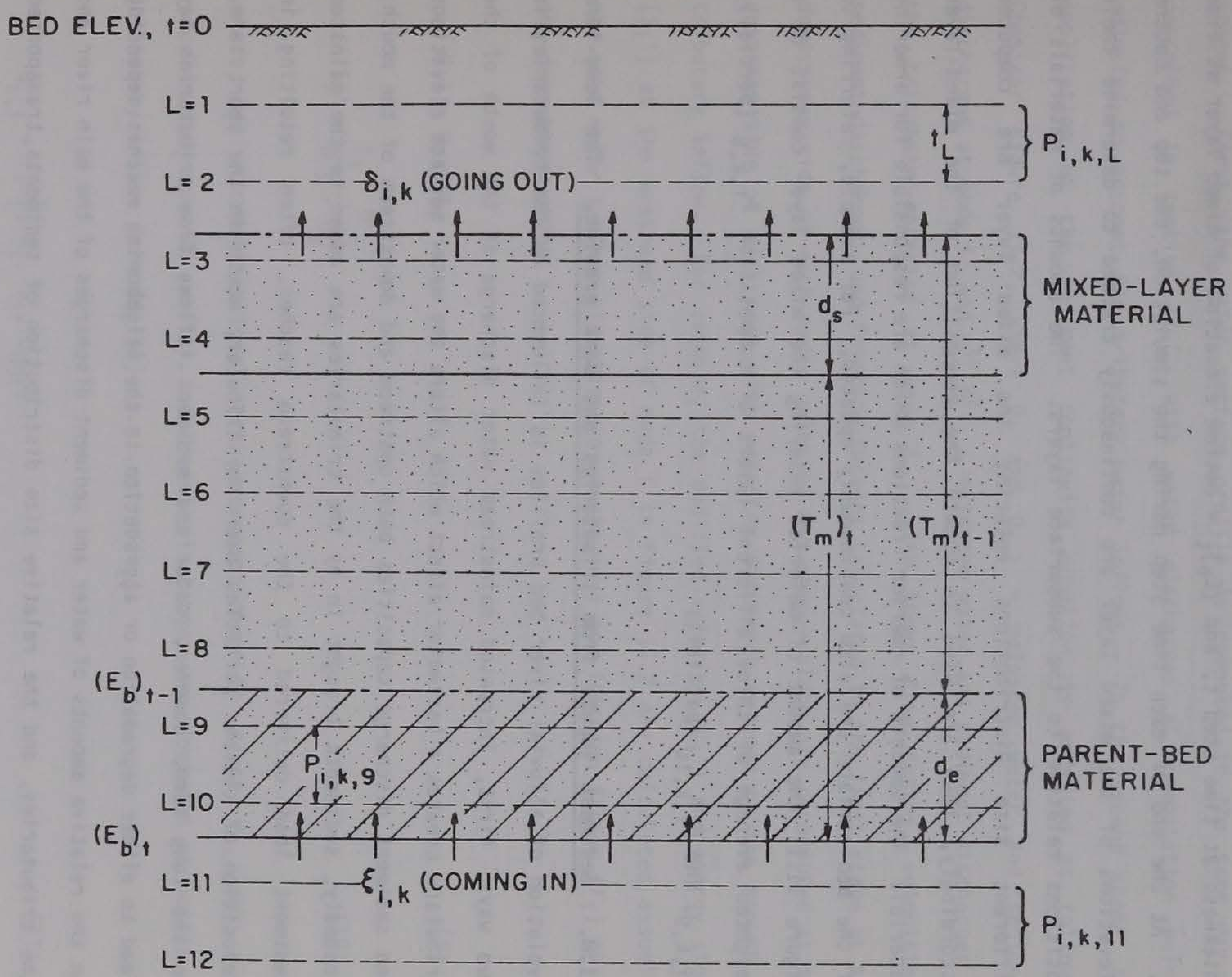


Figure II.1 Subsurface Layers and Mixed Layer Composition defined as shown; other quantities shown in this figure are: d_s = depth of degradation, d_e = depth of materials entering mixed layer, $(T_m)_t$ = mixed-layer thickness at time step t, and $(E_b)_t$ = bottom elevation of mixed layer at time t. At the end of each time step during the simulation, the top and bottom elevations of the mixed layer are continuously tracked to determine their positions relative to the subsurface layers. The amounts of materials of different size distributions entering the mixed layer are computed accordingly, then are used to update the composition of the mixed-layer material. The amounts of coarser fractions which are responsible for armoring of the bed surface are also continuously updated. For example, referring to Figure II.1, the amount of material entering the mixed layer consist of a weighted average of three different layers of composition $P_{i,k,8}$ (partial), $P_{i,k,9}$, and $P_{i,k,10}$ (partial).

II.H. **Sediment inputs from tributaries and bank erosion.** The long-term evolution of alluvial river bed profiles is influenced by the tributaries in two ways: first, increased mainstream water discharge at the mouth of the tributary creates a backwater effect which alters the water surface elevations and sediment discharge capacities both upstream and downstream of the mouth; secondly, sediments brought in by the tributaries are added to the mainstem sediment load delivered to the downstream reaches, often resulting in deposition of coarser particles near the tributary mouth in the short term. In the long term, however, water and sediment inflows from tributaries may lead to either degradation or aggradation in the neighboring reaches depending on the relative amounts of water and sediment discharges of the main river and the tributaries, and the relative size distribution of sediments transported by the main river and tributaries.

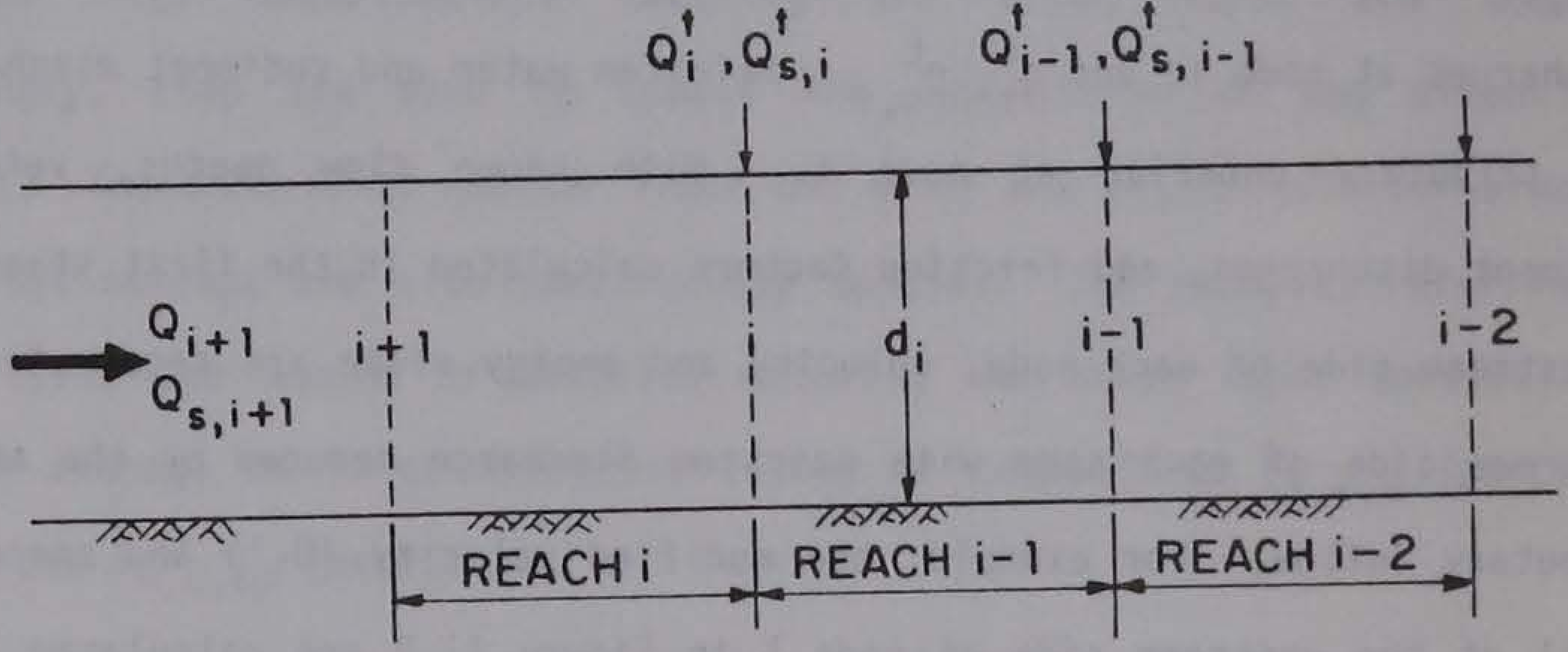
The influence of tributary inflows is considered in IALLUVIAL in two stages. First, the water surface profile is computed in the same way as described in section II.C, with water discharges at computation points adjusted to account for tributary water inflows. In the second stage, the application of the sediment continuity equation is modified as follows. Consider Figure II.2, where Q_i and $Q_{s,i}$ = mainstem water and sediment discharges at node i; and Q_i^t, $Q_{s,i}^t$ = mainstem water and sediment discharges in the tributary entering at node i. With known flow depths, velocities, sediment discharges, and friction factors calculated in the first stage at the downstream side of each node, velocity and energy slope are recomputed at the upstream side of each node with mainstem discharge reduced by the amount of tributary inflow. For example, the modified velocity (U_i') and energy slope (S_i') at the upstream side of node i in Figure II.2 are calculated assuming the same water surface elevation (or depth, d_i) and friction factor (f_i) as at the downstream side:

$$U_i' = Q_{i+1}/A_i \tag{9}$$

$$S_i' = \frac{f_i \cdot U'^2_i}{8\ g \cdot d_i} \tag{10}$$

where A_i = cross-sectional area corresponding to depth d_i, and g = acceleration due to gravity. Sediment discharges are computed at points of tributary inflow from Eq. (1), e.g., at node i:

$$Q_{s,i}' = f(U_i', d_i, S_i', D_{50i}) \tag{11}$$



$$Q_i = Q_{i+1} + Q_i^t$$

$$Q_{i-1} = Q_i + Q_{i-1}^t$$

Figure II.2 Schematic Representation of Tributary Inflows where $Q'_{s,i}$ = recomputed value of $Q_{s,i}$, and D_{50i} = median bed-material size at node i. The depths of degradation or aggradation for sediment fraction k ($\delta_{i,k}$) in the three reaches shown in Figure II.2 are obtained (for $Q_{s,i} > Q_{s,i+1}$) from:

$$\delta_{i,k} = \frac{(Q'_{s,i} - Q_{s,i+1})}{(1 - p)\ B} \frac{\Delta t}{\Delta x} \cdot P_{di,k} \tag{12}$$

$$\delta_{i-1,k} = \frac{(Q'_{s,i-1} - Q'_{s,i})}{(1 - p)\ B} \cdot \frac{\Delta t}{\Delta x} \cdot P_{di-1,k} - \frac{Q^t_{s,i}}{(1 - p) \cdot B} \frac{\Delta t}{\Delta x} \cdot P^t_{i,k} \tag{13}$$

$$\delta_{i-2,k} = \frac{(Q_{s,i-2} - Q'_{s,i-1})}{(1 - p) \cdot B} \cdot \frac{\Delta t}{\Delta x} \cdot P_{d_{i-2,k}} - \frac{Q^t_{s,i-1}}{(1 - p) \cdot B} \cdot \frac{\Delta t}{\Delta x} \cdot P^t_{i-1,k} \tag{14}$$

where Δt = time interval, Δx = reach length, p = porosity, B = channel width, $P_{di,k}$ = fraction of sediment discharge in size interval k and reach i (Eq. (5)), and $P^t_{i,k}$ = fraction of sediment discharge in size interval k for the tributary at node i. Positive values of $\delta_{i,k}$ in the above relations (12, 13, and 14) indicate net degradation, and negative values indicate net aggradation. The second term in Eqs. (13) and (14) gives the contribution from the tributary, and its magnitude relative to the first term (contribution from the main stream) determines the net amount of degradation or aggradation. A check on the consistency of sediment continuity (given by Eqs. (13) and (14)) is made for all fractions such that sediments brought in by tributaries are allowed to pass as suspended load (provided sufficient transport capacity is available at the downstream section), even though a negative value of $\delta_{i,k}$ is given by Eq. (13) or (14). This situation may arise when a finer-size fraction of bed material is removed completely in a previous time step, which makes $P_{di-1,k} = 0$ in Eq. (13), for example, and $\delta_{i-1,k}$ becomes negative (deposition) even though the flow is capable of transporting sediments in that size interval. This procedure allows a partial check on the consistency of the sediment-continuity equation, a full treatment of which requires strict preservation of continuity of each sediment-size interval (contemplated in future refinement of IALLUVIAL). It may be noted that in the absence of tributaries, $Q'_{s,i} = Q_{s,i}$ for all i and the second term disappears in Eqs. (13) and (14). The above formulations take into account, though indirectly, the variations in the size distribution of sediment discharge between the main channel and tributaries.

For the cases when $Q_{s,i} < Q_{s,i+1}$, Eqs. (12), (13), and (14) are modified by replacing $P_{di,k}$'s with $P_{i,k}$'s, where $P_{i,k}$ = fraction of bed material in size interval k in reach i.

Sediment inflows from tributaries are given as inputs to the program and are expressed as power-law functions of water discharge:

$$Q^t_{s,i} = a_i (Q^t_i)^{b_i} \tag{15}$$

where a_i and b_i are coefficients obtained from the sediment rating curve for the tributary at node i as determined by analysis of available data, see Figures III-6 though III-12; $Q^t_{s,i}$ = tributary sediment discharge (tons/day); and Q^t_i = tributary water discharge (cfs). Values of a_i, b_i are entered as inputs to the program and are assumed to be constant in time, see Section III.F. In considering sediment inflow at the upstream boundary, IALLUVIAL treats the upstream flow as one of the tributaries. Size distributions of tributary sediment inflows, $P^t_{i,k}$, are given as inputs to the program, see again Section III.F.

Erosion of bank materials at high flows supplies a part of the sediment transport capacity of streamflow. This contribution is perhaps minor for natural river reaches, but may become significant in a reach downstream of a reservoir which traps virtually all incoming sediment load. The Missouri River reach between the Gavins Point Dam and Ponca (a length of about 57 miles) is essentially a meandering stream with erodible bankline and experiences considerable loss of land due to bank erosion (about 200 acres/year). IALLUVIAL was, therefore, modified as part of this study to incorporate the effects of bank erosion on the evolution of the river bed.

The mechanics of bank erosion are complex and involve many controlling factors. Some important factors are stream discharge and water surface elevation and their rates of variation with time, composition of bank materials, channel location and alignment, wave heights, and groundwater elevation relative to the stream water surface elevation and rate of seepage. Quantification of the entire process, even if possible, would involve going beyond the one-dimensional framework of IALLUVIAL. Consequently the present formulation in IALLUVIAL adopts the following simple approach:

$$Q^b_{i,k} = E_{b_i} \; P^b_{i,k}; \; Q_i \geq Q_{min} \qquad (16)$$

$$Q^b_{i,k} = 0; \; Q_i < Q_{min} \qquad (17)$$

where $Q^b_{i,k}$ = rate of bank erosion in reach i for sediment size interval k; Q_i = water discharge in reach i; Q_{min} = minimum water discharge (cfs) above which erosion ocurrs; E_{bi} = user-specified bank erosion rate in reach i (cu. ft./mile/day); and $P^{b}_{i,k}$ = fraction of bank-eroded material in reach i for size interval k. The values of E_{bi}, Q_{min} and $P^{b}_{i,k}$ are given as inputs to the program. An option to take $P^{b}_{i,k}$ as equal to that of the bed-material size distribution has also been provided in the program. The sediment continuity equations, given by Eqs. (12) through (14), are modified due to bank erosion as follows:

$$\delta_{i,k} = \delta_{i,k}(\text{by 12, 13, or 14}) - E_{bi}P^{b}_{i,k}\frac{\Delta t}{(1-p)\,B} \tag{18}$$

A check is made on sediment continuity, Eq. (18), as described earlier to assure that the eroded bank material of each size interval k is not deposited when the flow is capable of transporting it.

II.I. <u>Program organization.</u> The computer code of IALLUVIAL has been reorganized and considerably extended to incorporate additional features as well as to improve computational efficiency under the scope of the present study. Dynamic storage allocation of a large number of dimensioned arrays has been incorporated in the present code to optimize memory requirements and thus to enhance operational ease. The new version of IALLUVIAL consists of MAIN and 16 subroutines: SMAIN, SEDBED, START, CHANGE, DREDGE, WATPRO, RESIS1, TRASF, SECPRO, SLOAD, ARMOR, HYSORT, VSORT, SHIELD, TRIB, and ERROR1. An abbreviated block diagram of the program is shown in Figure II.3, which describes briefly the function of each subroutine and the flow of information among them.

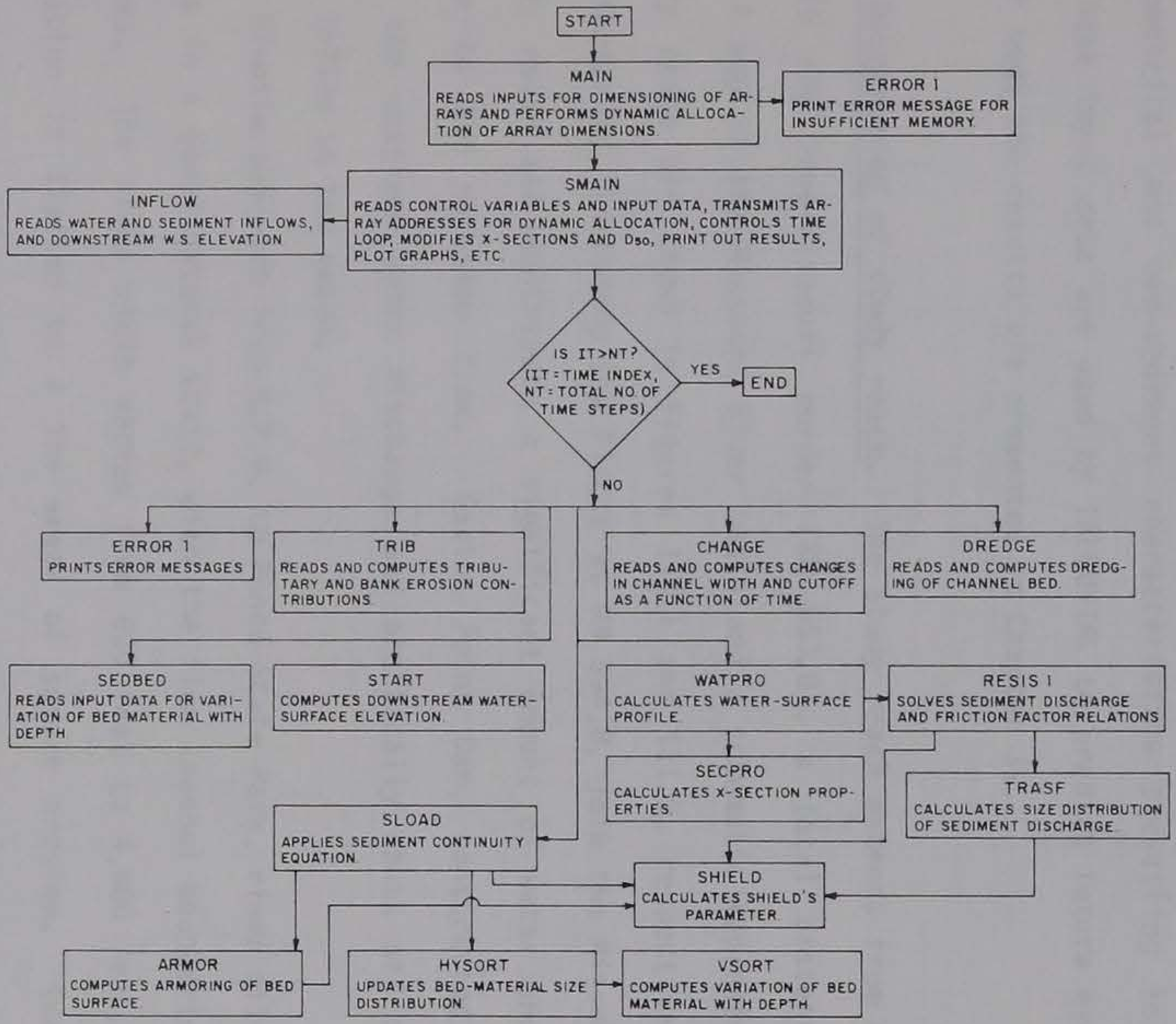


Figure II.3 Summary Block Diagram of ALLUVIAL

Appendix A describes the input data structure of IALLUVIAL, and Appendix B presents the scheme used for dynamic allocation of memory. Appendix C is a complete listing of the FORTRAN IV source program.

III. CONSTRUCTION OF MISSOURI RIVER MODEL

III.A. Introductory remarks. The objective of this chapter is to present the construction of an input data set representing the 258-mile reach of the Missouri River between Gavins Point Dam (G.P.D.) and the Iowa-Missouri border, with geometrical and bed-sediment characteristics prevailing in the year 1980. These input data are used by IALLUVIAL to predict future evolution of the river bed; the results are presented in Chapter IV.

III.B. Description of study reach. The study reach extends from G.P.D. (RM 811.0) to the Iowa-Missouri border (RM 553.0), a total distance of 258 miles. A map of the Missouri River basin and a schematic representation of the study reach are shown in Figures III.1 and III.2, respectively. Nine major tributaries, including the Platte at RM 594.8, join the Missouri within the study reach and contribute a significant amount of water and sediment discharge to the mainstem flow. Gavins Point Dam, constructed in 1956, controls the upstream water discharge and practically shuts off the entire sediment inflow to the reach.

The 57-mile subreach from G.P.D. to Ponca State Park, river mile 811.0 to 754.0, is in a quasi-natural state, with the flow channel meandering between high banks. The river width varies from 600 feet to 4,000 feet, and bank stabilization is limited to a few areas of severe erosion. Construction activities have stabilized both banks in the reach from Ponca to Sioux City, river mile 754.0 to 734.0, to limit the width to about 700 feet in most areas; however, the river width exceeds 1200 feet in some locations, allowing the thalweg to meander between the stabilized high banks. In the remaining part

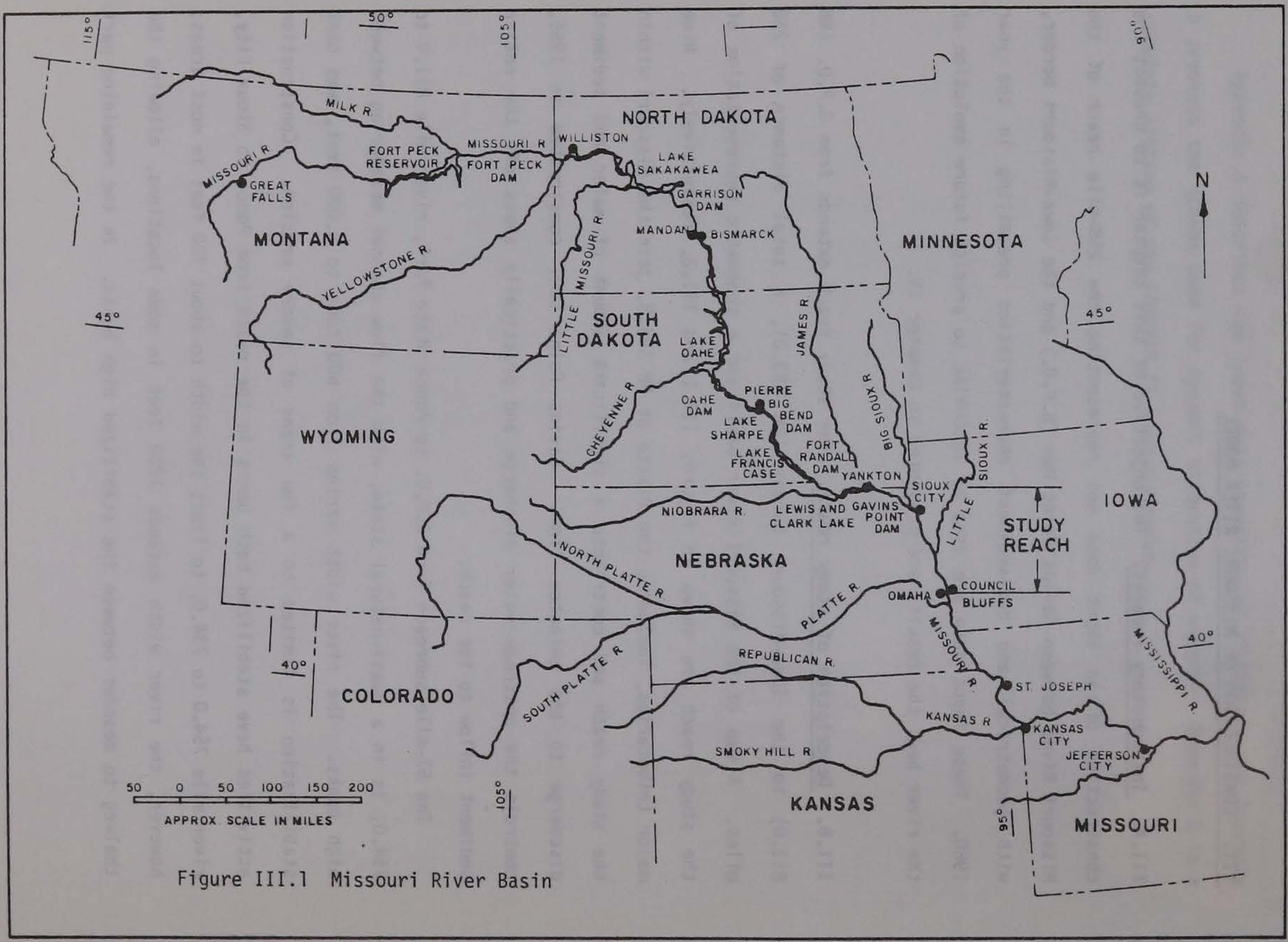


Figure III.1 Missouri River Basin

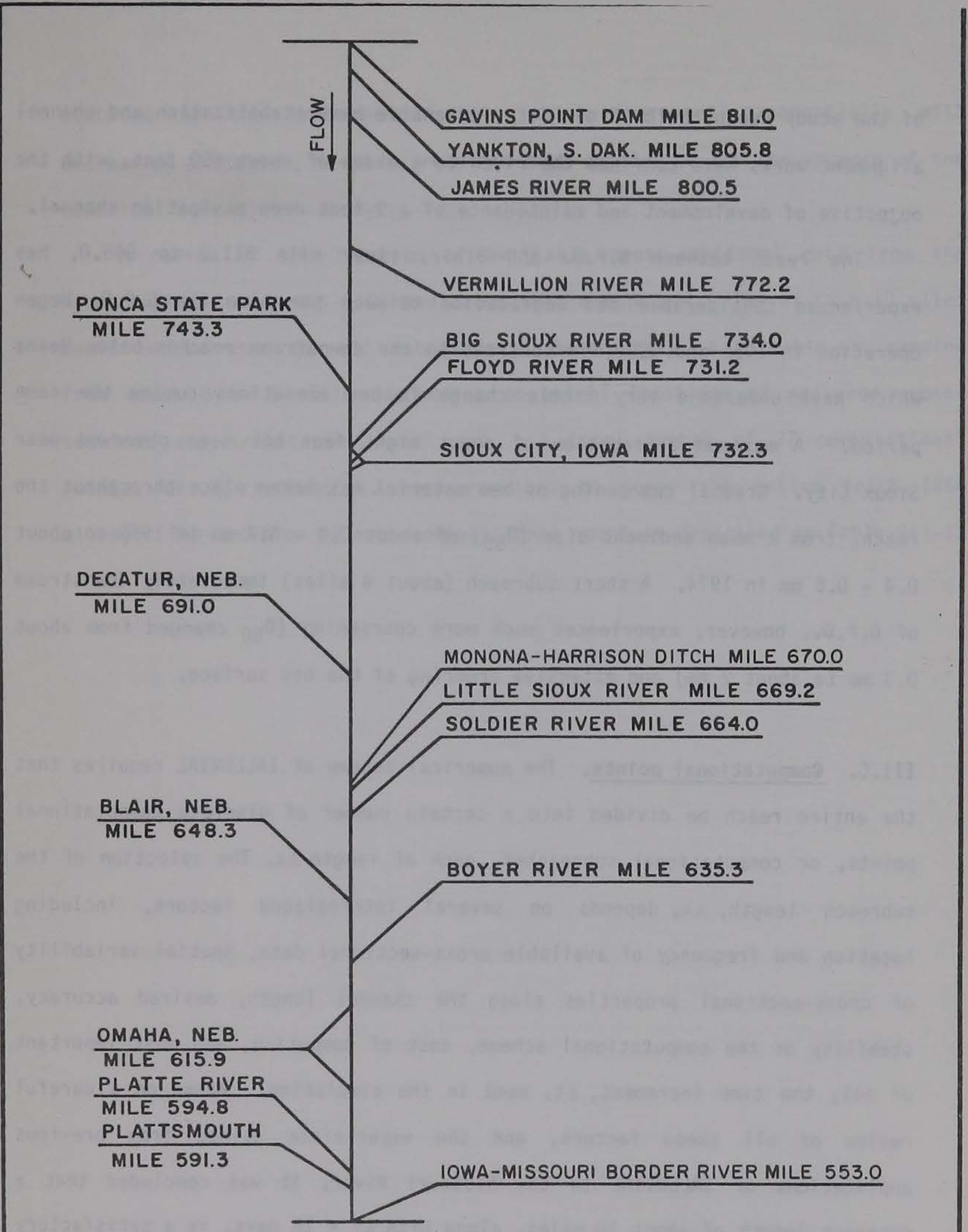


Figure III.2 Schematic Map of the Study Reach of the study reach, below Sioux City, extensive bank stabilization and channel alignment works have confined the river to a width of about 600 feet, with the objective of development and maintenance of a 9-foot deep navigation channel.

The reach between G.P.D. and Blair, river mile 811.0 to 648.0, has experienced considerable bed degradation between the time the G.P.D. began operation in 1956 and 1980, in contrast to the downstream reaches below Omaha which have undergone very little change in bed elevations during the same period. A maximum degradation of about eight feet has been observed near Sioux City. Gradual coarsening of bed material has taken place throughout the reach, from a mean sediment size (D_{50}) of about 0.2 - 0.3 mm in 1956 to about 0.4 - 0.5 mm in 1974. A short subreach (about 4 miles) immediately downstream of G.P.D., however, experienced much more coarsening (D_{50} changed from about 0.3 mm to about 2 mm) and extensive armoring of the bed surface.

III.C. Computational points. The numerical scheme of IALLUVIAL requires that the entire reach be divided into a certain number of discrete computational points, or computational subreaches, each of length Δx. The selection of the subreach length, Δx, depends on several interrelated factors, including location and frequency of available cross-sectional data, spatial variability of cross-sectional properties along the channel length, desired accuracy, stability of the computational scheme, cost of computing, and most important of all, the time increment, Δt, used in the simulation. Based on a careful review of all these factors, and the experieince gained from previous applications of IALLUVIAL to the Missouri River, it was concluded that a subreach length of about 10 miles, along with Δt = 15 days, is a satisfactory compromise among all the competing criteria. This selection was particularly dictated by the computation cost, which increases exponentially with decreasing Δx (which, in turn, requires even smaller Δt for convergence of the numerical scheme).

A review of the location of available cross-sectional data from the Hydrographic Survey Map (10) indicated that a constant value of $\Delta x = 10$ miles could not be used for all subreaches. Accordingly, a variable Δx, ranging from about 8 to 12 miles depending on actual locations of measured cross-sections and tributaries, was used. A total number of 27 computational points, or 26 subreaches, were required to cover the entire reach (258 miles). The location of each computational point is described in Table III-1.

Table III-1

List of Computational Points

Computational Point	River Mile (1960)	Remarks
1	553.0	Iowa-Missouri border
2	561.0	Nebraska City gauge
3	571.0	Lower Civil bend
4	581.0	Calumet Bartlett bend
5	591.0	Lower Plattsmouth bend
6	600.0	Upper Bellevue reach
7	610.5	Gibson bend
8	620.0	Omaha gauge (RM 615.0)
9	630.0	Upper Pigeon Creek bend
10	640.0	Upper Calhoun bend (Desoto cutoff)
11	648.2	Blair Highway Bridge
12	658.2	Peterson Cut off
13	669.5	Little Sioux bend
14	680.0	Upper Blencoe bend
15	690.0	Upper Decatur bend
16	700.0	Lower Monona bend
17	710.0	Winnebago bend
18	720.0	Omadi bend
19	731.2	Sioux City gauge (RM 731.1)
20	740.0	McCook Lake bend
21	750.0	Ponca bend
22	760.9	50.1 miles d/s of GPD
23	772.9	38.1 miles d/s of GPD
24	782.1	28.9 miles d/s of GPD
25	792.0	19 miles d/s of GPD
26	801.9	Yankton gauge (RM 805.8)
27	811.0	Gavins Point Dam

III.D. **Cross-sections.** Extensive data on cross-sectional properties along the study reach of the Missouri River have been collected by the U.S. Army Corps of Engineers, Omaha District. As described in section III.B, the reach from the Iowa-Missouri border (RM 553.0) to Ponca (RM 750.0) is essentially constricted between stabilized banks separated by 550 to 700 feet. Flow channels in this reach can be reasonably approximated by rectangular cross-sections. Accordingly, each cross-section in this reach (Ponca to Missouri border) is defined completely by a width and an average bed elevation. The Hydrographic Survey Map (10) was utilized to obtain the values of channel widths and average bed elevations at computational point 1 (RM 553.0) through computational point 21 (RM 750.0). From these input values, the program computes hydraulic radius and cross-sectional areas at different elevations above the bed.

The river reach above Ponca (RM 750.0) to the upstream boundary (G.P.D., RM 811.0) is characterized by irregular cross-sections and great variability in cross-sectional properties from point to point. In recognition of this fact, the Corps of Engineers, Omaha District, conducted in 1980 (and before) extensive field surveys in this reach to obtain detailed cross-sectional measurements at intervals of approximately 1 mile or more (14). From this survey the values of channel width, hydraulic radius and cross-sectional area at different elevations above the thalweg were calculated at each computational point and entered as inputs to the program (for computational points 22 through 27). This procedure preserves the variability of cross-sectional properties of any irregular shape from the point of view of hydraulic calculations. A summary of cross-sectional data used in the program is presented in Table III-2. Figures III.3 and III.4 show the longitudinal

Table III-2

Summary of Cross-Sectional Data, 1980

Computational Point	River Mile (1960)	Width (feet)	Bed Elevation (feet)	Remarks
1	553.0	600	889.85	Rectangular channel
2	561.0	675	900.82	Rectangular channel
3	571.0	575	910.25	Rectangular channel
4	581.0	575	919.93	Rectangular channel
5	591.0	550	930.12	Rectangular channel
6	600.0	575	938.39	Rectangular channel
7	610.5	600	946.80	Rectangular channel
8	620.0	600	956.11	Rectangular channel
9	630.0	600	965.13	Rectangular channel
10	640.0	600	973.78	Rectangular channel
11	648.2	600	981.06	Rectangular channel
12	658.5	650	988.99	Rectangular channel
13	669.5	600	1002.21	Rectangular channel
14	680.0	600	1010.69	Rectangular channel
15	690.0	600	1019.18	Rectangular channel
16	700.0	600	1028.93	Rectangular channel
17	710.0	600	1039.47	Rectangular channel
18	720.0	600	1050.46	Rectangular channel
19	731.2	600	1061.03	Rectangular channel
20	740.0	700	1070.02	Rectangular channel
21	750.0	700	1081.66	Rectangular channel
22	760.9	--	--	Irregular shape (details used)
23	772.9	--	--	Irregular shape (details used)
24	782.1	--	--	Irregular shape (details used)
25	792.0	--	--	Irregular shape (details used)
26	801.9	--	--	Irregular shape (details used)
27	811.0	--	--	Irregular shape (details used)

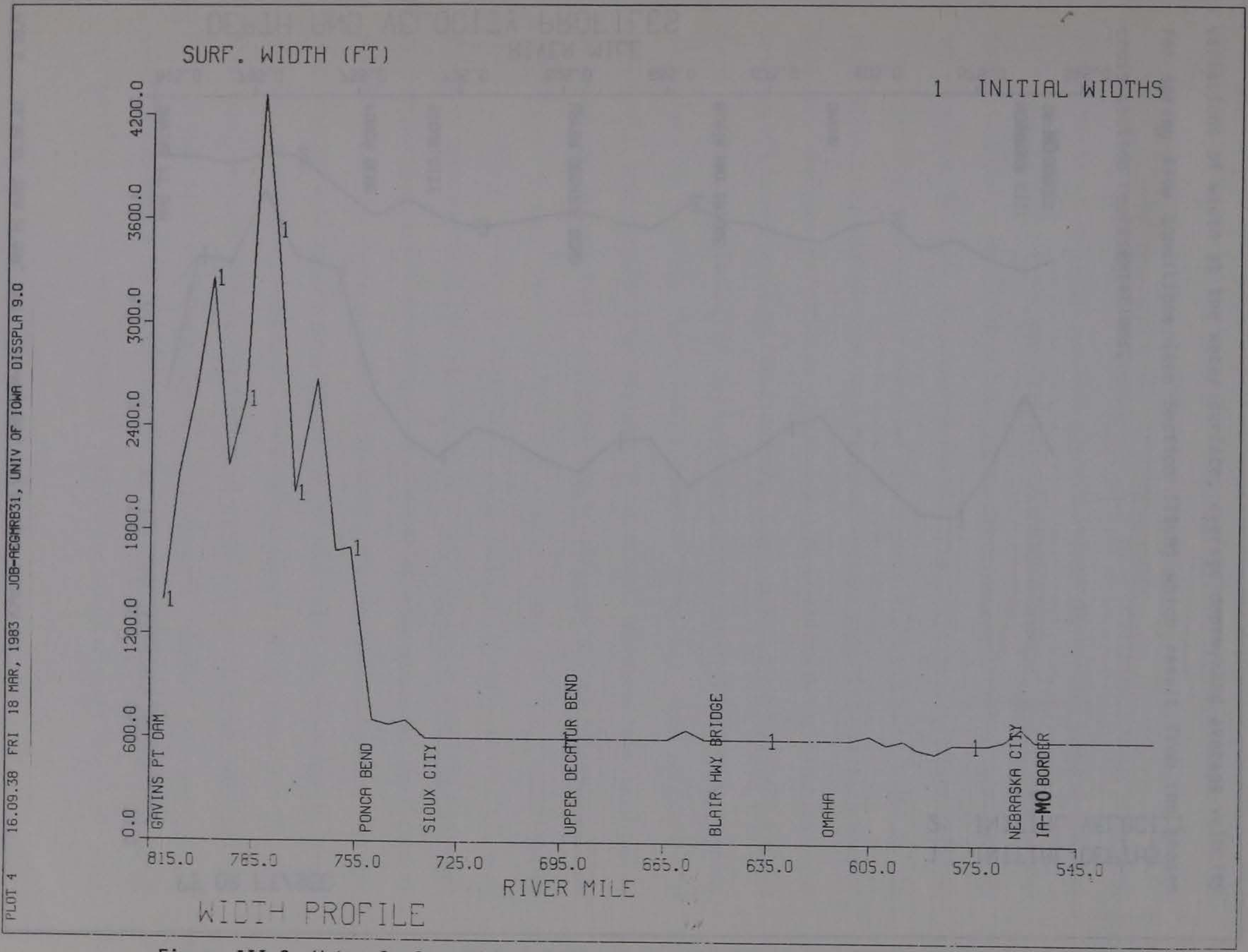


Figure III.3 Water Surface Width at Beginning of Simulations (spring flows, see Table III-7)

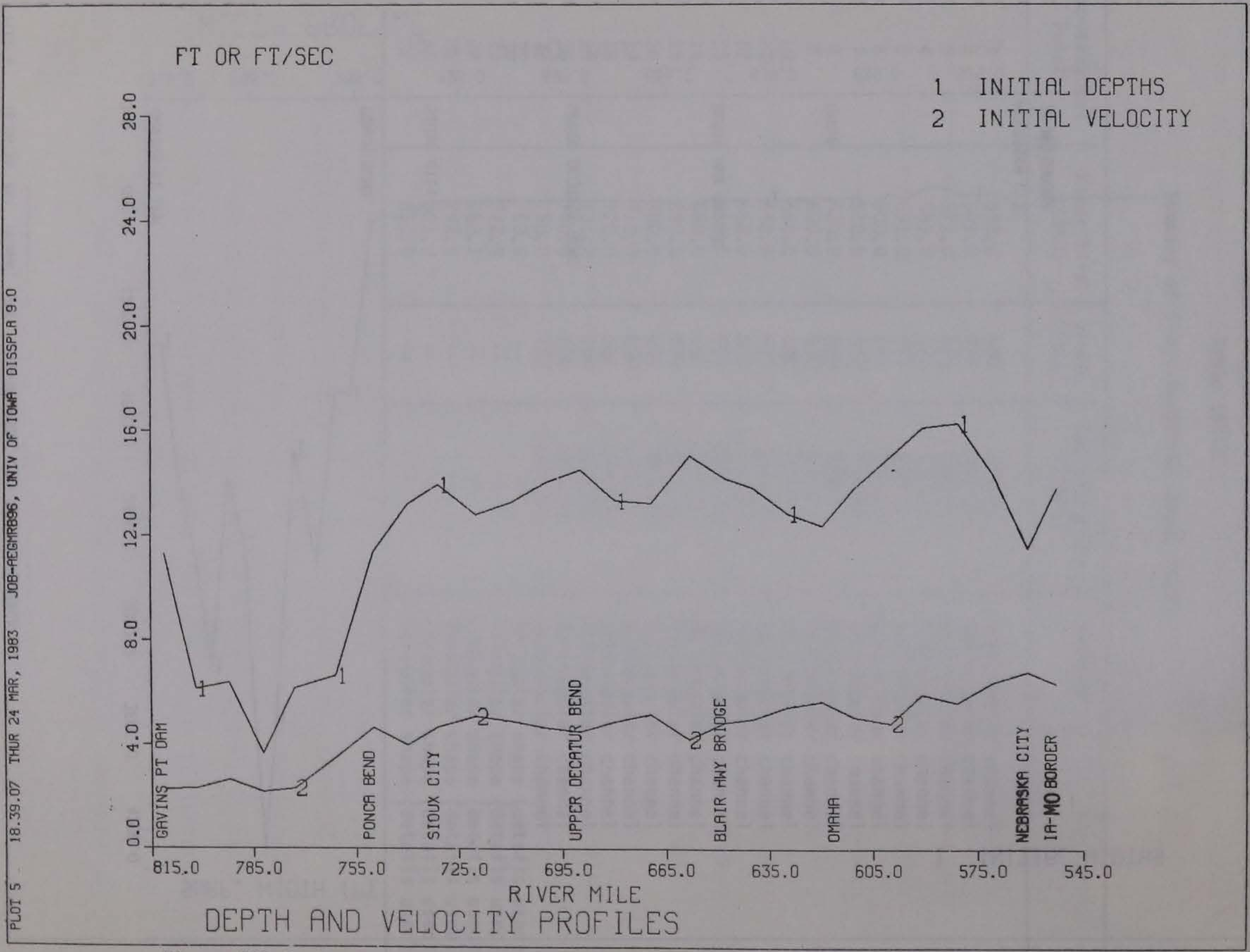


Figure III.4 Depths and Average Velocities at Beginning of Simulations (spring flows, see Table III-7) variations of width at the water surface, average depth, and average velocity for spring flow conditions (see Section III.H) which result from the chosen cross-section representations.

III.E. Bed-sediment composition. A large volume of bed-material size distribution data for the study reach was obtained from the Corps of Engineers, Omaha District. It was, however, necessary to invest a major amount of time and effort to process and analyze this large collection of tables and graphs to obtain suitable longitudinal and vertical profiles of bed-sediment composition which reflect the bed condition of the study reach as of 1980 and are consistent with the formulation of IALLUVIAL. Two major difficulties encountered in this effort were: first, the resolution was poor, or non-existent, in the upper tail-end (coarser sediments) of the size distributions, yet these tails are known to be important in the development of bed armoring; secondly, in the case of core-drill data for subsurface sediment gradation, the variations in size distribution with depth and across a given cross-section were too great to make a meaningful estimate of the cross-section-averaged vertical variation of bed-sediment composition. These two difficulties led to the adoption of the procedures described in the following paragraphs.

Bed Material Size Distributions Bed-material size distributions for 1979 (latest) are available for the reach from Ponca to the downstream boundary at 5-mile intervals. Unfortunately, these distributions do not include sediment sizes in the coarest 10%; this was considered inadequate from the point of view of bed armoring which usually involves the coarser sediments included in the coarsest few percent of a distribution. Fortunately, there were available a few detailed sediment size distributions, though at large longitudinal intervals, which included upto 99% of the material. As a compromise, these five detailed distributions were used to extend the 5-mile distributions beyond the 90% size by the procedure sketched on Fig. III.5. The 99% size was estimated as a constant multiple of the 90% size, the constant being calculated by linear interpolation from the closest two detailed distributions; the 100 % size was fixed at 19.10 mm (on the basis of earlier detailed analyses of bed material size in the twelve-mile reach below Gavins Point Dam); and actual detailed distributions were used for computational points close to their locations. For the reach upstream of Ponca, linear interpolations between the detailed distributions available at Ponca (RM 750.0) and Yankton (RM 805.8) were used to estimate the initial bed-material size distributions at all computational points in this reach. Bed-material size distributions, thus estimated to represent the bed condition of the river as of 1980, are summarized in Table III-3 (see also Curve 1 of Fig. IV.4).

Subsurface Size Distribution Core-drill logs were prepared by the Corps of Engineers in 1980 at five locations: river miles 752.5, 709.6, 685.0, 680.0, and 640.5. At each location, five drillings were made at five closely-spaced sites. From a careful examination of the core-drill logs, which indicated extreme variations in sediment-size distributions with depth and among different holes at the same location, and from consideration of the fact that only five data points in a reach of 258 miles were available, it was concluded that available data are inadequate for a reliable representation of the vertical variation of sediment composition in the study reach. It was, therefore, assumed that the bed-material compositions as presented in Table III-3 extend to indefinite depths below the bed.

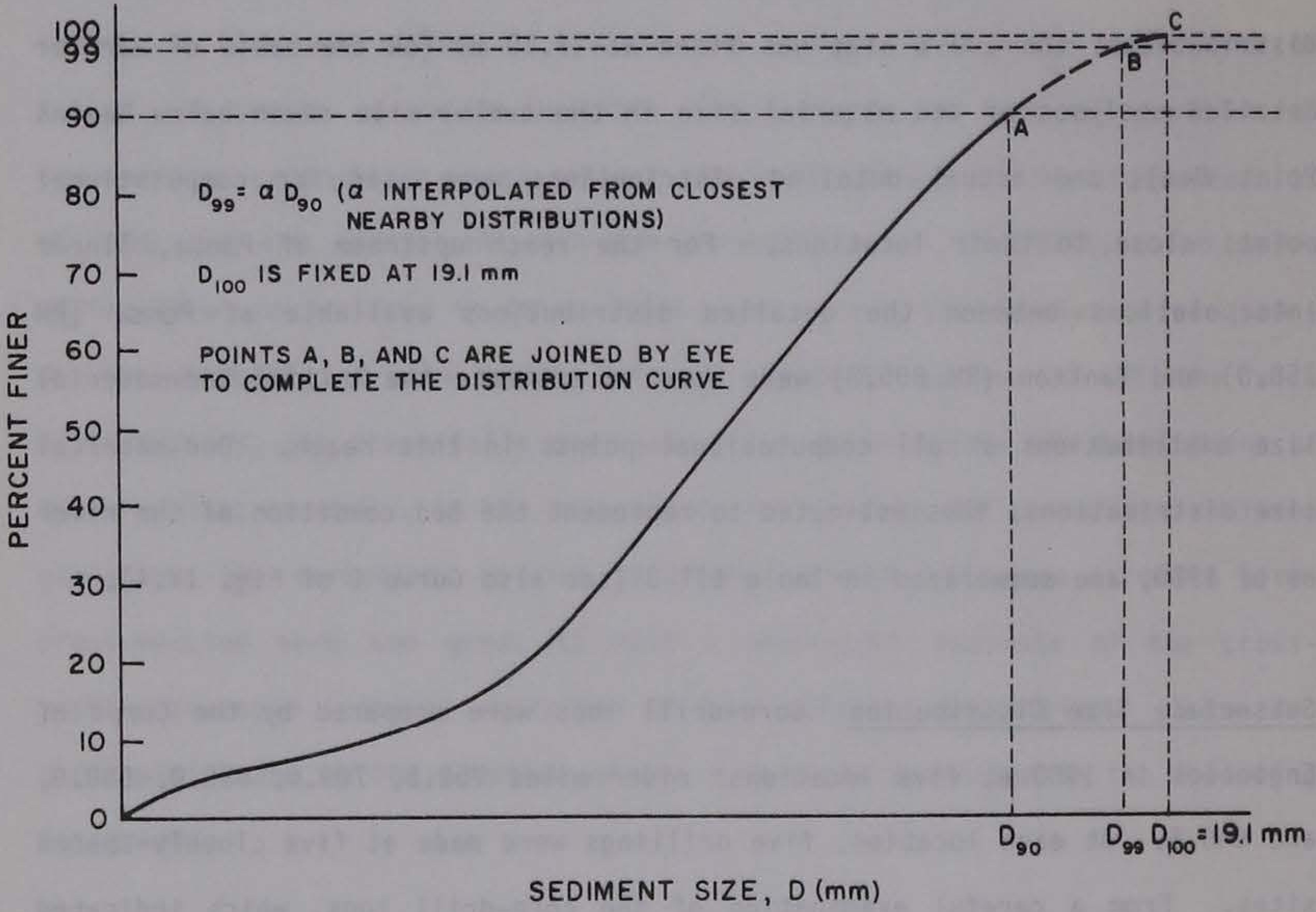


FIGURE III 5. PROCEDURE FOR ESTIMATION OF COARSE TAILS OF BED MATERIAL SIZE DISTRIBUTIONS.

Table III-3

Summary of Initial Bed-Material Size Distribution (1980)

Sub-reach No.	Down-stream River Mile	D_{50} (mm)	Cumulative distribution function for indicated sediment size (mm) (fraction finer)								
			.062	.149	.297	.590	1.19	2.40	4.80	9.52*	19.10*
1	553.0	.251	0	.040	.710	.970	.990	.996	.998	.999	1.00
2	561.0	.228	0	.100	.850	.973	.991	.996	.998	.999	1.00
3	571.0	.535	0	.016	.200	.570	.802	.944	.986	.996	1.00
4	581.0	.470	0	.018	.200	.708	.920	.982	.995	.998	1.00
5	591.0	.235	0	.086	.800	.976	.991	.996	.998	.999	1.00
6	600.0	.256	0	.030	.680	.970	.989	.995	.997	.998	1.00
7	610.5	.235	0	.070	.790	.970	.990	.995	.997	.999	1.00
8	620.0	.241	0	.070	.760	.968	.990	.995	.997	.998	1.00
9	630.0	.357	0	.032	.380	.996	.998	.995	.997	.998	1.00
10	640.0	.354	0	.022	.390	.960	.987	.995	.997	.998	1.00
11	648.2	.404	0	.018	.300	.850	.968	.990	.996	.998	1.00
12	658.5	.332	0	.040	.440	.940	.984	.994	.997	.998	1.00
13	669.5	.355	0	.040	.400	.905	.978	.992	.997	.998	1.00
14	680.0	.421	0	.202	.230	.870	.963	.983	.992	.996	1.00
15	690.0	.391	0	.030	.300	.925	.970	.985	.992	.997	1.00
16	700.0	.428	0	.029	.240	.820	.950	.979	.990	.996	1.00
17	710.0	.353	0	.024	.400	.925	.970	.987	.992	.997	1.00
18	720.0	.403	0	.020	.290	.870	.960	.982	.991	.997	1.00
19	731.2	.446	0	.016	.240	.750	.915	.965	.984	.994	1.00
20	740.0	.343	0	.028	.420	.930	.973	.988	.994	.997	1.00
21	750.0	.400	0	.032	.350	.777	.906	.953	.980	1.00	1.00
22	760.9	.385	0	.041	.379	.782	.905	.956	.976	1.00	1.00
23	772.9	.369	0	.050	.410	.787	.904	.960	.981	.999	1.00
24	782.1	.351	0	.057	.435	.791	.903	.963	.984	.999	1.00
25	792.0	.331	0	.065	.461	.795	.902	.966	.988	.999	1.00
26	801.9	.309	0	.073	.487	.799	.901	.969	.991	.999	1.00

* assumed to be immobile at all discharges used in this study

III.F. **Tributary sediment inflows.** Tributary sediment discharges are computed from power-law relations of the form given by Eq. (15). The values of the coefficients a_i and b_i in Eq. (15) were obtained by plotting observed monthly total suspended discharges (including wash load) against average monthly water discharge (7, 12), as shown in Figures III.6-III.12. The values of a_i were further adjusted to exclude sediment fractions of less than sand size (0.062 mm), as these are transported as wash load with no effect on the bed. The computed values of a_i and b_i for each tributary are listed in Table III-4. As no data were available for the James and Vermillion, their sediment rating curves were assumed to be the same as the Big Sioux. Nine major tributaries join the study reach, as shown in Figure III-2. Because of the large subreach length (8-12 miles, Table III-1), all tributaries could not be represented separately. Due to the small distance separating them, the Big Sioux and Floyd were combined and represented as one tributary located at RM 731.2. In the same way, the Little Sioux and Monona-Harrison were combined at RM 669.5. Average size distributions of sediment discharge for each tributary, derived from the limited available data for the Floyd, Little Sioux, Boyer, and Platte (15) are presented in Table III-5.

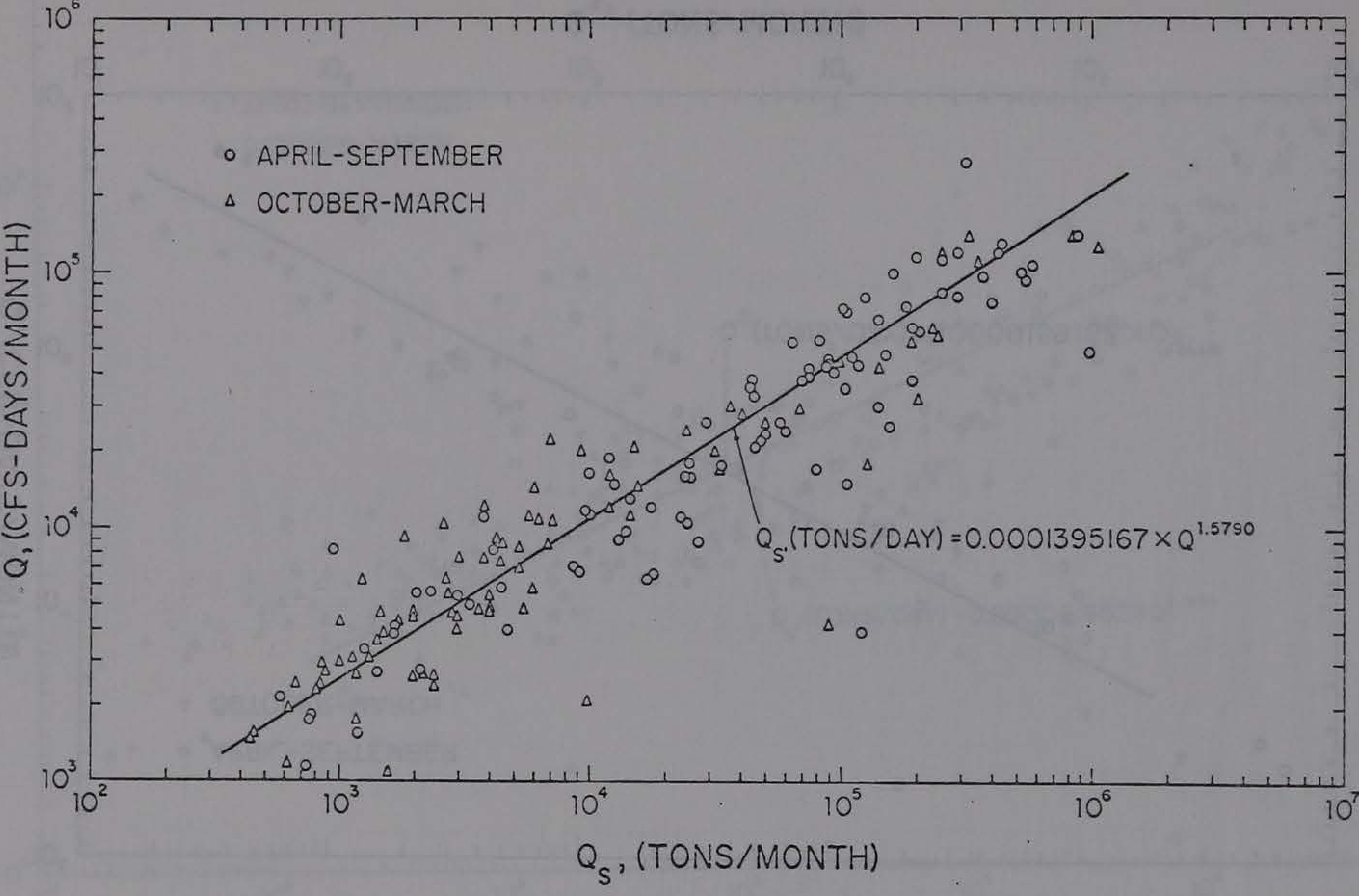


Figure III.6 Sediment Rating Curve for Big Sioux River

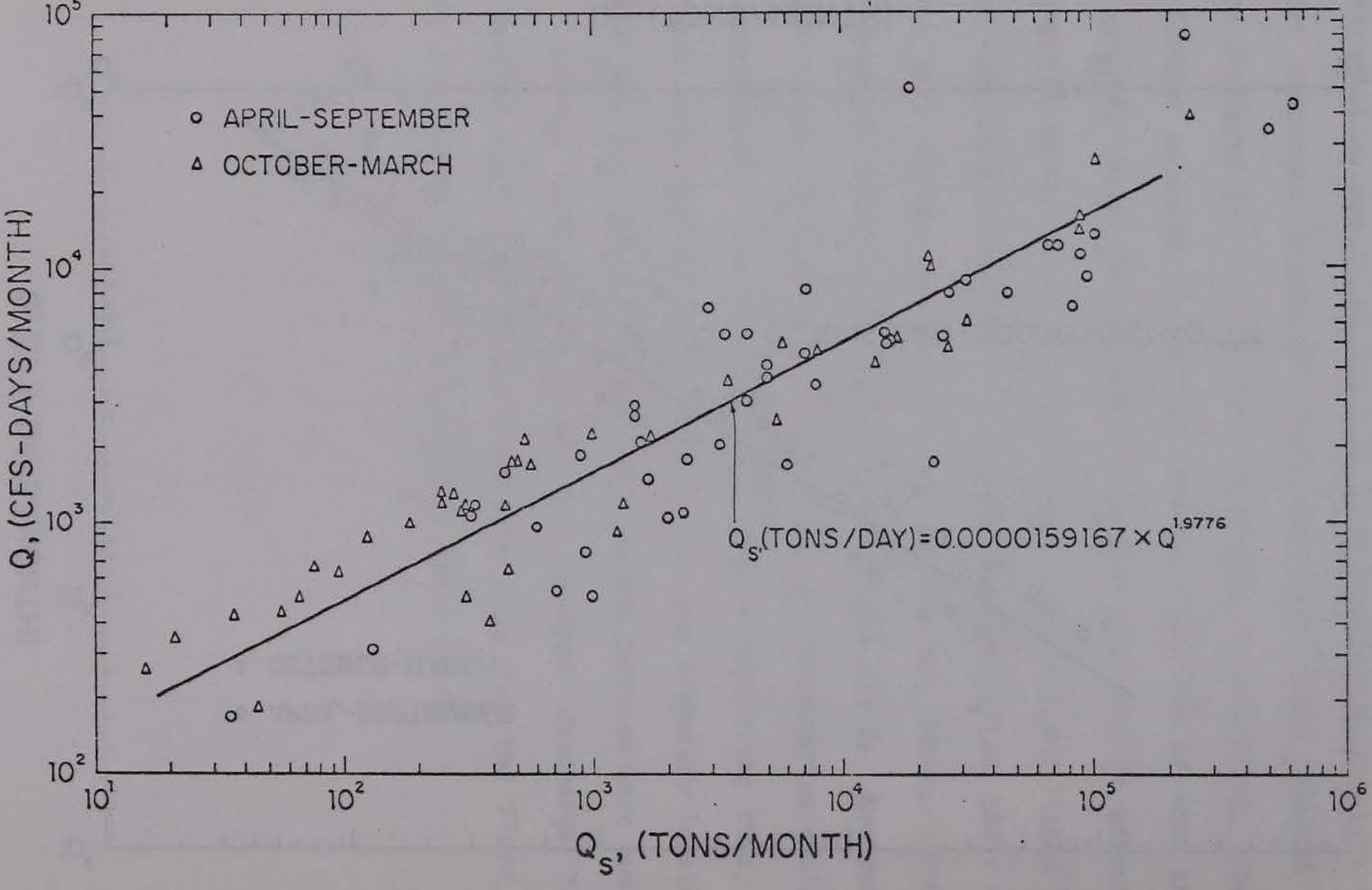


Figure III.7 Sediment Rating Curve for Floyd River

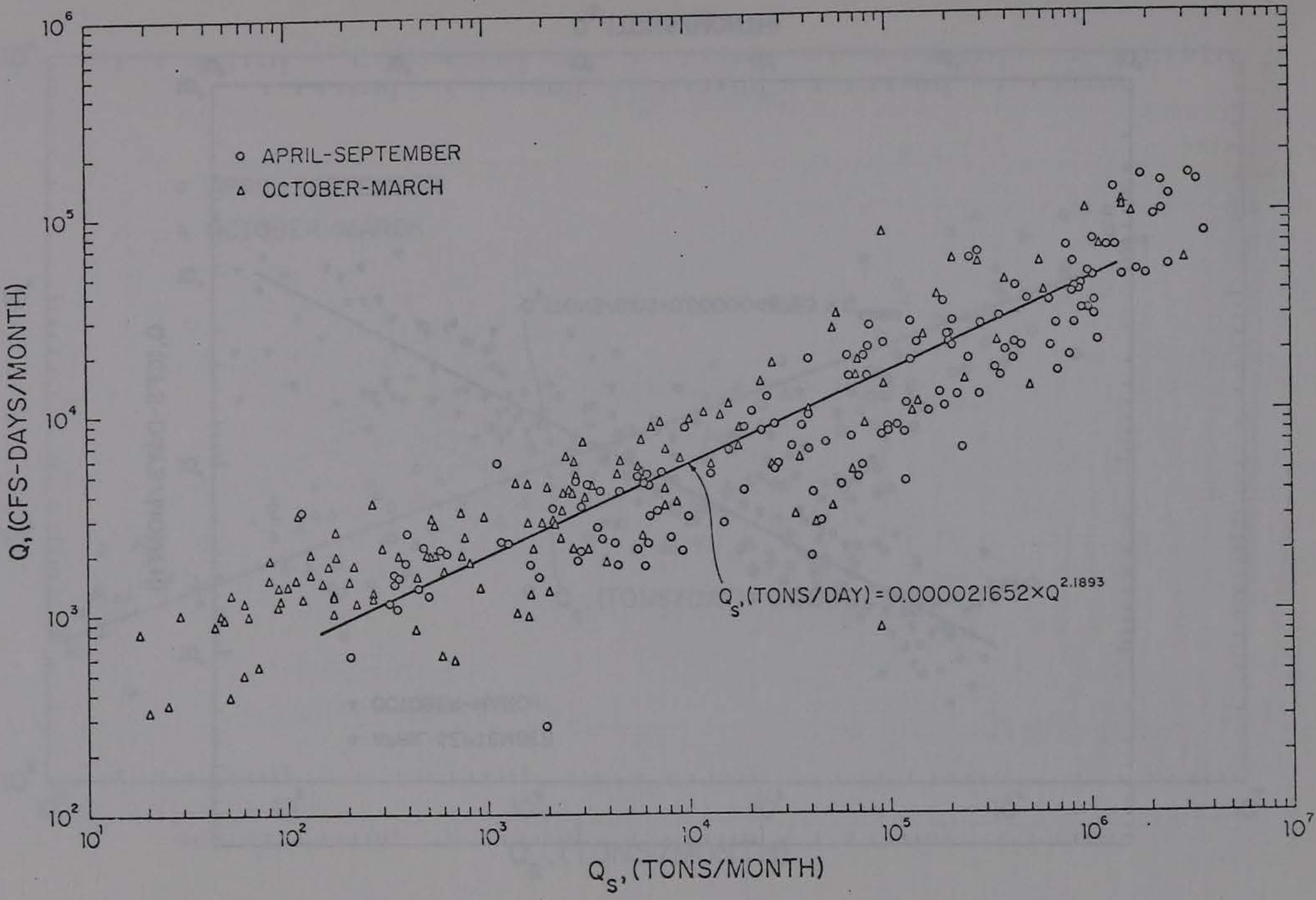


Figure III.8 Sediment Rating Curve for Monona-Harrison Ditch

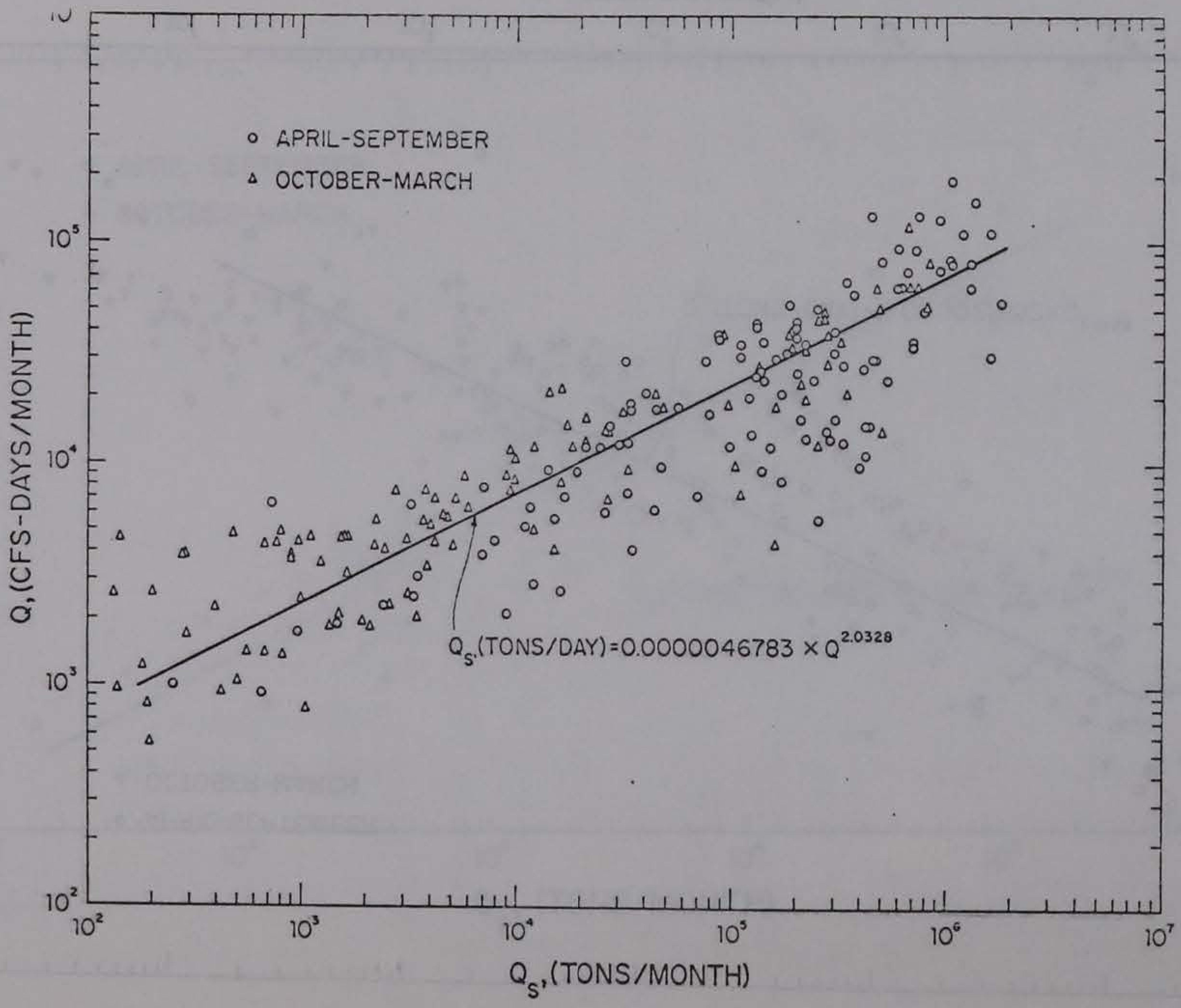


Figure III.9 Sediment Rating Curve for Little Soldier River

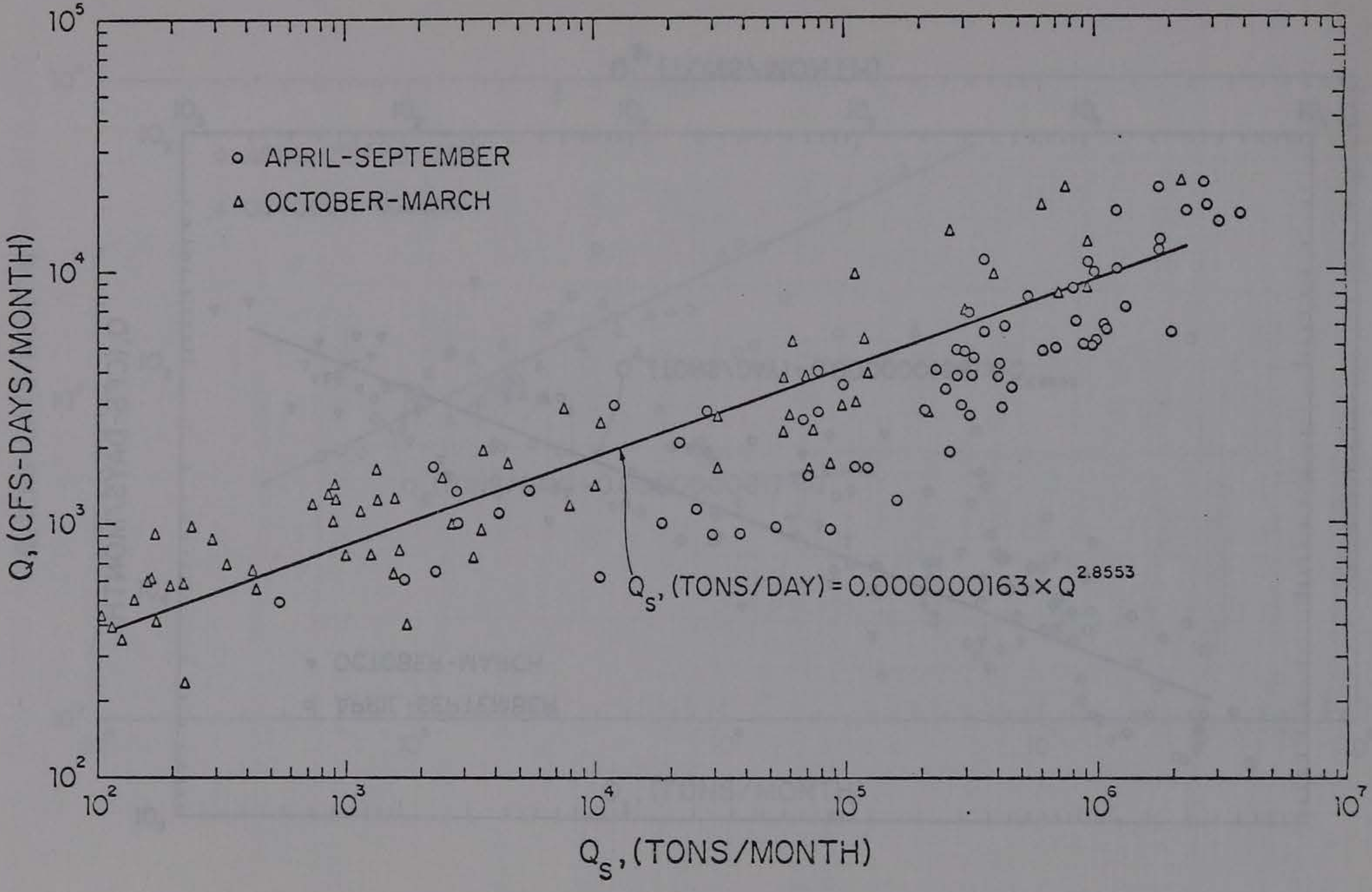


Figure III.10 Sediment Rating Curve for Soldier River

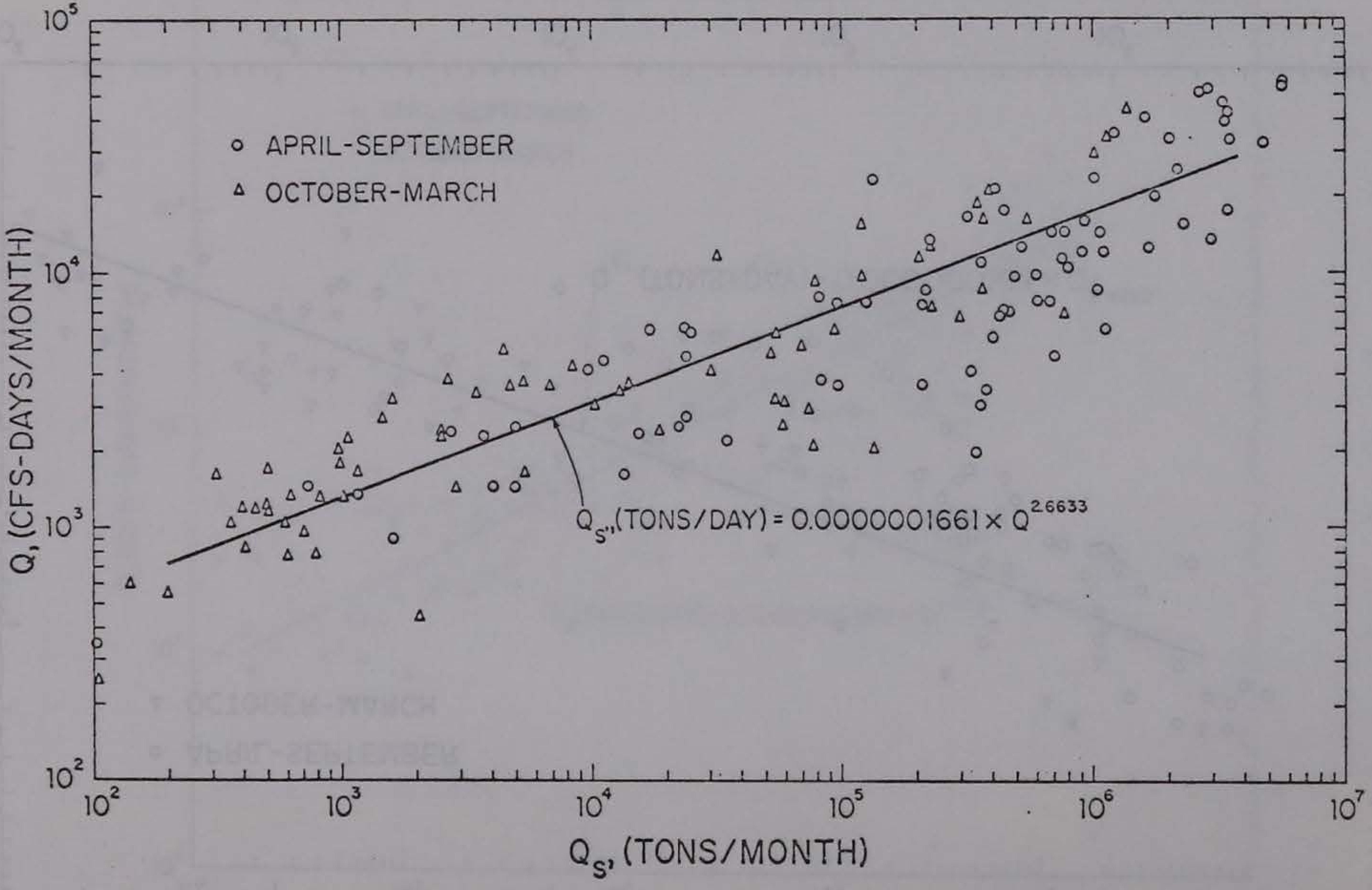


Figure III.11 Sediment Rating Curve for Boyer River

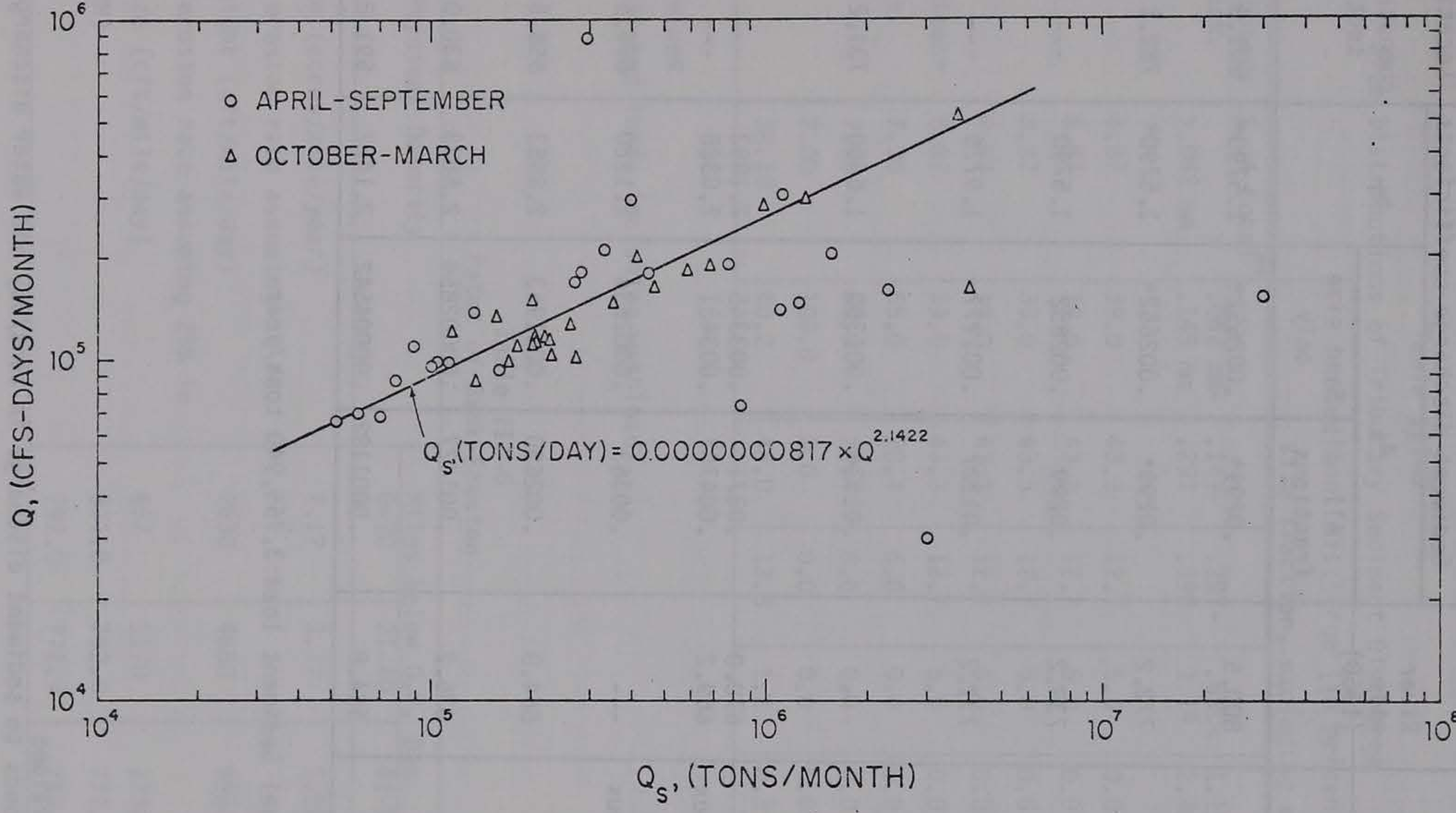


Figure III.12 Sediment Rating Curve for Platte River

Table III-4

Summary of Sediment Rating Curves Data for Tributaries

Name of tributary	River mile (1960)	Sediment discharge coefficients			Location (RM of computational section)
		** a_i		b_i	
		All fractions	Sand size only		
James	800.5	.0299*	.002652*	1.5790*	801.9
Vermillion	772.2	.0299*	.002652*	1.5790*	782.1
Big Sioux	734.2	.0299	.002652	1.5790	---
Floyd	731.2	.01327	.001177	1.9776	---
Big Sioux + Floyd	---	.01534	.001360	1.6400	731.2
Monona-Harrison	670.0	.0371	.003345	2.1893	---
Little Sioux	669.2	.004707	.003431	2.0328	---
Monona-Harrison + Little Sioux	---	.00363	.0002634	2.1220	669.5
Soldier	664.0	.002690	.0001963	2.8553	658.5
Boyer	635.2	.001427	.00002854	2.6633	630.0
Platte	594.8	.0001192	.00004542	2.1422	591.0

Total Annual Sediment load:3,765,940 tons/year

*Assumed values

**Corresponds to sediment discharge in tons/day and water discharge in ft^3/sec (cfs)

Table III-5

Size Distributions of Tributary Sediment Discharge

Name of tributary sed. disch.	% of total** >.062 mm	Sediment discharge (in percent) for each size fraction, excluding washload					
		.062 mm-.149 mm	.149-.297	.297-.590	.590-1.19	1.19-2.40	2.40-4.80
James*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Vermillion*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Big Sioux*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Floyd	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Monona-Harrison*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Little Sioux	7.30	65.0	28.4	6.6	0.0	0.0	0.0
Soldier*	7.30	65.0	28.4	6.6	0.0	0.0	0.0
Boyer	2.00	100.0	0.0	0.0	0.0	0.0	0.0
Platte	38.10	40.2	46.0	12.3	1.2	0.3	0.0

* Assumed values

** Total measured load, including washload

Table III-6

Rates of Bank Erosion

Physical Quantity	Miles below G.P. Dam		
	0-20	21-40	41-60
Erosion rate (acres/mile/year)	2.12	3.77	5.58
Volumetric erosion rate assuming 10 ft. bank height (cft/mile/day)	2630	4680	6930
Volumetric erosion rate assuming 25% in sand size (cft/mile/day)	657	1170	1732
Location (RM)	811.0-792.0	792.0 772.9	772.9 750.0

III.G. Bank erosion. The study reach below Ponca has been protected from bank erosion by extensive bank stabilization works. Bank erosion in this reach is assumed to be zero in the present simulations. The 58-mile reach between Gavins Point Dam and Ponca is in a quasi-natural state, and is considered to be subject to bank erosion during the simulation periods. Future rates of bank erosion have been estimated from observed (1959-75) rates for the reach, varying from 2.12 to 5.58 acres/mile/year (9). Assuming a bank height of ten feet containing 25% of sand-size material or coarser (based on Reference 2), the volumetric rate of bank erosion varies from 657 to 1732 cft/mile/day. Table III-6 presents the rates of bank erosion adopted for each reach. Due to the lack of availability of more precise data, the size distribution of eroded bank materials has been assumed to be the same as that of the adjacent bed material.

III.H. Discharge hydrographs. The water discharge hydrograph at the upstream boundary has been taken to be equal to the rates of release from the Gavins Point Dam, which have been approximated by a two-stage hydrograph: 36,000 cfs during the navigation season (April to November); and 15,000 cfs during the non-navigation season (December to March). The water discharge hydrograph for each tributary was assumed to consist of two constant components: a high discharge (Q_1) for the first four months (April to July) of the navigation season and a low flow (Q_2) for the remaining eight months of the year. The values of Q_1 and Q_2 were computed such that $Q_2 = Q_1/4$ while yielding an average annual volume equal to the observed value for the available period of record (11, 16). The discharge hydrographs can be combined to yield the composite annual hydrograph for the entire reach, consisting of constant discharges in each of the three trimesters (April to July, August to November, and December to March) of the year, as summarized in Table III-7 and Figure III.13. The annual hydrograph was repeated for each year of simulation as shown in Fig. III.14, in most runs, except as modified for certain prognosis scenarios as described in Section IV.A.

Table III-7

Summary of Discharge Hydrograph

Inflow Point	River Mile	Discharge (cfs) in each trimester		
		April to July	Aug. to Nov.	Dec. to March
Upstream (G.P.D.)	811.0	36,000	36,000	15,000
Tributaries				
James	800.5	776	192	192
Vermillion	772.2	240	60	60
Big Sioux	734.2	1,668	417	417
Floyd	731.2	348	87	87
Monona-Harrison	670.0	432	108	108
Little Sioux	669.2	1,560	390	390
Soldier	664.0	248	62	62
Boyer	635.2	590	147	147
Platte	594.8	10,800	2,700	2,700
Total for all tributaries		16,662	4,163	4,163
Total (upstream & tributaries)		52,662	40,163	19,163

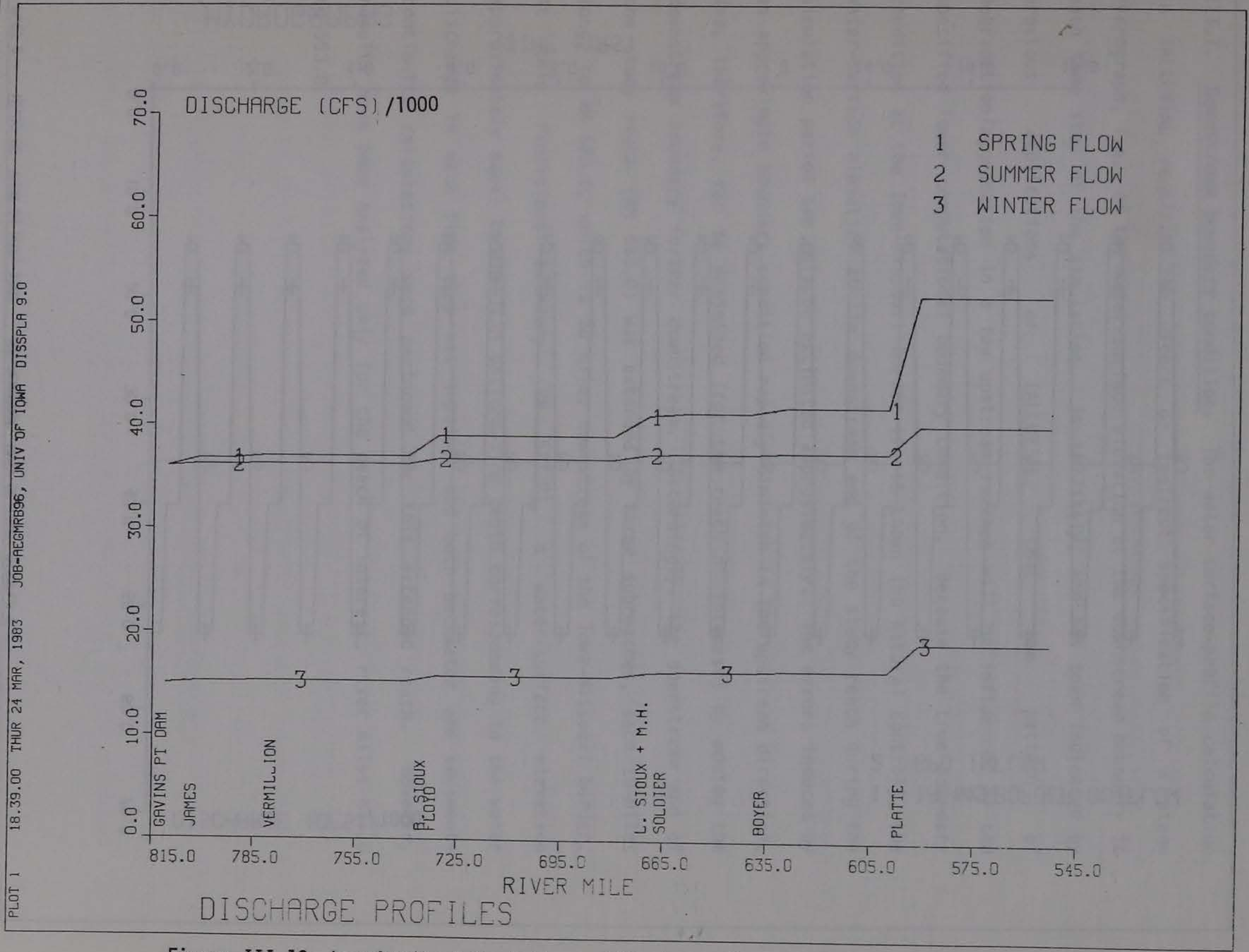


Figure III.13 Longitudinal Variation of Discharge in Each Trimester

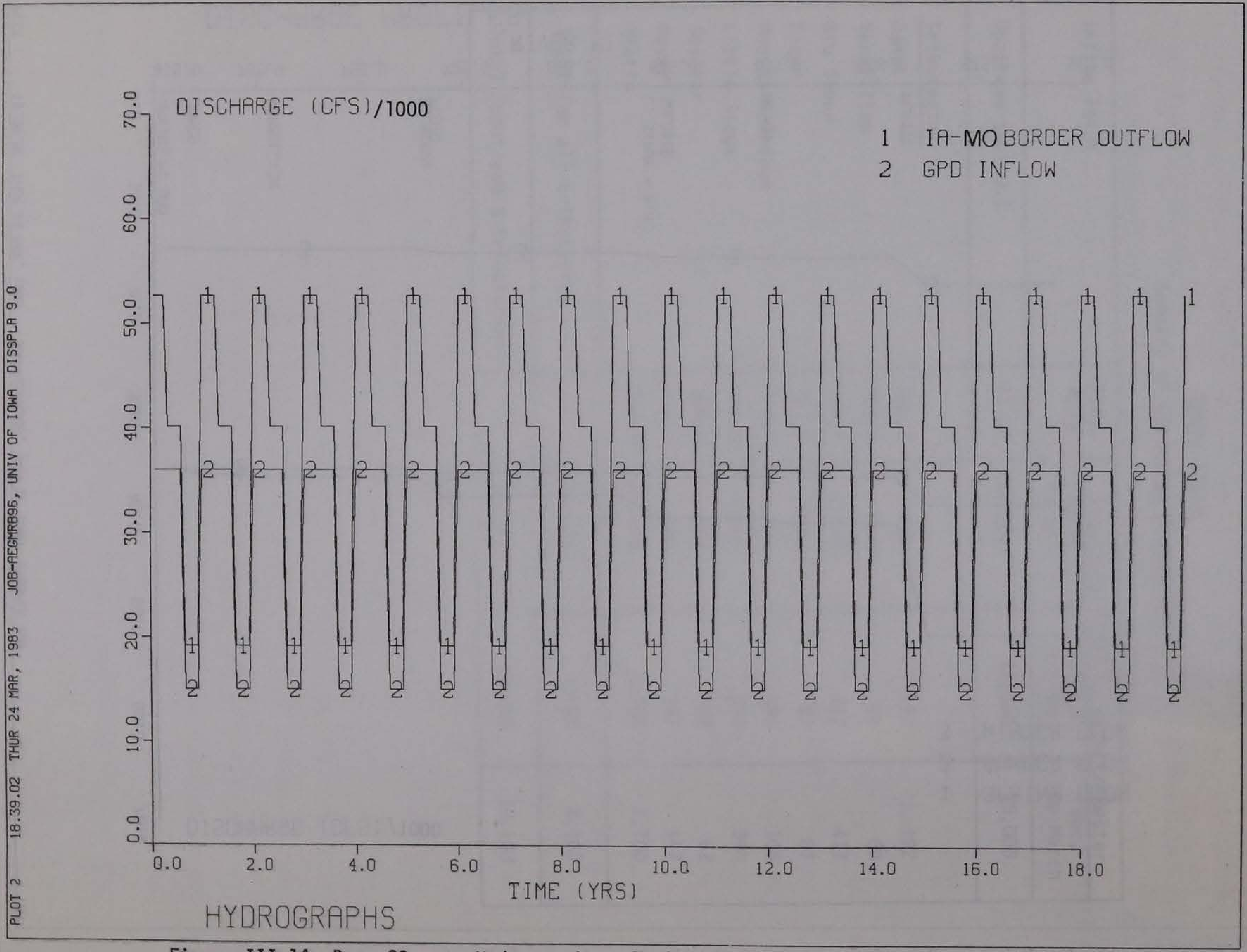


Figure III.14 Base 20-year Hydrograph at Gavins Point Dam and Iowa-Missouri Border

III.I. **Downstream boundary condition.** The water-surface-profile calculation in IALLUVIAL requires the direct or indirect specification of a stage hydrograph, i.e., of the water-surface elevation at the downstream boundary in each time step of the simulation. It is likely, and has been indicated by previous applications of IALLUVIAL, that the pattern of degradation/aggradation in a few upstream reaches will be influenced by the specified lower computational boundary condition. Because the true boundary condition at the Iowa-Missouri border is not known (no natural control), the water-surface elevation at the downstream end of the study reach during the simulation period can only be estimated approximately. The errors induced by an approximate boundary condition rapidly diminish in the upstream direction, and, therefore, can be minimized (for the reach of interest) by moving the downstream boundary further downstream. Accordingly, the downstream end of the study reach (RM 553.0) was extended by three subreaches, each 10-miles long, to RM 523.0, which is 30 miles downstream of the Iowa-Missouri border. At this fictitious boundary (RM 523.0), a water-surface elevation approximately equal to the TLTM uniform-flow depth corresponding to the water discharge in each time step was imposed, and both backwater and sediment-continuity calculations were performed for this extended reach. However, results have been analyzed only for the reach of interest, river miles 811.0 to 553.0.

IV. APPLICATION OF MISSOURI RIVER MODEL

The primary purpose of this study was to predict future bed degradation in the Missouri River for a range of schematic river management scenarios. These scenarios, suggested by the Advisory Panel in several meetings, are not specific proposed plans of action; they are idealized situations chosen to reveal the physical and hydrological factors which are of primary importance in determining the rate and amount of future bed degradation. Section IV.A describes each scenario in detail; Section IV.B analyzes the prognosis simulations for each scenario; and Section IV.C draws several general conclusions on future degradation based on the prognosis runs.

IV.A Description of Prognosis Scenarios. All the scenarios are based on the general Missouri River data described in Section III; only modifications of the basic data are described below.

IV.A.1 Scenario S1: 20-year Prognosis, Present Conditions. This is the base run with which all subsequent ones are compared. Run S1 is intended to predict river bed evolution from 1980 to 2000 under present conditions, i.e., if there is no change in hydrologic regime and if the channel is maintained in its present geometry and alignment. These conditions correspond to a natural continuation of Run V in Reference (5), although the present study incorporates much more detailed data.

IV.A.2 Scenario S2: Upper Basin Diversion. Since the sediment transport capacity of the Missouri is directly related to its water discharge, any reduction in the mean annual flow could potentially reduce the degradation.

Run S2 was designed to test the effect of a constant out-of-basin diversion of 3 million acre-feet per year (about 4,100 cfs) on bed degradation. Accordingly the mainstem inflow hydrograph at Gavins Point Dam (See Section III.H) was uniformly reduced by 4,100 cfs; tributary discharges were left at their normal values.

IV.A.3 **Scenario S3: Constant Flow of 65,000 cfs.** Under the assumptions used for this study (vertically homogeneous bed material, no rock controls) the only natural mechanisms for stopping degradation are a flattening of the overall river slope (which is an insignificant mechanism) and the coarsening of bed material, including development of a stable armor coat on the bed. This armor coat develops as finer sediments are entrained into suspension and transported downstream, leaving behind the coarser, or armoring, material. Since a certain amount of degradation (removal of finer material) must occur before an armor coat can form, the ultimate degradation can be thought of as independent of the time required to attain it. In other words, the amount of degradation which must occur before a new, stable bed elevation is reached would be about the same whether it was attained over a long period of time at a low discharge, or over a short period of time at a high discharge. Therefore the purpose of Run S3 was to simulate a fictitious, constant, high discharge of 65,000 cfs released continuously from Gavins Point Dam (this represents roughly the diked channel capacity at Omaha), in order to predict the ultimate degradation without having to run the model for an inordinate amount of time. Tributary water and sediment discharges were kept at their usual values for this run.

IV.A.4 Scenario S4: 200-ft widening of navigation channel. There are three possible immediate causes for the excessive degradation in the Missouri: shut-off of sediment supply by Gavins Point Dam, increase in channel slope due to cutoffs, and increase in depths and velocities due to channel narrowing. Run S4 is designed to isolate the effect of channel narrowing (diking) by repeating Run S1 with the channel in the controlled reach (downstream of RM 750) widened by 200 feet, with the same initial bed elevations and sediment size distribution.

IV.A.5 Scenario S5: 400-foot widening of navigation channel. Run S5 is an extension of S4 to 400-foot widening of the channel in the controlled reach.

IV.A.6 Scenario S6: Sediment Input from Gavins Point Dam. The purpose of Run S6 was to ascertain the extent to which the shut-off of sediment supply by Gavins Point Dam is responsible for degradation in the controlled reach. This was accomplished by repeating Run S1, but with the sediment load at Gavins Point Dam assumed to be at its equilibrium value (as determined by the TLTM computation) rather than zero as in all other runs. The resulting equilibrium inflow load was about one million tons per year.

IV.A.7 Scenario S7: Artificial Armoring of Controlled Reach. As has been discussed in Section IV.A.3, degradation can ultimately be limited only by a gradual coarsening and armoring of the bed as finer materials are entrained into the flow. The term "artifical armoring" refers to the dumping of imported coarse material onto the bed in an attempt to accelerate the coarsening/armoring process by artificial means. The purpose of Run S7 is not to simulate any particular artificial armoring plan studied by the U.S. Army Corps of Engineers or others, but rather to determine the sensitivity of degradation to an idealized artificial coarsening of the bed material. This was accomplished by repeating Run S1 with the cumulative distribution function for bed material size distributions in the controlled reach shifted up to 1% downward for sizes greater than 2.40 mm, but with no change in the maximum size found on the bed, as shown schematically in Figure IV.1 (the idealized distribution shown does not represent actual Missouri River data). Interpreted physically, this represents an increase of about 10% in the amount of material coarser than 2.40 mm but finer than 19.1 mm.

IV.A.8 Scenario S8: Localized Artificial Armoring. The purpose of Run S8 was to follow up a suggestion made at the last Advisory Panel meeting, involving localized artificial armoring. If any such armoring project were ever to be undertaken, it would involve not the entire controlled reach, as in Run S7, but rather a small portion of it, where degradation problems were acute. Run S8 followed the general conditions of Run S7, except that the artificial coarsening of bed material was done only in the 10-mile reaches immediately upstream and downstream of Sioux City (RM 731.2).

IV.A.9 Scenario S9: Constant Discharge 29,000 cfs. Analysis of Run S1 (discussed in Section IV.B) showed that most of the degradation was occurring during the spring, when navigation releases of 36,000 cfs plus spring runoff in the tributaries combined to yield annual maximum discharges in the model. During winter low flows, very little degradation occurred. This suggest that any decrease in maximum flows could have a significant impact on

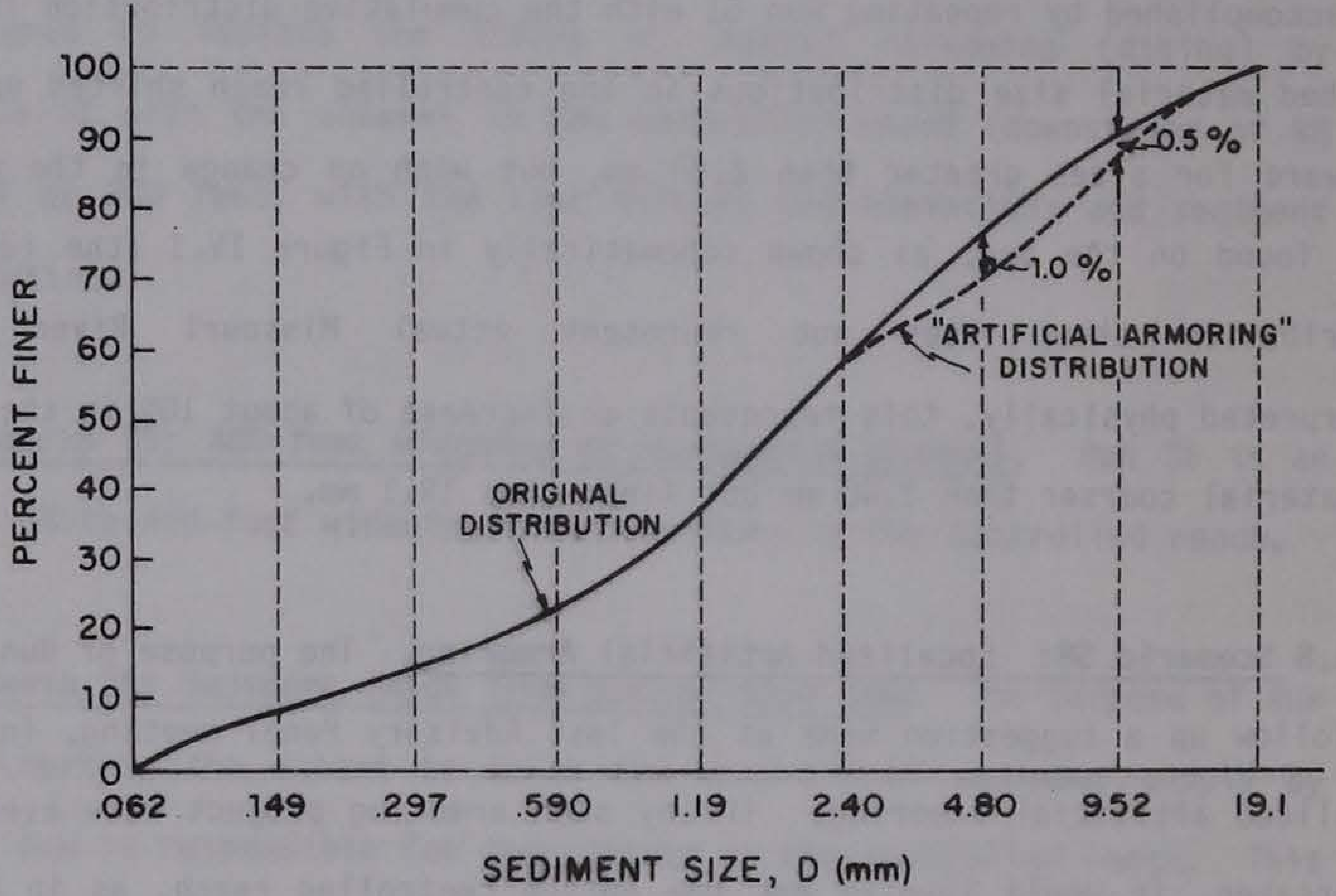


FIGURE IV 1. ARTIFICIAL ARMORING REPRESENTATION IN THE MISSOURI RIVER MODEL.

degradation. Now, the tributary discharges are not subject to control, and Gavins Point Dam must, on the average, release the mean annual flow of the Missouri Basin above Yankton. Run S9 used the conditions of Run S1, but with a constant release of 29,000 cfs from Gavins Point Dam (which produces the same annual volume as the two-stage hydrograph described in Section III.H).

IV.A.10 **Scenario S10: 1952 Flood Hydrograph.** It is axiomatic in river engineering that in natural rivers, changes in channel alignment and bed elevation occur primarily during major hydrologic events. While the upstream control reservoirs on the Missouri have largely precluded the possibility of major flooding below Gavins Point Dam, it is nonetheless of interest to know how much degradation might have occurred during major historical floods. Since the data set used in this study represents the Missouri in its present (1980) configuration, it cannot be used to reproduce an actual natural-river situation. However it is possible to simulate a historical flood hydrograph entering the present-day river, in order to obtain some idea of the amount of degradation that could occur during such an event. Accordingly, Run S10 simulates the 1952 Yankton, S.D. flood hydrograph (1952 water year, 17) entering the present model at Gavins Point Dam. A computational time step of 5 days was used to allow detailed resolution of the shape of the hydrograph, which is shown on Figure IV.2. Actual 1952 tributary discharge hydrographs were also used for this run (17).

IV.B Analysis of Simulated Scenarios.

IV.B.1 **Introduction.** The primary variable of interest in the prognosis runs is the progression of bed degradation with time all along the study reach of

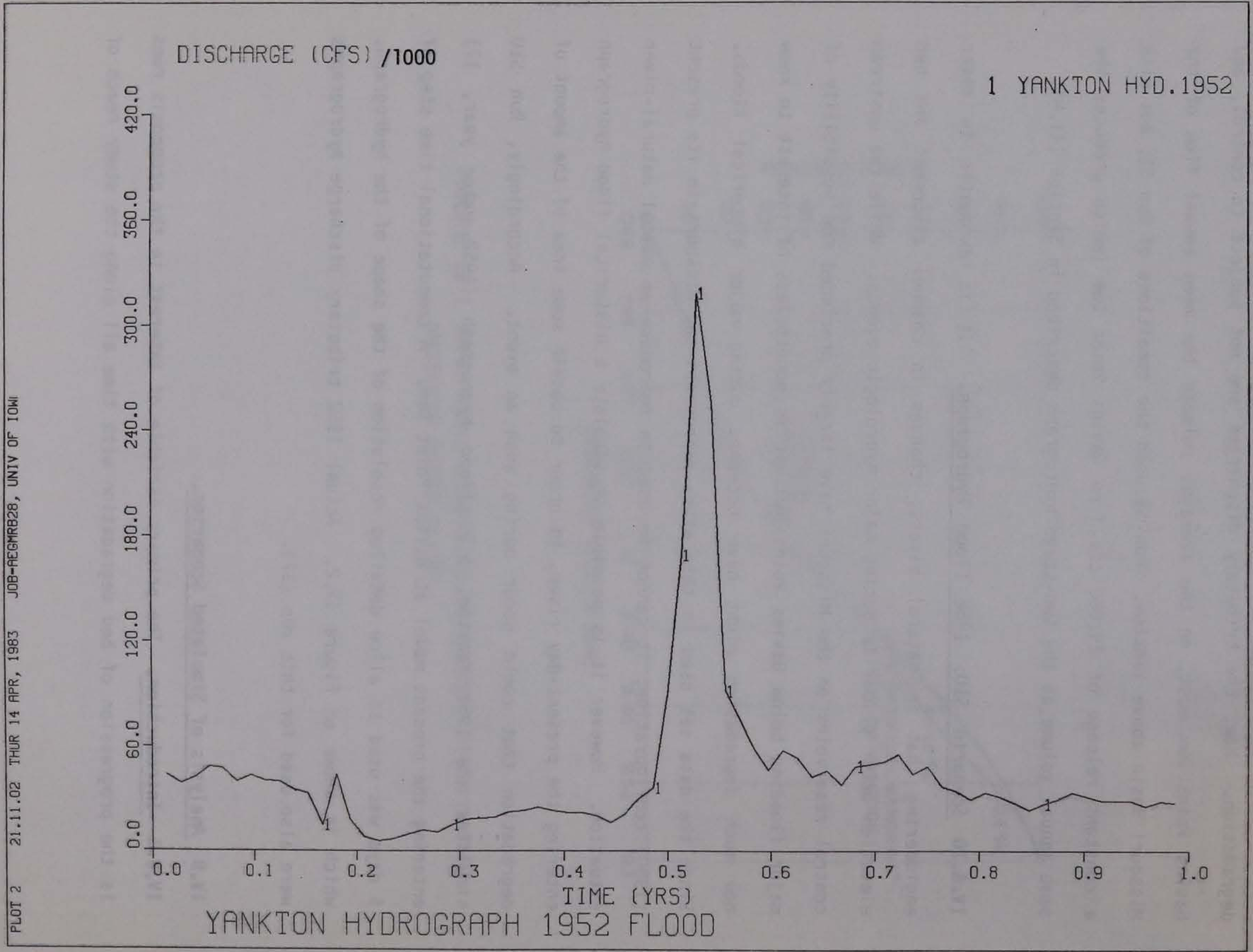


Figure IV.2 1952 Flood Hydrograph at Yankton, S.D.

the Missouri. However the degradation is but one representation of a complex process invovling many hydraulic variables. Accordingly it appears appropriate first to analyze the basic prognosis Run S1 in some detail to obtain an overview of the interrelationships among the more important variables. Subsequent analysis of the other runs will consist in proceeding from Gavins Point Dam downstream, noting the effects of the various scenarios as compared to Run S1. Finally, the one-year Run S10 will be analyzed separately.

IV.B.2 **Analysis of Run S1.** The overall results of this base 20-year prognosis run are shown on Fig. IV.3, which compares water surface and bed elevation profiles from Gavins Point Dam to the Iowa-Missouri border at the beginning (curves 1 and 2) and at the end (curves 3 and 4) of the simulation. The maximum future degradation in the uncontrolled reach is about two feet just below Gavins Point Dam, where there is no sediment inflow to supply the river's transport capacity. There is virtually no degradation from RM 780 to 770, but the effects of the controlled reach begin to be seen at RM 760.9, where about three feet of degradation is predicted.

Degradation occurs in the controlled reach from its upstream end down to the vicinity of Omaha. The maximum degradation is about four feet near RM 680; the average throughout this reach is roughly two feet.

From Omaha to the Platte River confluence there is general deposition, approaching three feet near RM 610; this appears to be due to the Platte River, whose fairly coarse sediment load cannot readily be transported by the Missouri, and whose large water inflow causes a backwater effect upstream of the confluence.

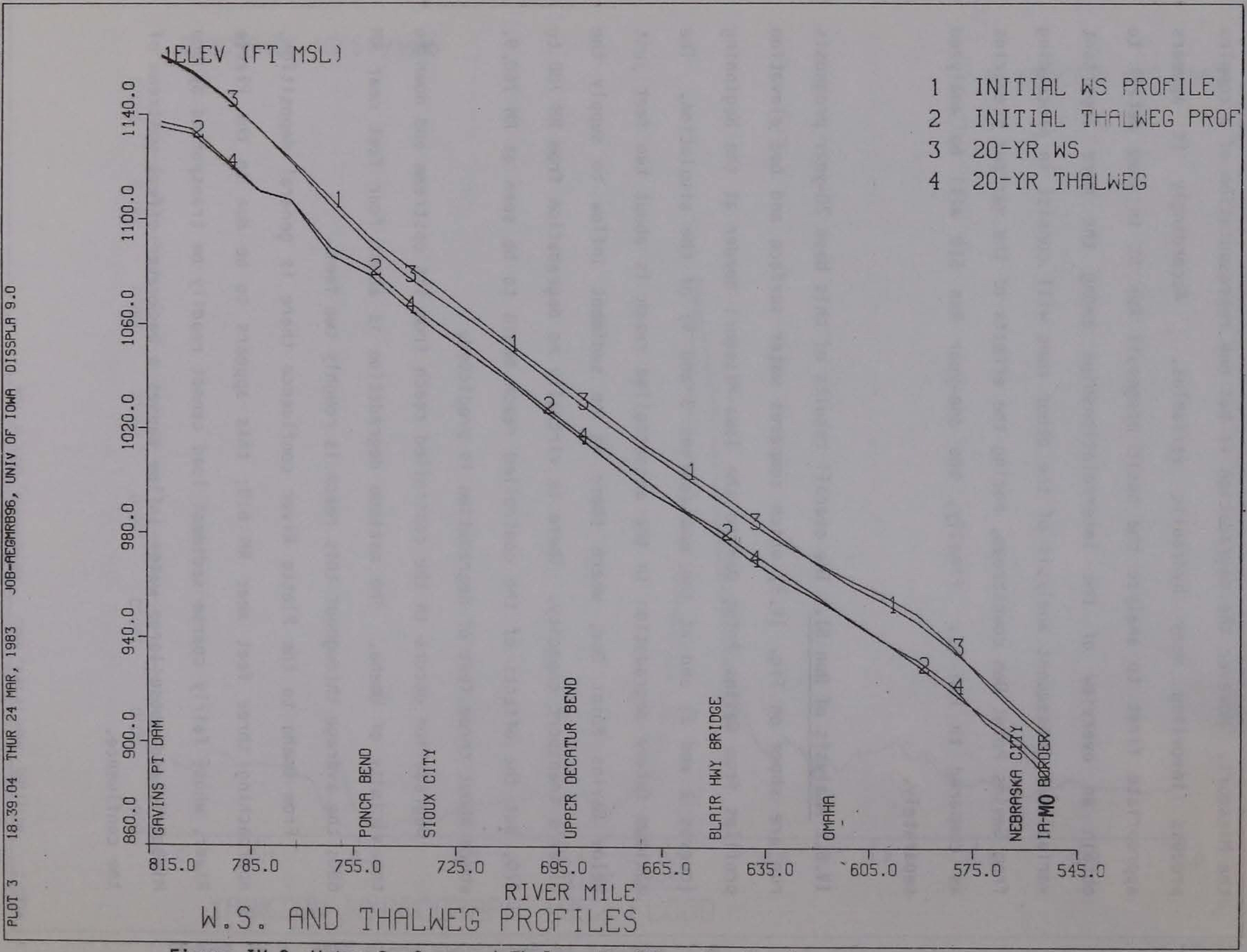


Figure IV.3 Water Surface and Thalweg Profiles for Run 1

Below the Platte River confluence there is a general trend of degradation, attaining a maximum of about two feet near RM 570. The apparent deposition below the Iowa-Missouri border should be discounted, as this reach of the river is strongly influenced by the approximate downstream boundary condition employed.

The water surface profiles on Fig. IV.3 (corresponding to springtime conditions) exhibit the same general behavior as the bed profiles; the maximum additional lowering in twenty years is somewhat less than four feet, near RM 740. it should be noted that the water surface elevation is affected by both the bed elevation and bed material size, so that in general there is no reason to expect maximum bed degradation and maximum water surface lowering to occur at the same point along the river.

Figure IV.4 shows another aspect of the results of Run S1, namely, the changes in bed material size and the concomitant development of bed armoring. Curve 1 shows the median bed material size at the beginning of the simulation. From Gavins Point Dam down to Omaha the median size is relatively constant, varying between 0.30 and 0.45 mm. From Omaha to near the Platte River confluence the material is somewhat finer, reflecting the deposition in this reach caused by the Platte's backwater effect. The rapid increase in D_{50} to about 0.5 mm below the Platte reflects the local steepening of the Missouri's energy slope due to the Platte's water inflow.

Curve 2 of Figure IV.4 shows the computed median bed material size after twenty years. The most notable change in D_{50} occurred just below Gavins Point Dam, where the absence of any sediment inflow caused a fairly rapid coarsening of the bed material, finer sizes being preferentially removed to satisfy the Missouri's transport capacity. The coarsening is much less dramatic in the

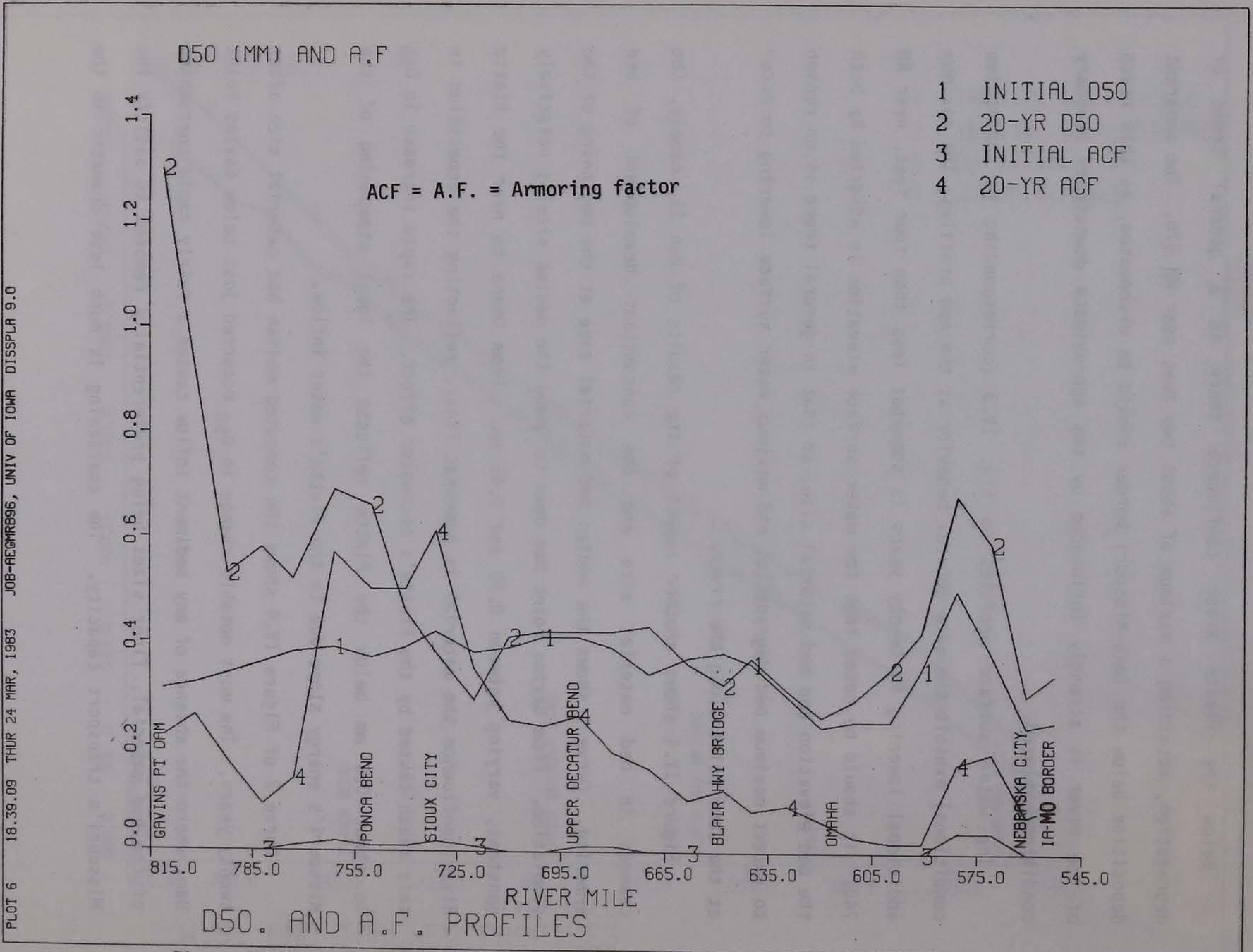


Figure IV.4 D_{50} and Armoring Factor Profiles for Run S1 remainder of the model. There is no significant net change in D_{50} from about Sioux City to Omaha, this being the reach of systematic degradation as discussed earlier. Below Omaha the apparent slight 20-year coarsening of the bed material is not significant, as a more detailed analysis of the time-history of D_{50} in this reach has shown that the random variations in D_{50} from one year to the next can be greater than the apparent 20-year change suggested by curves 1 and 2 of Figure IV-4.

Curve 3 of Figure IV-4 shows the armoring factor (fraction of bed area covered by armoring-size material, Eq. (8)) after the first time step of 15 days. This factor was set to zero initially; the small positive values shown in the figure represent the beginnings of the armoring process as computed by IALLUVIAL. Curve 4 shows the armoring factor after 20 years of simulation. The roughly 0.2 armoring factor just below Gavins Point Dam may seem low in view of the two feet of degradation there. This is explained by referring again to curve 2 of Figure IV.4, showing that it was the considerable coarsening of the bed material, rather than the development of a stable armor coat, which limited the degradation below the dam. It is known from on-site observations (see for example Fig. 2.87, page 182 of Reference 8) that a stable armor coat probably exists at the present time below the dam, but this was not taken into account in the initial conditions for the prognosis runs of this study. In future studies it may be useful to simulate this initial armoring condition where it is known to exist.

The 20-year armoring factor decreases to about 0.1 in the uncontrolled reach below Gavins Point Dam, reflecting the fact that little or no additional degradation occurs in that reach. Then it rises to nearly 0.6 in the upstream portions of the controlled reach, consistent with the computed three-to-four feet of degradation as noted earlier, and availability of armoring size fractions. It is in fact the approach of the armoring factor to 1.0 that represents, or is the mechanism for, arresting the ultimate degradation in the controlled reach (assuming no bedrock or other controls, as is the case in this study). From about Sioux City on downstream the armoring factor progressively decreases to a low of about 0.03 below Omaha, reflecting the decreased degradation and even deposition observed as one moves downstream. The armoring factor increases once more from the Platte confluence at RM 591.5, attaining 0.2 above Nebraska City. This local increase reflects the availability of more armoring size freactions than in other portions of the studied river, as seen in the bed material size distribution data of Table III-3 (RM 571.0 in particular).

The many additional dependent variables whose computed variations with time constitute the complete results of Run S1 could be analyzed in detail; but this analysis would add little to the basic understanding of the dynamics of the Missouri model given by bed and water surface elevations, median bed material size, and armoring factor. Appendix D contains listings of all computed variables for Run S1 after 5,10,15, and 20 years of simulation. The time-variation of bed elevations for Run S1 as well as the other runs are analyzed in detail in the following sections.

Table IV-1 summarizes the computed degradations for all runs of this study, as well as Runs IV-A and IV-B of Reference 3. These two runs simulated past degradation, 1955 to 1975, using a simplified data set for the Missouri River, and the same Gavins Point Dam releases as Run S1. Case IV-B differs from IV-A in its inclusion of tributaries and erosion of relatively coarse bank material, having the same composition as the local bed sediments. One

Table IV-1

Summary of Degradation Computations

RM (1960)	Computed Degradation for Indicated Period and Run, in feet											
	1955-1975*		1980-2000							1980-1990	1980-1990	1980 1981
	IV-A	IV-B	S1**	S2	S4	S5	S6	S8	S9	S3	S7	S10
811.0			2.0	1.6	1.6	2.1	-1.0	2.1	2.1	1.4	1.4	0.5
810.9	4.2	3.6										
801.9			2.0	1.8	1.9	1.3	-0.3	2.0	1.9	2.5	1.2	0.7
801.2	3.5	3.0										
792.0			1.0	1.1	1.4	1.2	0	1.0	0.7	1.5	0.6	0.2
791.4	1.3	0.9										
782.1			0.3	-0.4	-0.2	-0.2	0.1	0.3	-0.3	-0.7	-0.1	-0.2
781.7	1.6	1.0										
772.9			-0.1	-0.7	-0.3	0.2	-0.1	-0.1	-0.3	-0.4	-0.2	0.1
771.9	3.3	2.1										
762.2	4.7	3.3										
760.9			2.7	2.3	2.2	2.3	2.7	2.5	1.6	2.6	1.5	0.6
752.4	6.2	5.1										
750.0			2.9	2.4	2.1	0.8	2.9	2.6	1.5	2.2	1.4	0.2
742.7	5.6	5.8										
740.0			2.6	2.4	1.7	0.4	2.7	1.9	2.1	2.7	1.1	-0.2
732.9	6.6	6.7										
736.2			3.0	2.8	2.0	1.1	3.1	2.1	2.5	3.3	1.4	1.0
723.2	7.2	7.3										
720.0			2.7	2.2	1.7	1.5	2.8	2.8	2.6	4.0	2.0	1.0
713.4	6.1	6.7										
710.0			1.1	0.6	0.5	0.6	1.1	1.6	1.2	2.1	1.2	0
703.7	5.3	5.9										
700.0			1.4	0.9	0.8	0.6	1.4	1.7	1.5	2.4	1.3	-0.7
693.9	5.8	6.9										
690.0			1.8	1.1	0.9	0.8	1.7	1.9	1.5	1.6	1.0	0.3
684.2	5.9	7.6										
680.0			3.7	3.0	2.7	2.3	3.4	3.7	3.5	4.8	2.4	0.7
674.4	4.4	5.7										
669.5			3.4	3.0	1.9	0.9	3.2	3.6	3.2	1.3	1.4	-0.1
664.7	4.0	4.2										
658.5			0.2	0.5	-0.4	-1.1	0.3	0.6	0	-2.9	-1.4	0.1
654.9	3.8	4.4										
648.2			1.9	2.2	1.3	0.9	2.3	2.1	1.7	-3.5	-1.0	1.2
645.2	3.8	5.8										
640.0			2.0	2.5	2.0	1.7	2.4	2.1	2.0	-3.0	0.6	1.1
635.4	1.2	2.6										
630.0			2.0	2.6	2.2	1.4	2.2	2.4	2.2	-2.0	0.1	1.5
625.7	-1.8	-1.0										

Table IV-1 (cont.)

Summary of Degradation Computations

RM (1960)	Computed Degradation for Indicated Period and Run, in feet											
	1955-1975*		1980-2000							1980-1990	1980-1990	1980 1981
	IV-A	IV-B	S1**	S2	S4	S5	S6	S8	S9	S3	S7	S10
620.0			-0.6	0.5	0.3	0.1	-0.5	0	0.6	-2.5	-0.9	0.6
615.9	-0.9	0.3										
610.5			-2.7	-1.1	-1.7	-0.8	-2.9	-2.1	-0.2	-0.7	-5.0	-0.7
606.2	0.3	0.9										
600.0			-1.3	-0.5	-1.4	-0.9	-1.6	-1.2	0	0.6	-5.2	-0.2
591.0			0.9	0.8	0.4	-0.3	1.0	0.4	0	-14.7	-11.5	0.4
581.0			0.3	0.5	0.1	-1.2	0.9	0.3	-0.9	-21.3	-13.7	1.4
571.0			1.7	2.3	2.3	2.1	2.1	2.1	0.7	-1.5	-0.2	2.9
561.0			1.7	2.3	2.7	2.9	1.8	1.8	0.7	0	1.1	1.9
553.0			0.5	0.8	1.0	1.1	0.5	0.5	-0.9	-0.1	0.1	0.1

*runs IV-A and IV-B taken from Reference 3

** Run S1: Present condition
Run S2: Upper basin diversion of 3 MAF/yr
Run S3: Constant discharge of 65,000 cfs
Run S4: 200 ft wider navigation channel
Run S5: 400 ft wider navigation channel
Run S6: Gavins Point Dam absent
Run S7: Artificial armoring in controlled reach
Run S8: Localized artifical armoring
Run S9: Constant discharge of 29,000 cfs
Run S10: With 1952 flood hydrograph

expects the bed response to be affected by two distinct factors; the increase in water discharge due to tributary inflow, and the supply of sediment from tributaries and bank erosion. Tributaries increase the average annual discharge at Omaha by about 21%, whereas the annual bank and tributary sediment supply corresponds to only about 4% of the average annual total sediment load at Omaha. Comparison of the simulation results for Runs IV-A and IV-B tends to confirm that the increased discharges are the predominant influence. In the uncontrolled reach above Sioux City, the supply of sediment from the banks and tributaries is apparently sufficient to more than compensate for the increased water discharge (and transport capacity), as seen in the net decrease in degradation of the order of one foot. Downstream of Sioux City, the stabilized banks supply no additional sediment, and the increased discharges cause up to 1.9 feet of additional degradation.

IV.B.3 Bed Evolution in the Uncontrolled Reach.

Figures IV.5-IV.10 show the computed bed elevation changes at the six computational points between Gavins Point Dam and Ponca Bend, for Runs S1 through S9. One characteristic feature of all the runs and points is a relatively rapid change in bed levels during the first several years, followed by a more gradual evolution approaching equilibrium. The inital rapid changes reflect the fact the the computation assumed no bed armoring at the beginning of the simulations, so that it was necessary for some initial degradation to occur before enough armor-size material could accumulate on the bed to begin to slow down further degradation.

At Gavins Point Dam (Figure IV.5) the nine runs exhibit three distinct kinds of bed responses. Runs S1, S3, S5, S7, S8, and S9 differ very little

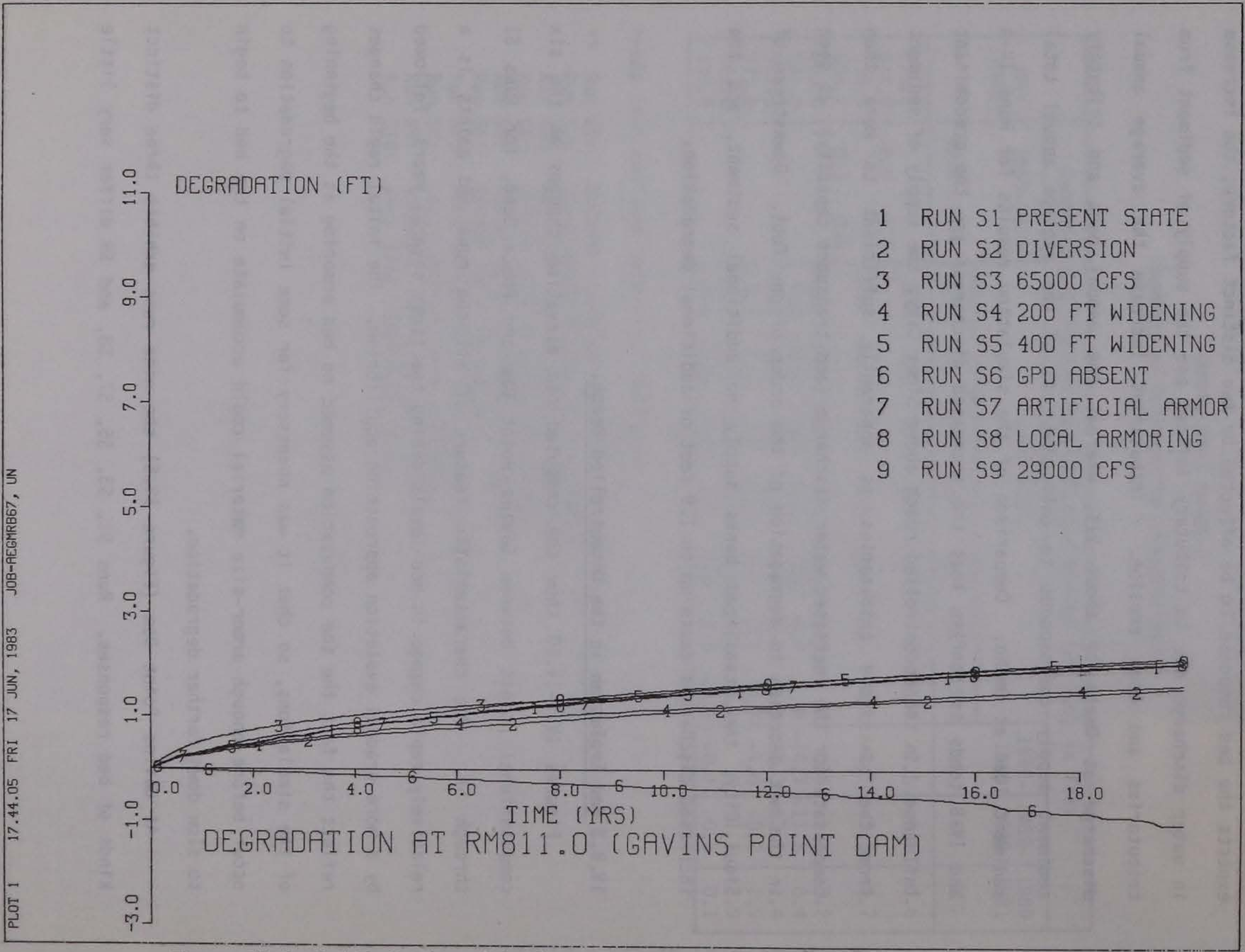


Figure IV.5 Bed Evolution with Time, RM 811.0

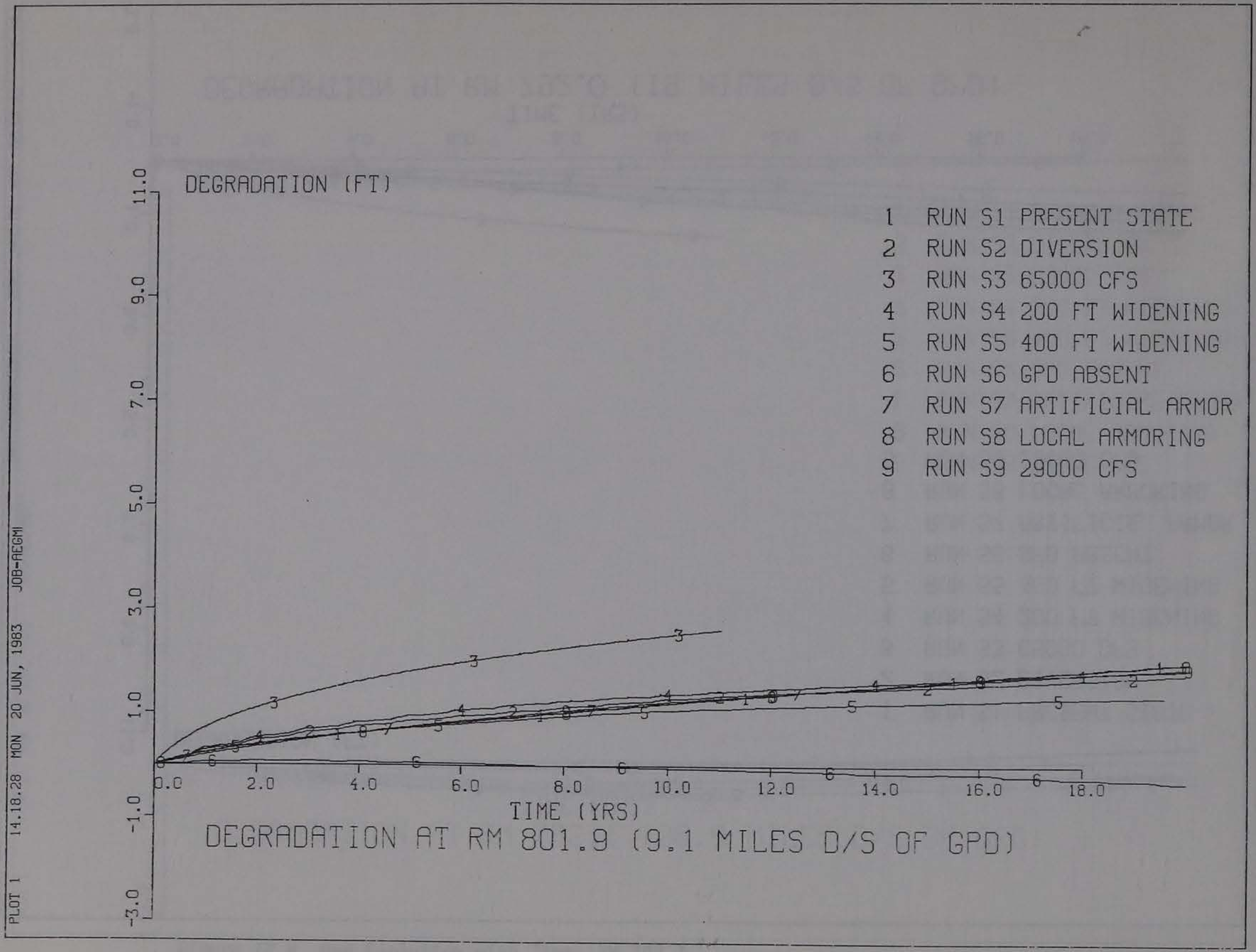


Figure IV.6 Bed Evolution with Time, RM 801.9

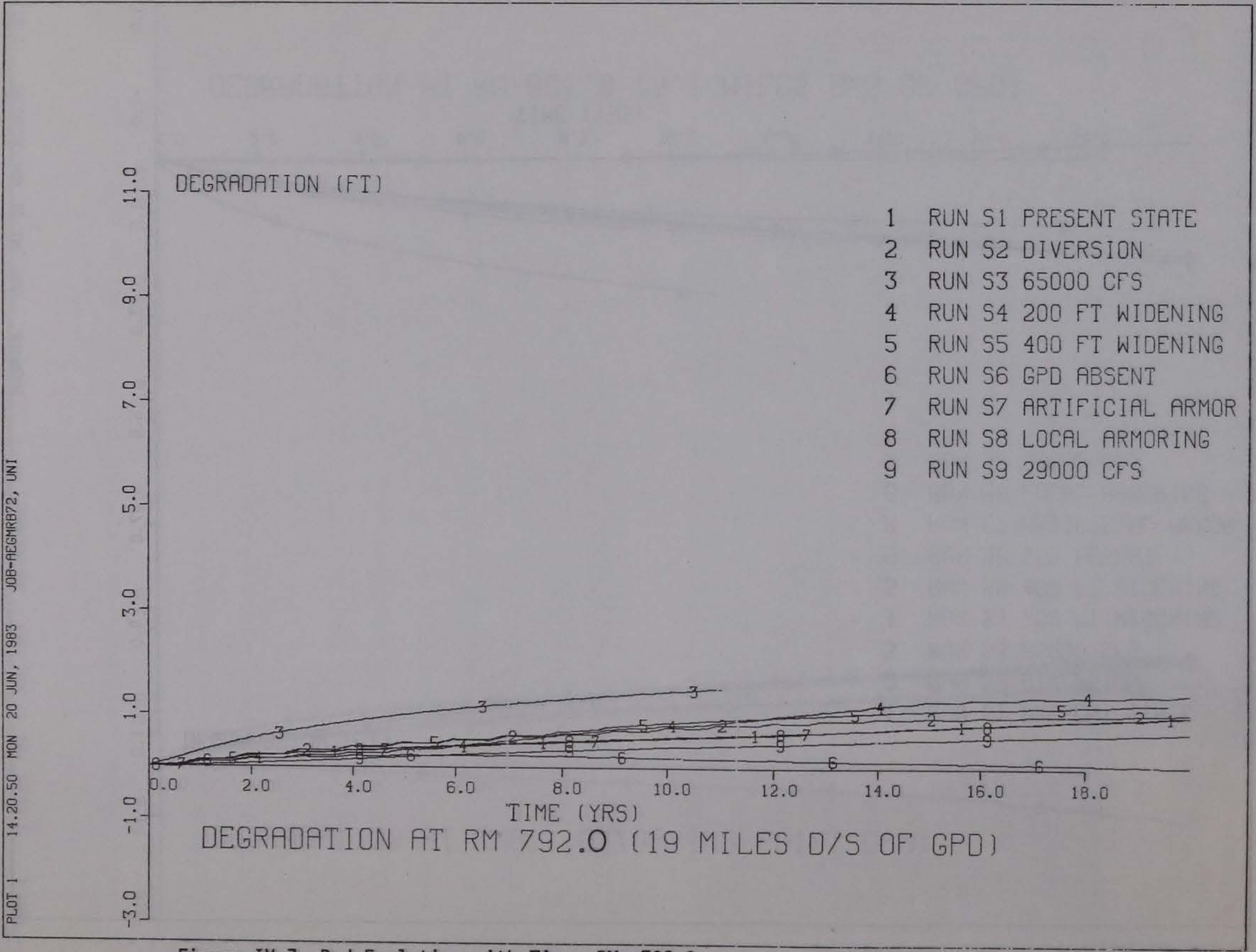


Figure IV.7 Bed Evolution with Time, RM 792.0

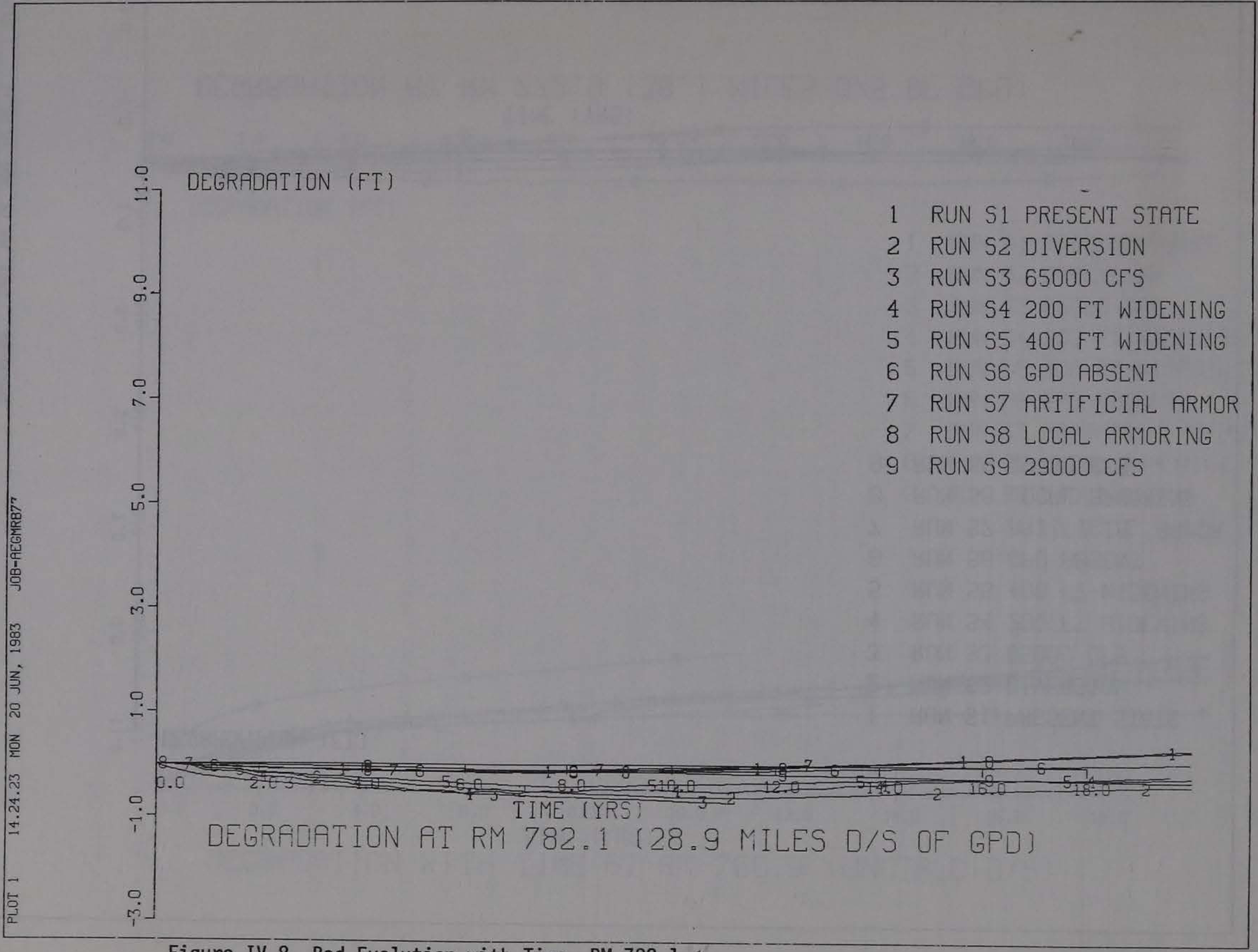


Figure IV.8 **Bed Evolution with Time, RM 782.1**

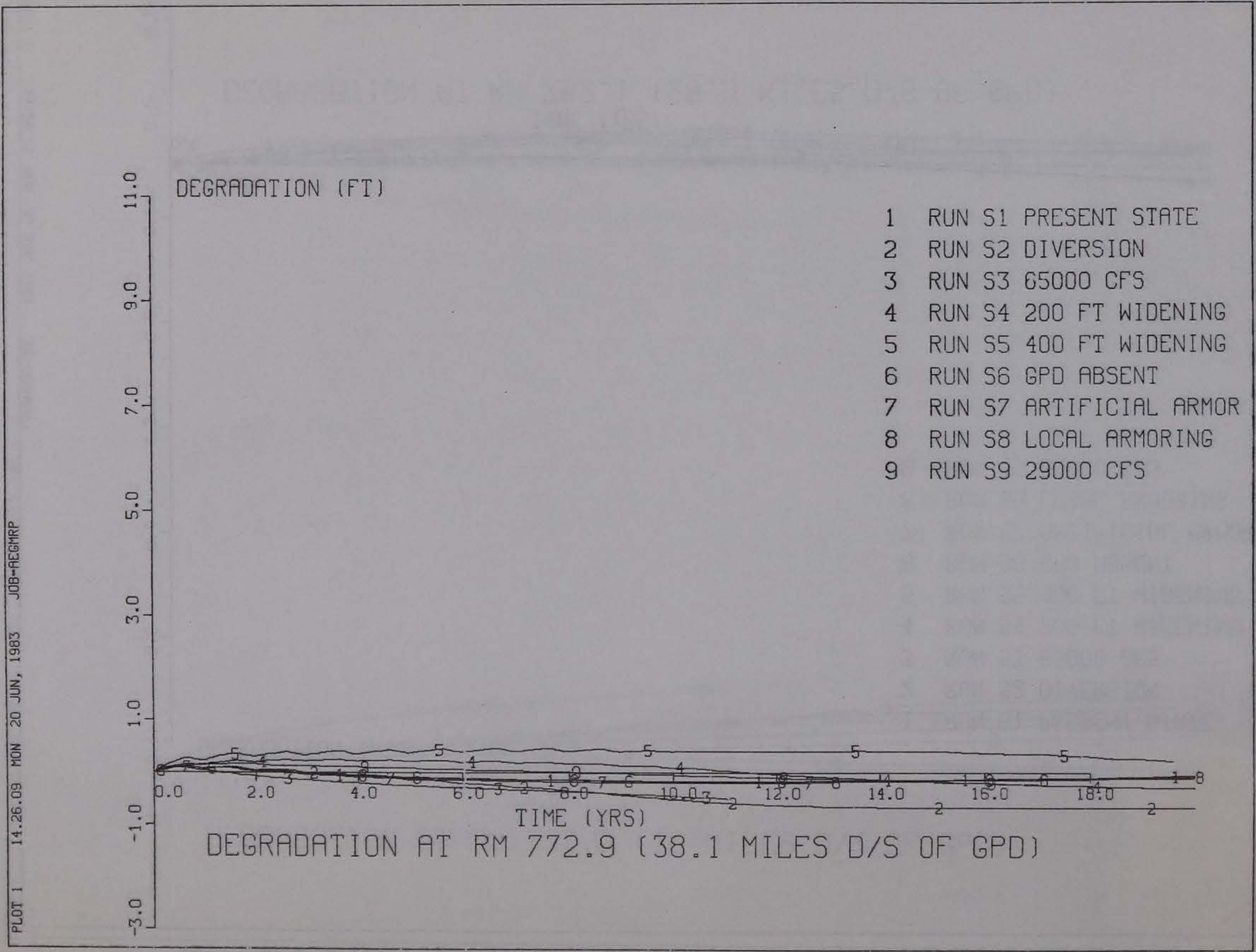


Figure IV.9 Bed Evolution with Time, RM 772.9

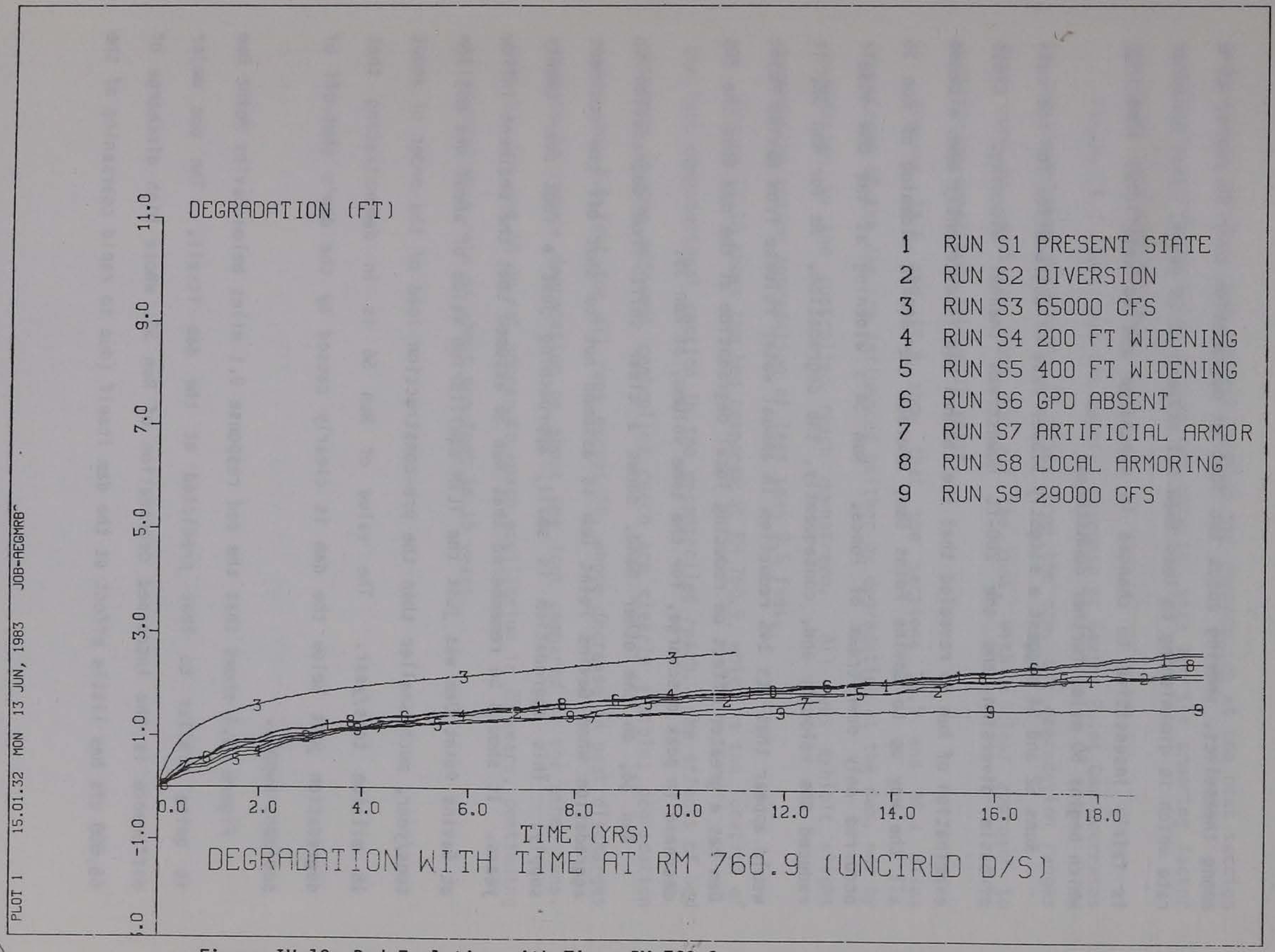


Figure IV.10 Bed Evolution with Time, RM 760.9

among themselves, showing about two feet of degradation over 20 years, at a rate which is diminishing to less than 0.1 ft/year at 20 years. This behavior is fairly insensitive to changes in discharge and to artificial armoring, which begins 50 miles further downstream.

Runs S2 and S4 suggest a slightly slower rate of degradation for the out-of-basin diversion and the 200-ft downstream channel widening. Close examination of Run S4 revealed that the channel had inadvertently been widened all the way up to Gavins Point Dam, whereas the 400-ft widening of Run S5 occurred only downstream of Ponca. Run S4's widening at the dam itself reduced the velocity and, consequently, the degradation. As for Run S2, it would appear that its 14% reduction in annual water release from Gavins Point Dam has a greater effect on reducing local degradation at the dam than the 20% decrease in peak discharge, for the same volume, of Run S9.

Run S6, on the other hand, shows a clear shift from degradation to aggradation when Gavins Point Dam is assumed not to shut off the sediment supply. This aggradation is small, approaching just a foot over twenty years. It should be remembered that Run S6 assumed that the sediment inflow at Gavins Point Dam was just the TLTM equilibrium value of about one million tons/year, much smaller than the pre-construction load of the order of about 18 million tons/year. The value of Run S6 is in demonstrating that degradation just below the dam is clearly caused by the dam's shut-off of sediment supply.

Figure IV.6 shows that the bed response 9.1 miles below Gavins Point Dam is quite similar to that predicted at the dam itself. The one major difference is the increased degradation of Run S3, whose high discharge of 65,000 cfs has little effect at the dam itself (due to rapid coarsening of the bed material there) but roughly doubles the degradation at the next section downstream, where both the median bed material size and the armoring factor are lower (see Fig. IV.4).

Figure IV.7 shows that the general response at Gavins Point Dam decreases in the downstream direction; 19 miles from the dam, the degradation ranges from zero to about one foot for all the runs, with a clear approach to equilibrium conditions beyond 15 years.

Figures IV.8 and IV.9 show that the sections 28.9 and 38.1 miles downstream of the dam are influenced neither by degradation at the dam, nor by degradation in the controlled reach downstream. All runs exhibit slight degradation and/or aggradation of less than 0.5 feet.

Figure IV.10 shows the bed response at RM 760.9, which is the location of the last computational section in the uncontrolled reach. The effects of bed response in the adjacent controlled reach are clearly visible; degradation approaches 2.5 feet for all runs except S9, whose decrease in peak discharges appears to reduce degradation by about one foot compared to the other runs. Runs S1, S6, and S8 do not appear to reach equilibrium in 20 years, continuing to degrade at a rate of about one foot in 15 years.

IV.B.4 **Bed Evolution in the Controlled Reach Above Omaha.** Figures IV.11 - IV.24 show the computed degradation at the 14 computational sections of the controlled reach above Gibson Bend.

The bed responses of Runs S3 and S7, which differ markedly from the other runs, are considered separately in Section IV.B.6 after analysis and discussion of the non-anomalous cases.

Of the many different aspects of bed response as predicted by the prognosis runs, perhaps the most important one is the approach to equilibrium conditions, i.e., the tendancy toward cessation of further degradation and/or deposition. Examination of the trends at the end of the various simulations shows that the sections at and below Omadi Bend (RM 720.0, Figure IV.14) reach, after about 10-12 years, a state of quasi-equilibrium for all the runs (except S3 and S7, see earlier remarks). We say "quasi" equilibrium because Figures IV.19 to IV.24 show that short-term degradation and/or aggradation cycles of a year or two duration persist below Little Sioux Bend (RM 669.5) at 20 years, even though there appear to be no persistent long-term net bed level changes occurring. On the other hand the first three sections of the controlled reach, at Ponca Bend (RM 750.0), McCook Lake Bend (RM 740.0) and Sioux City (RM 731.2) do not appear, with the exception of Run S5, to have reached equilibrium in twenty years. The rate of degradation is decreasing at McCook Lake Bend and Sioux City, suggesting that an equilibrium situation is indeed being approached, but the degradation rate is still constant and as high as 0.1 ft/year at Ponca Bend for Run S1. These observations about time to equilibrium apply, with a few exceptions, to all the prognosis runs except S3 and S7. We now turn to a more detailed consideration of the effect of the various scenarios.

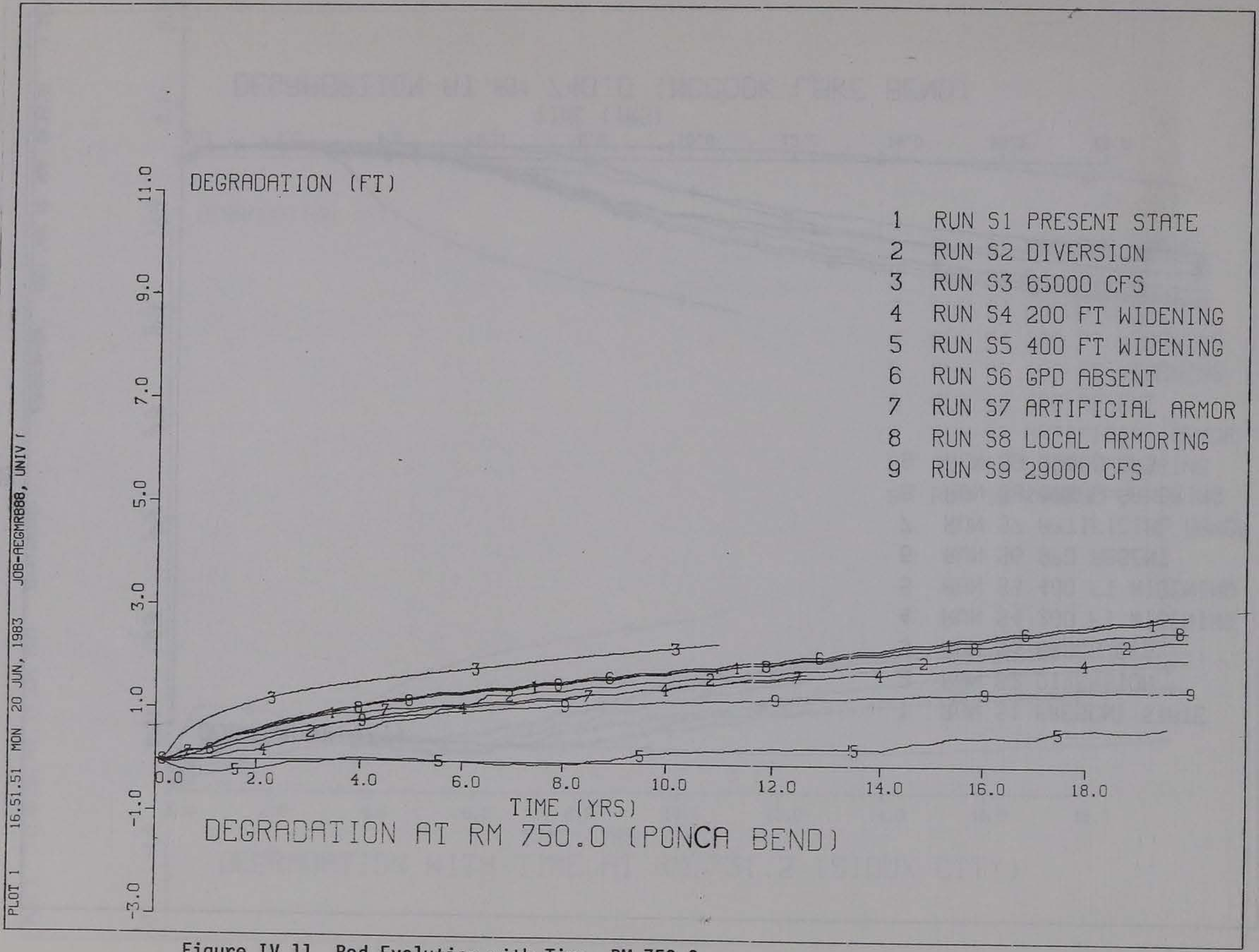


Figure IV.11 Bed Evolution with Time, RM 750.0

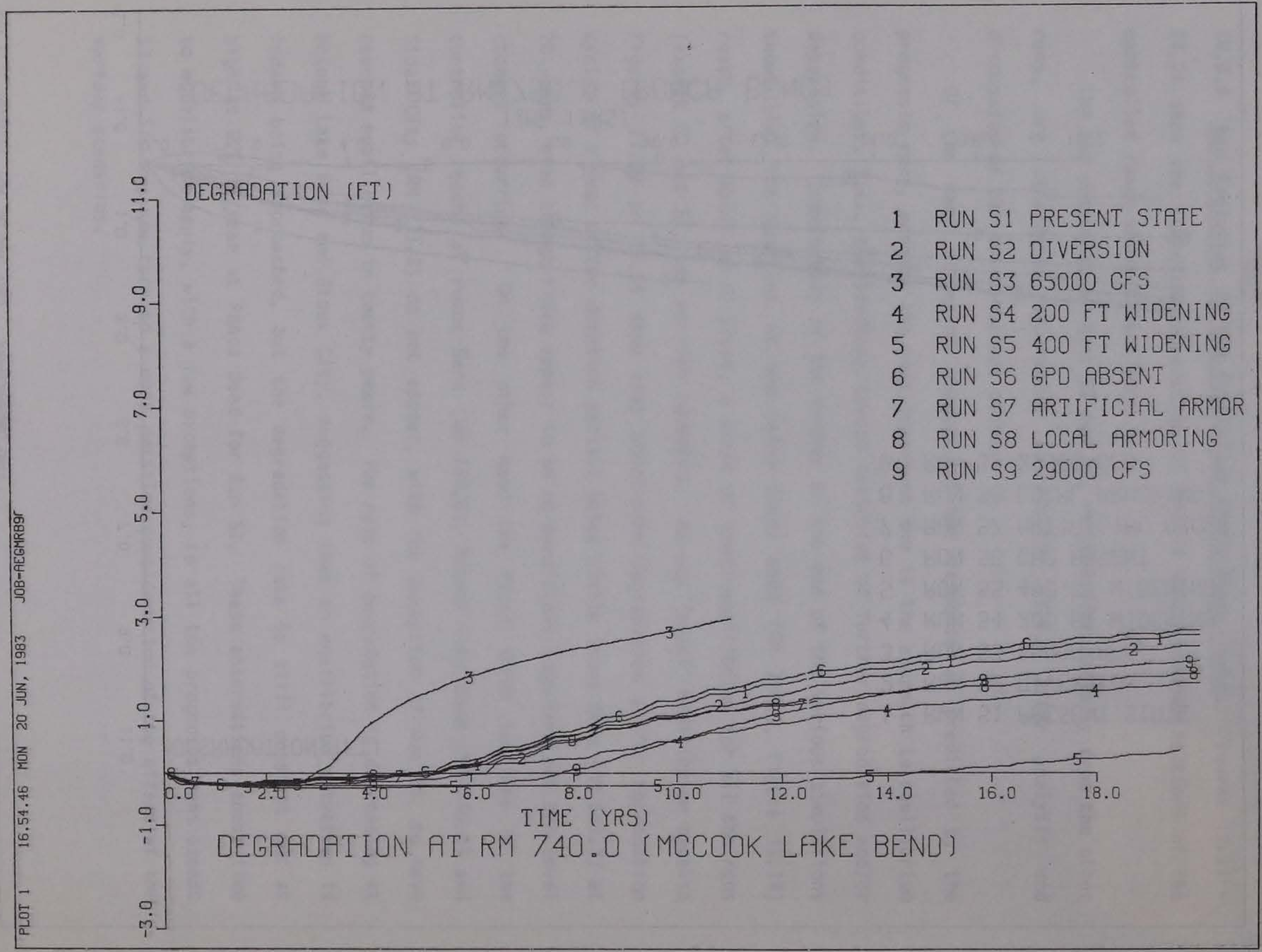


Figure IV.12 Bed Evolution with Time, RM 740.0

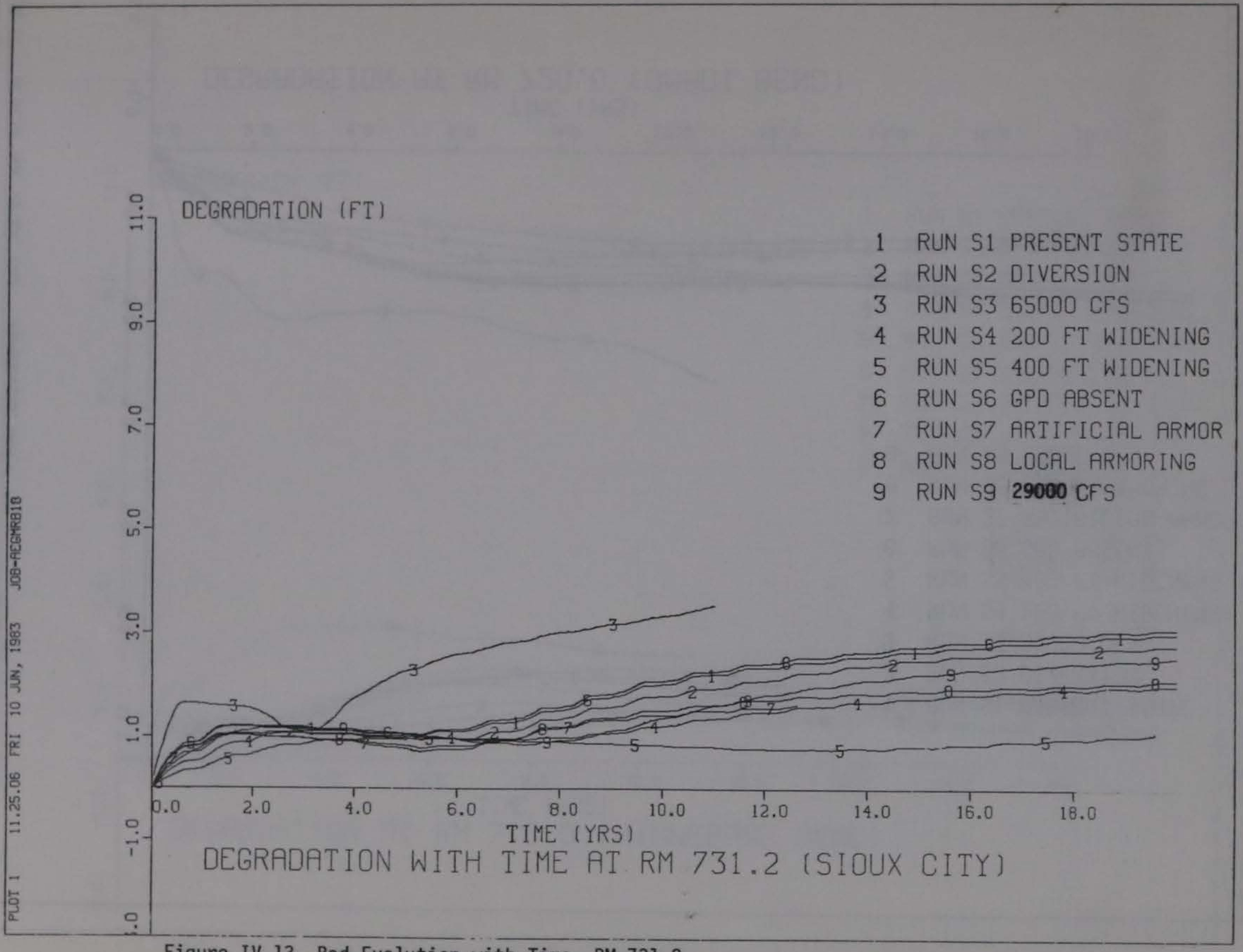


Figure IV.13 Bed Evolution with Time, RM 731.2

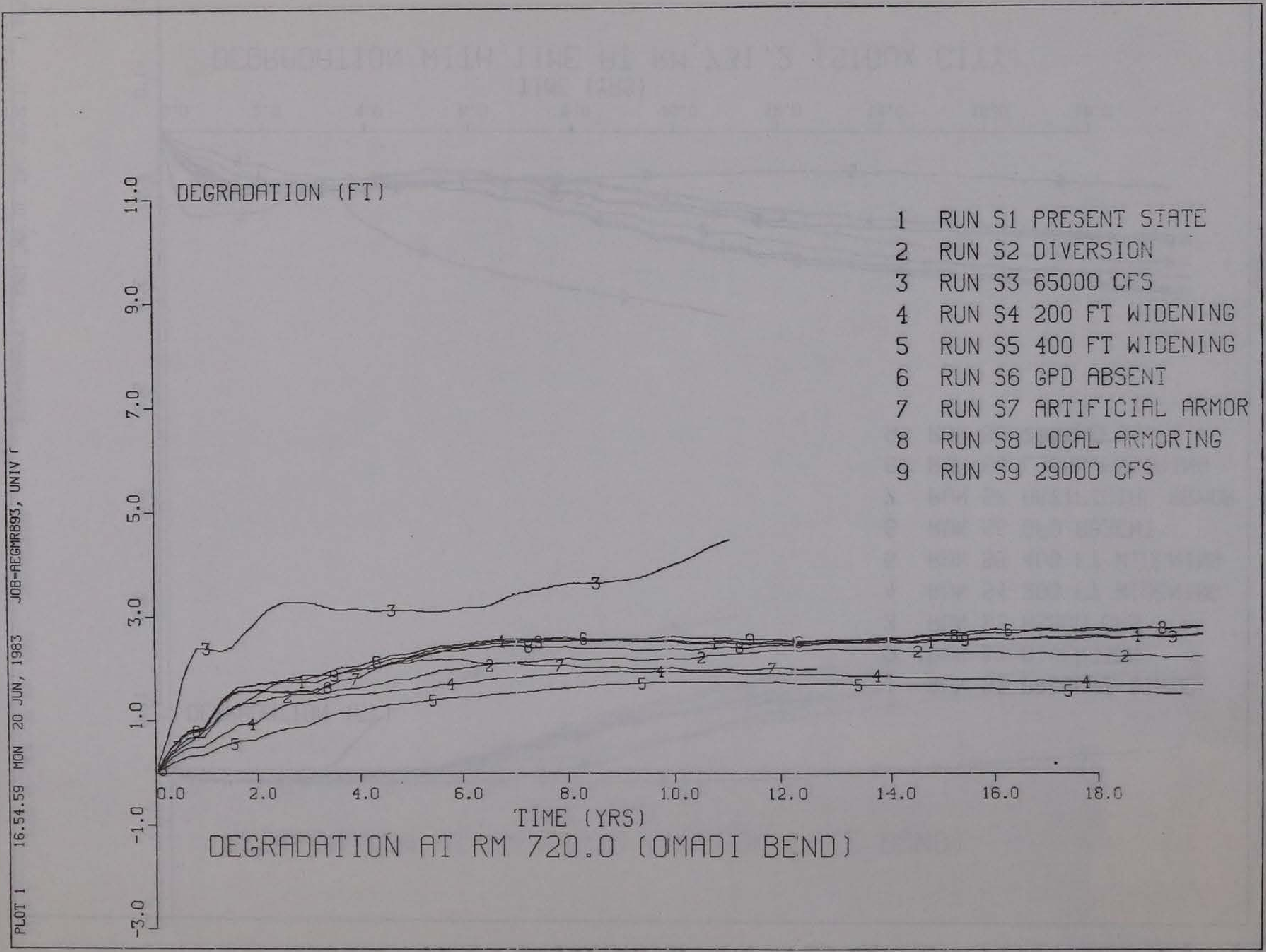


Figure IV.14 Bed Evolution with Time, RM 720.0

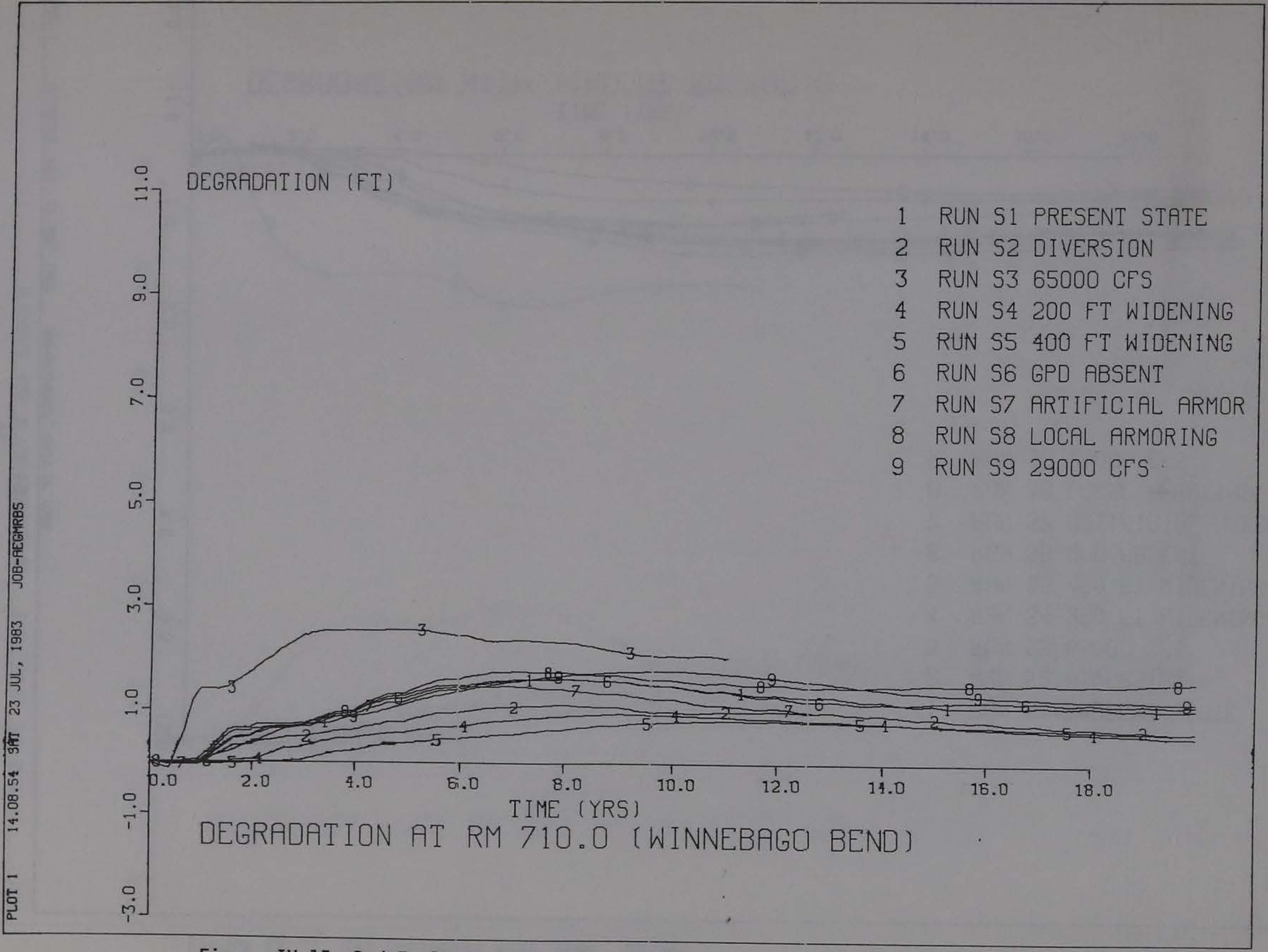


Figure IV.15 Bed Evolution with Time, RM 710.0

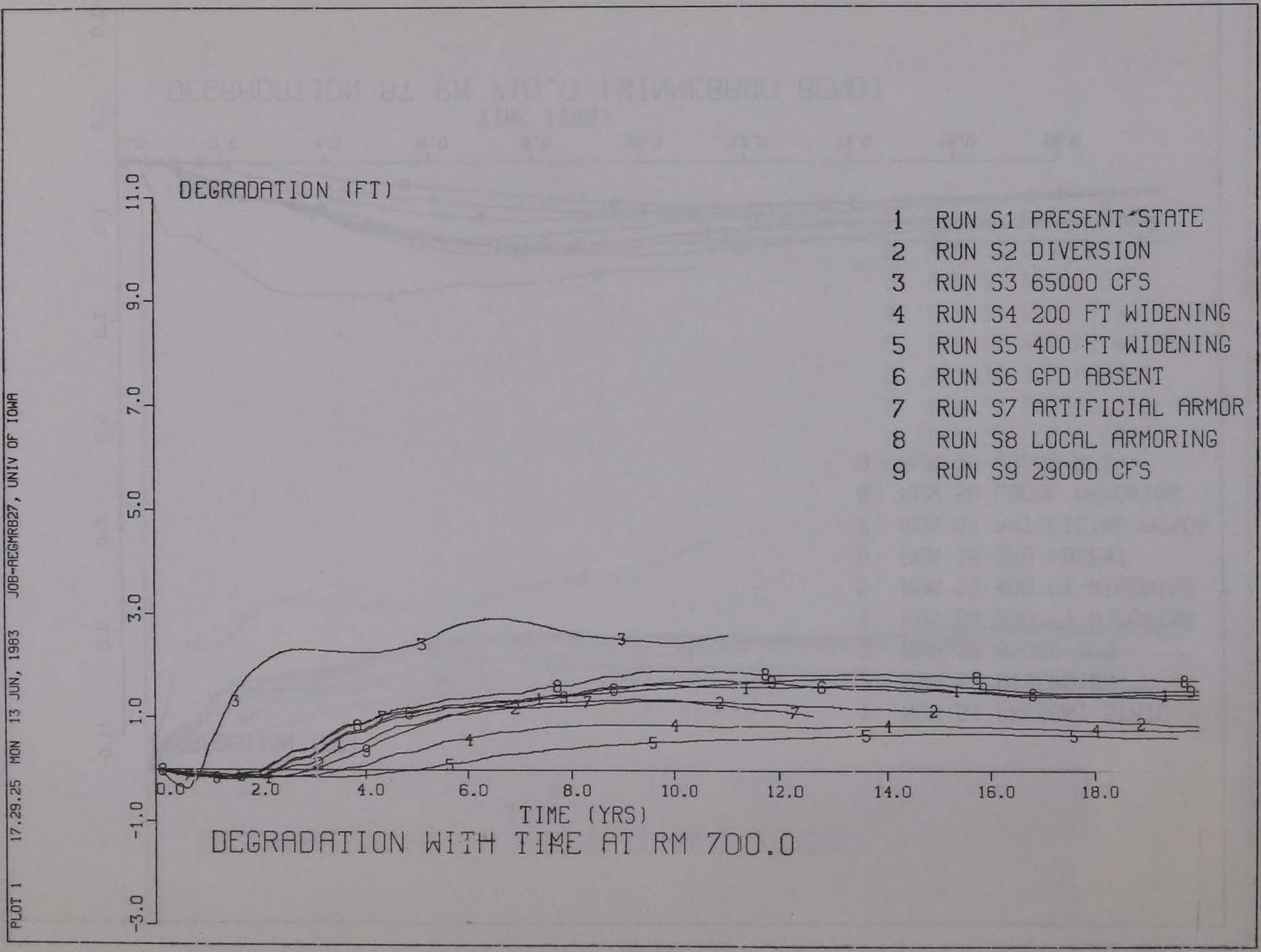


Figure IV.16 Bed Evolution with Time, RM 700.0

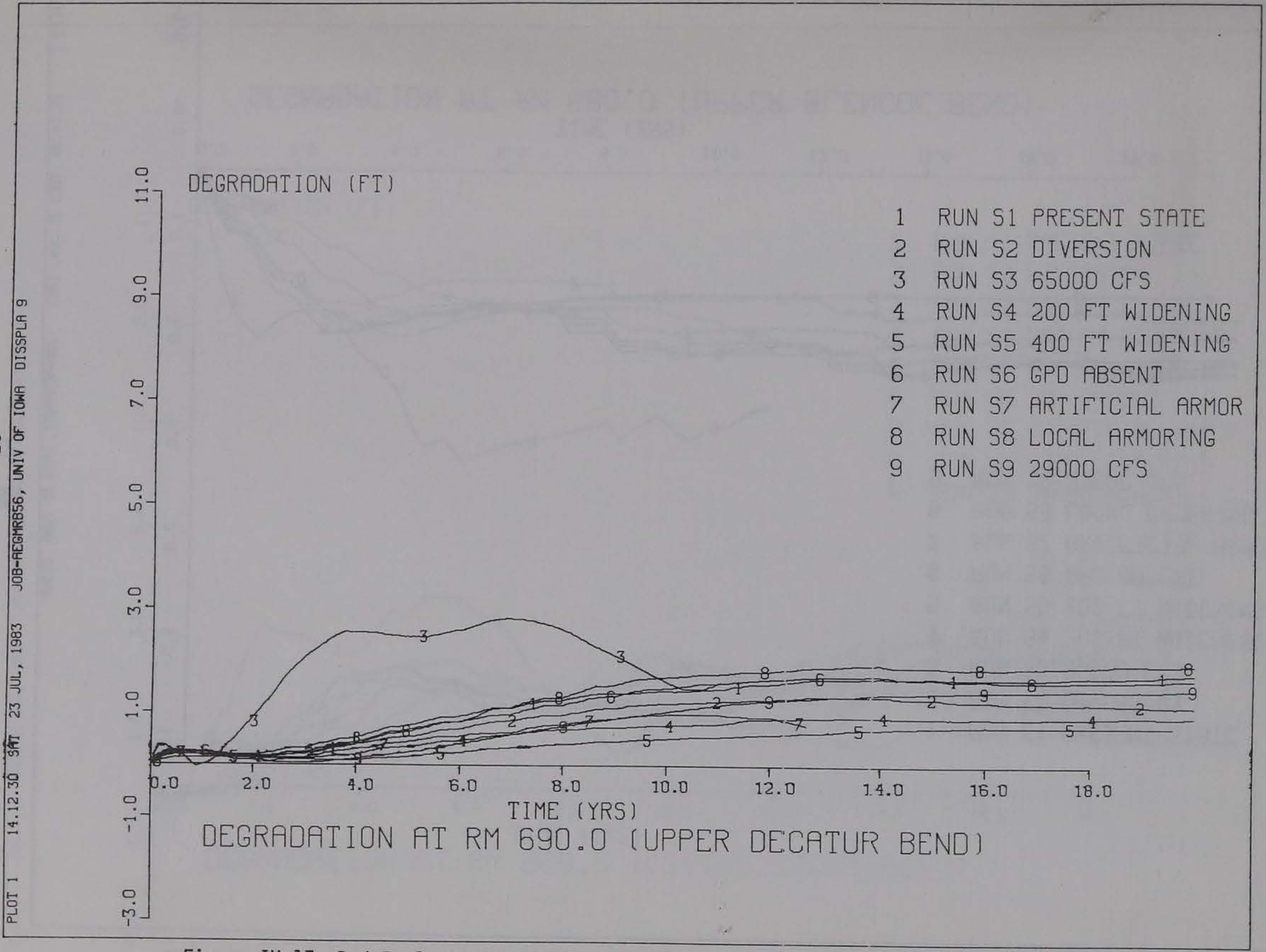


Figure IV.17 Bed Evolution with Time, RM 690.0

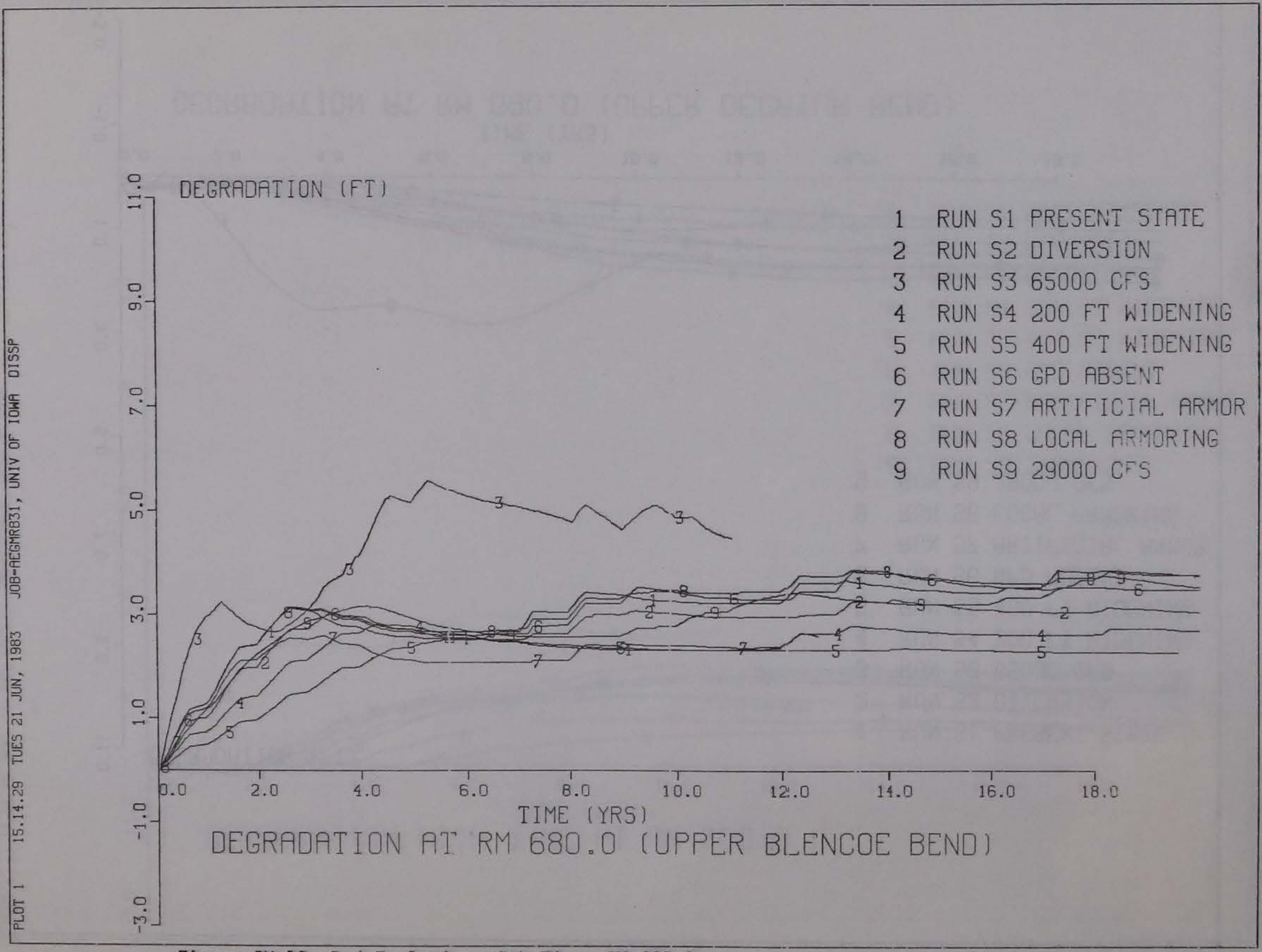


Figure IV.18 Bed Evolution with Time, RM 680.0

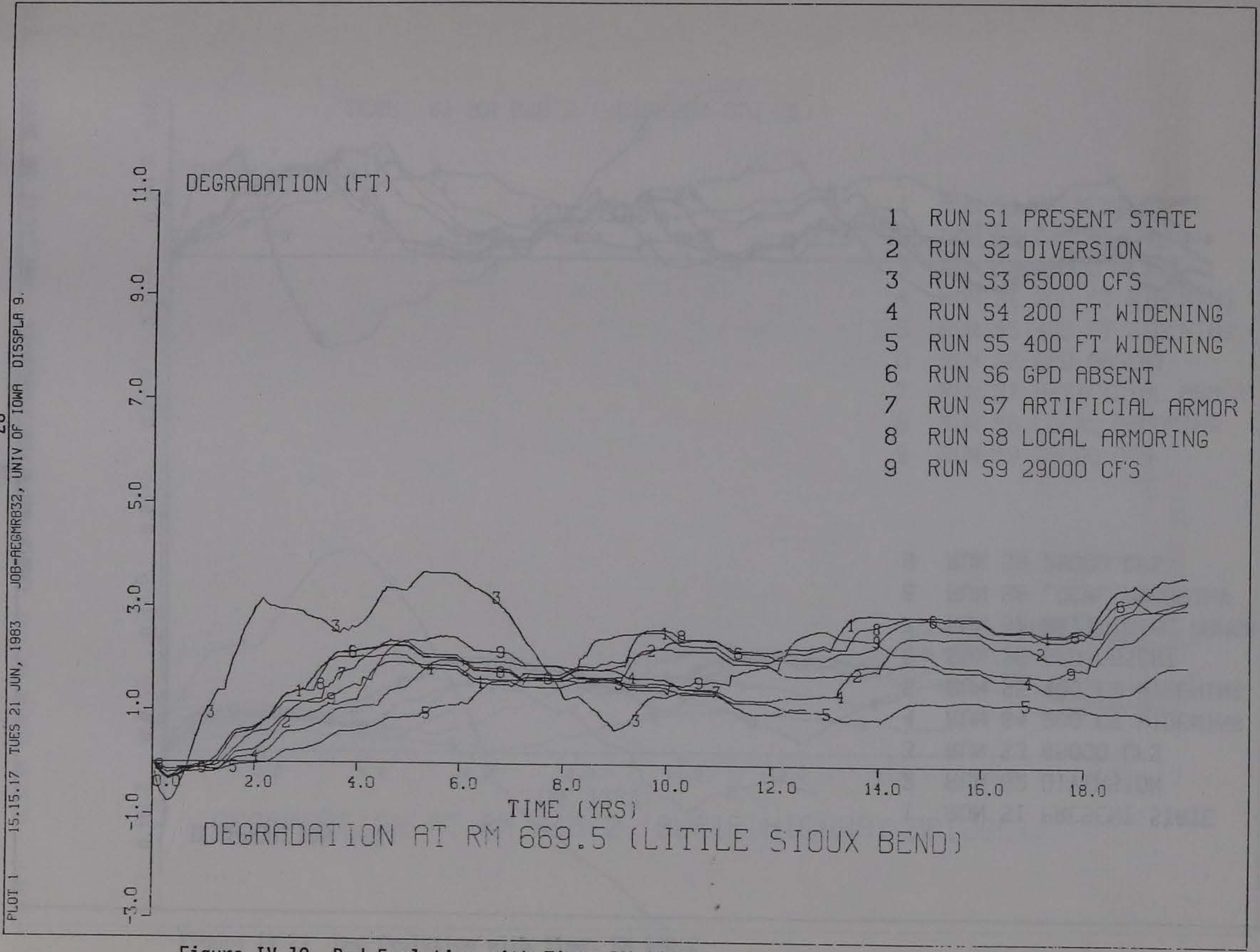


Figure IV.19 Bed Evolution with Time, RM 669.5

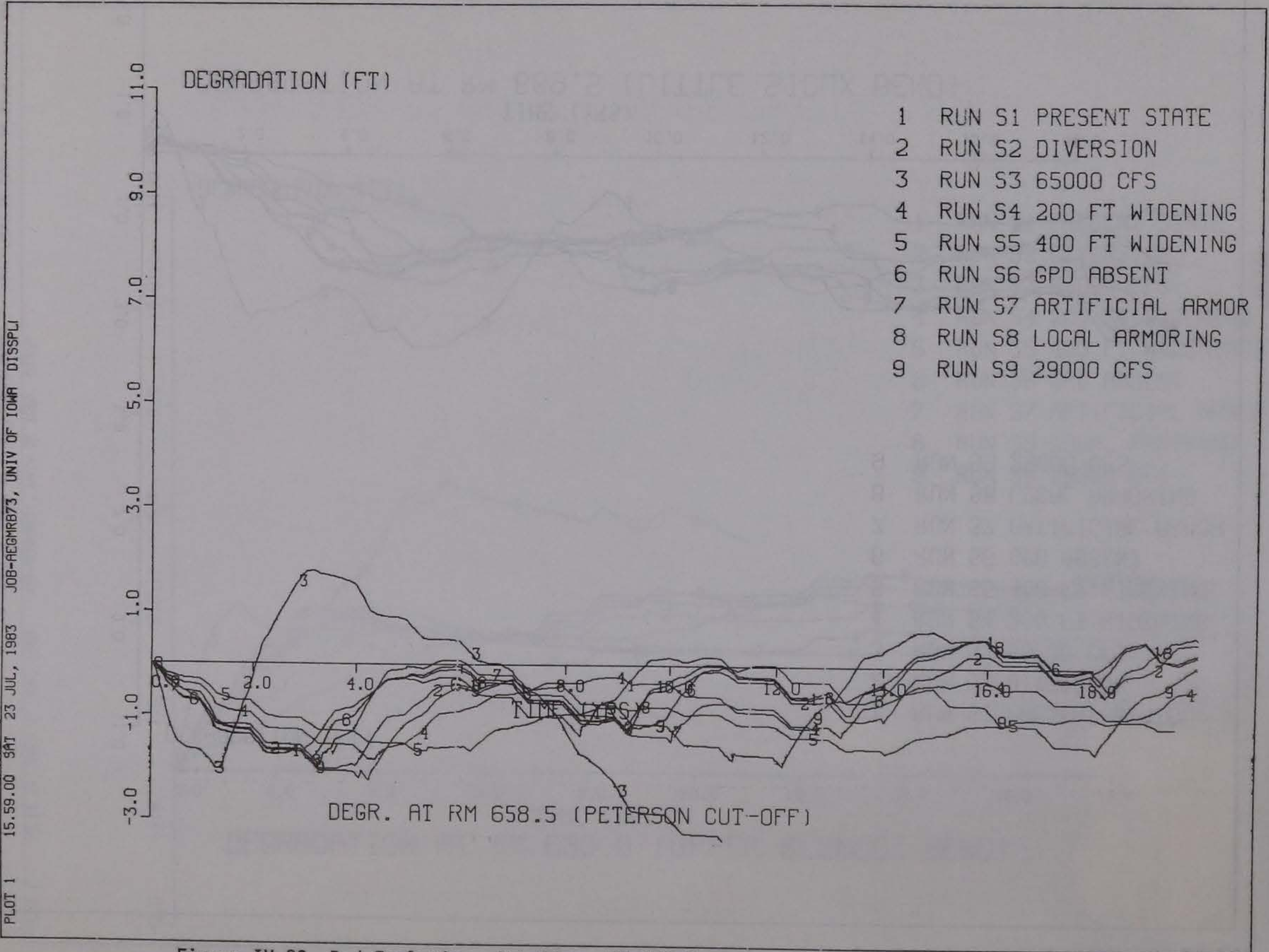


Figure IV.20 Bed Evolution with Time, RM 658.5

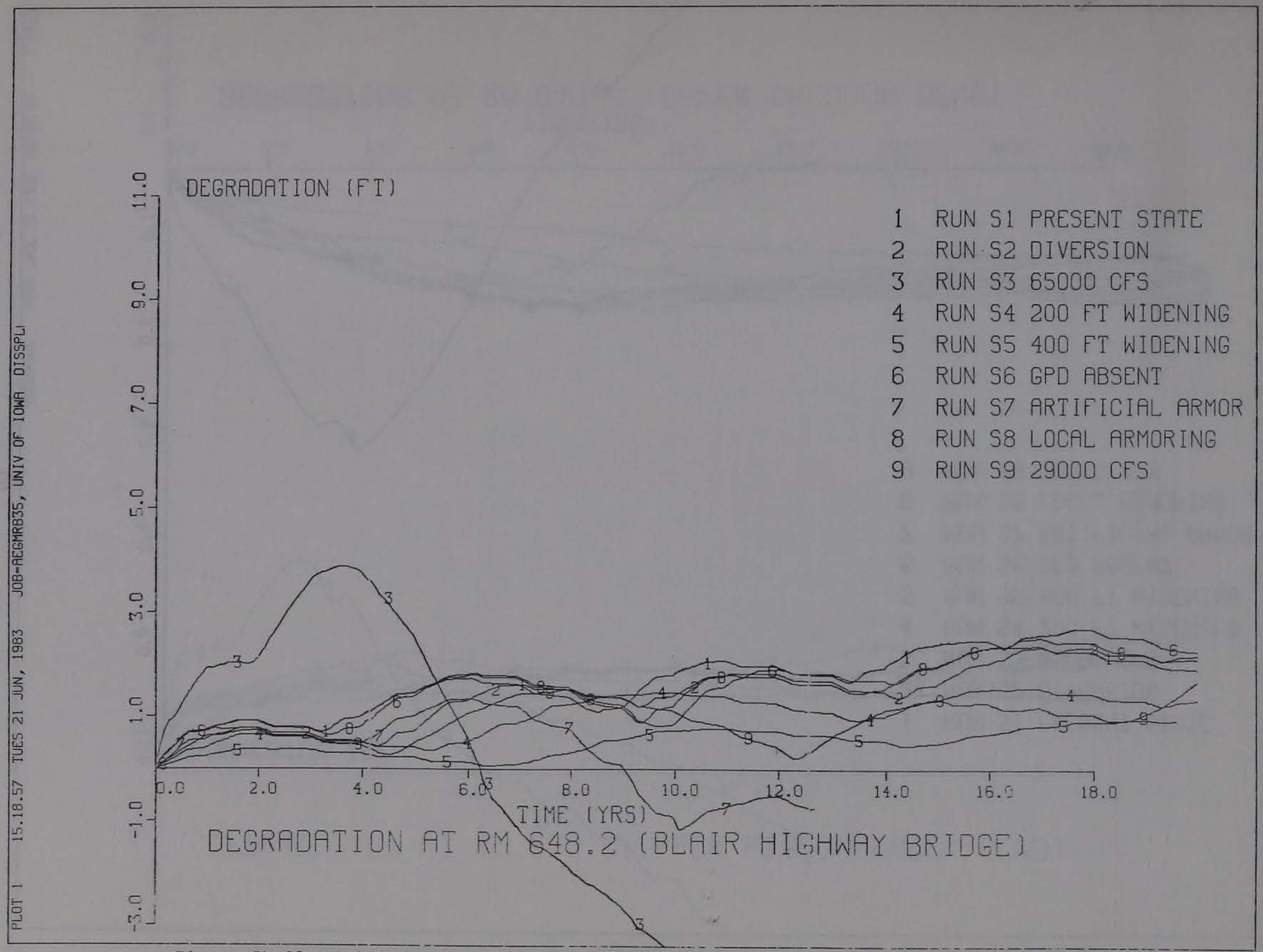


Figure IV.21 Bed Evolution with Time, RM 648.2

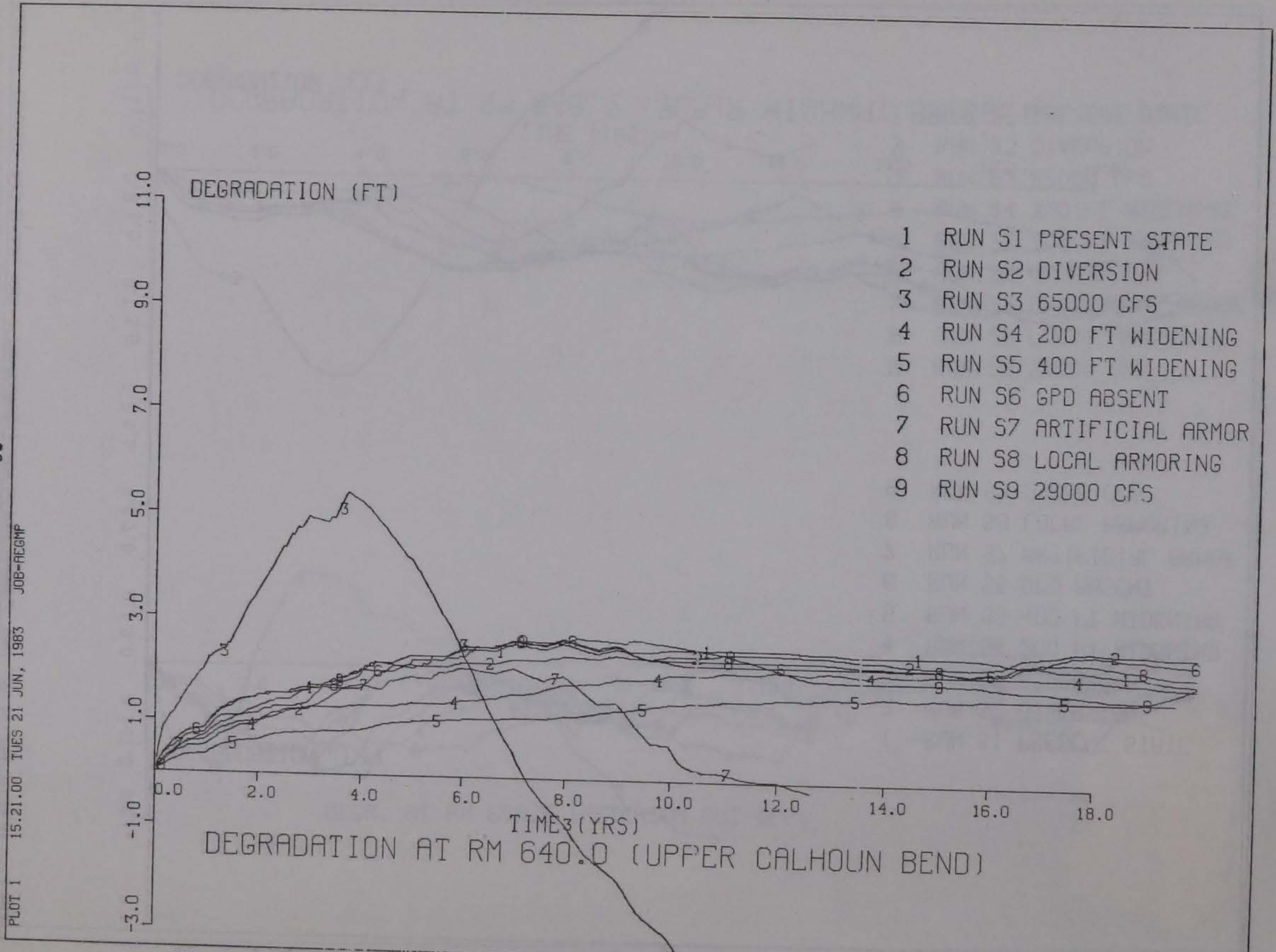


Figure IV.22 Bed Evolution with Time, RM 640.0

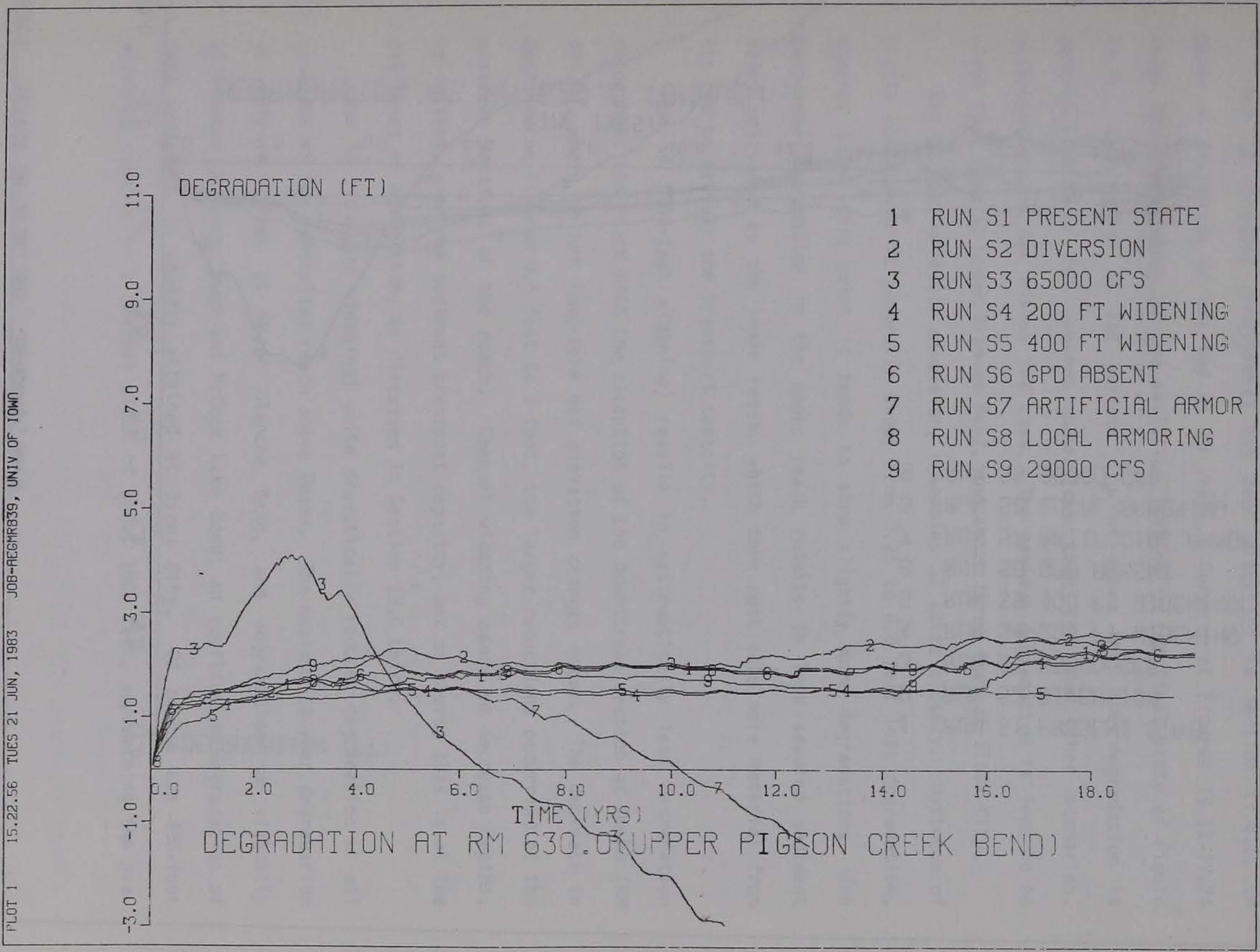


Figure IV.23 Bed Evolution with Time, RM 630.0

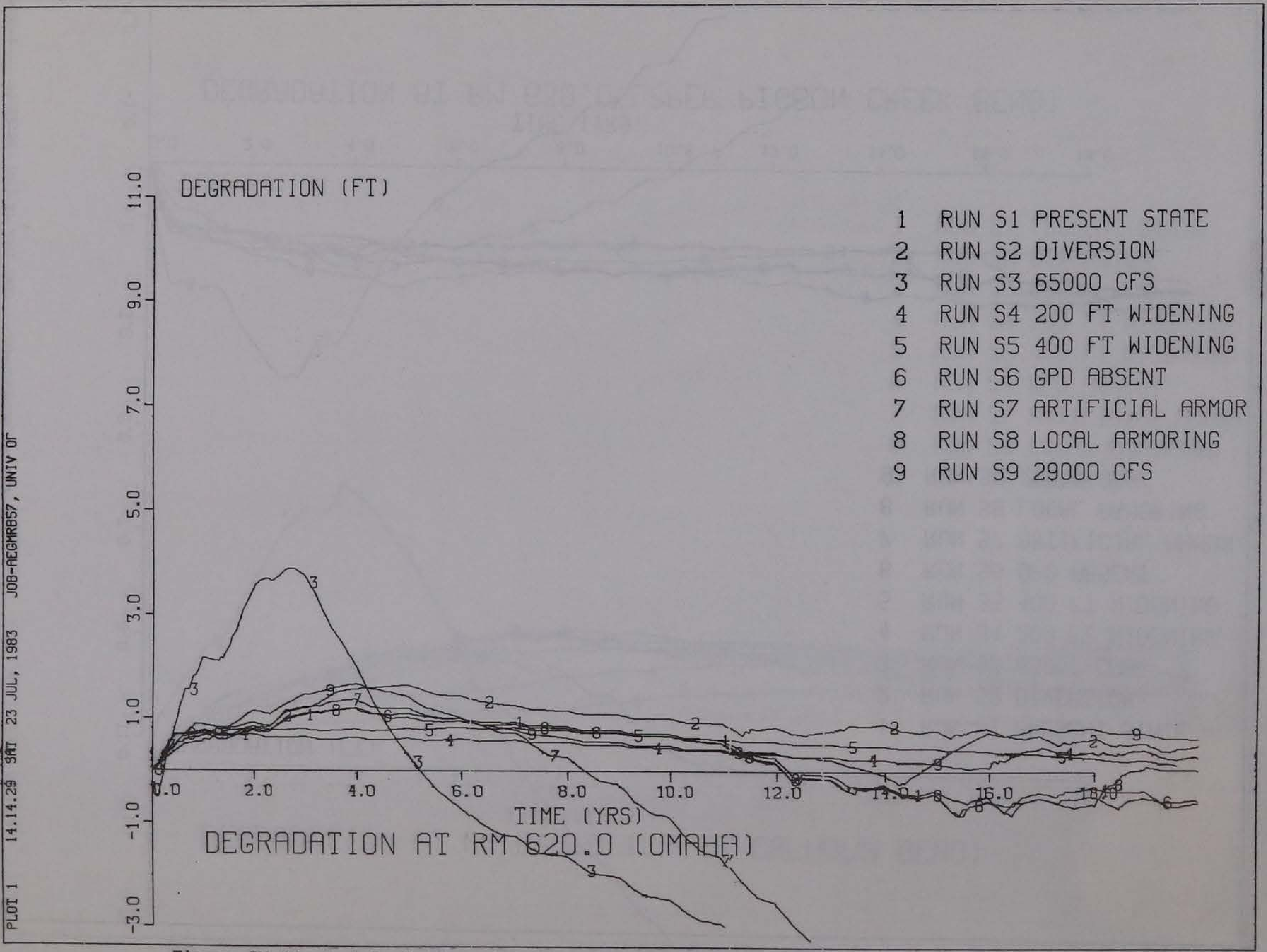


Figure IV.24 Bed Evolution with Time, RM 620.0

Run S1 (present conditions) has been discussed in Section IV.B.1, in terms of the state of the bed at 20 years. Curve 1 of Figures IV.11-IV.24 shows the time-history of bed evolution leading to the final state of Figure IV.3. Examination of the various figures shows that the degradation is generally greater for present conditions than for the other scenarios, although this is not always the case. The maximum degradation is seen to be about four feet at Upper Blencoe Bend, and about three feet at Sioux City.

Run S2 (out-of-basin diversion) resembles S1 quite closely. Upstream of Little Sioux Bend it generally shows from 0.25 to 0.5 feet less degradation, whereas below this point it tends to show slightly more degradation. The decreased degradation in the upper reach results in less scoured sediment being delivered to the lower reach, which then must take more material from its bed to satisfy the transport capacity.

Run S4 (200-foot widening) results in systematically less degradation throughout the reach with the exception of the downstream section at Omaha (RM 620.0), where no net long-term bed elevation changes occur. The decrease in degradation is from 0.5 feet to 1 foot, the larger reductions occurring at the upstream sections of the reach. Channel widening tends to decrease depths, velocities, and thus sediment transport capacity, but of course this is at the detriment of navigation, as discussed in Section IV.C below.

Run S5 (400-foot widening) quite dramatically reduces degradation at all sections of the controlled reach above Omaha. The maximum 20-year degradation is only 2.5 feet at Upper Blencoe Bend, and degradation is virtually eliminated at Ponca Bend and McCook Lake Bend; an equilibrium degradation of just one foot is rapidly attained at Sioux City. Of course the 400-foot widening results in a channel width of about 1000 feet, approaching the prechannelization width which presumably represented a near-equilibrium condition.

Run S6 (sediment input from Gavins Point Dam) has virtually the same response as S1. Figure IV.5 showed a shift from degradation to aggradation between Runs S1 and S6, but this effect is primarily local, extending less than 20 miles downstream of the dam. The different responses of Runs S1, S4, S5, and S6 clearly suggest that it is the channel narrowing, and not the shutoff of sediment supply at Gavins Point Dam, which is primarily responsible for degradation in the controlled reach.

Run S8 (localized armoring) shows a decrease in degradation of the order of one foot at Sioux City and McCook Lake Bend, and a smaller decrease of about 0.25 feet at Ponca Bend. These are the only three sections directly affected by the slight coarsening of bed material in the two computational reaches above and below Sioux City, as described in Section IV.A.8. However, this local decrease in degradation has an indirect effect at Lower Monona Bend, (RM 700.0), and Upper Decatur Bend, where a slight increase in degradation results from the diminished sediment supply arriving from the now-partially-stablized Sioux City area. In short, Run S8 suggests that local artificial armoring in an area of severe degradation will not have a major effect on downstream reaches.

Run S9 (constant mean annual mainstem flow of 29,000 cfs) shows a general decrease in degradation, attributable to the decrease of about 20% in navigation season (annual maximum) discharges above Omaha. The decrease compared to Run S1 is greatest at Ponca Bend, amounting to about 1.5 feet, although it ranges from negligible to 0.5 feet at other downstream sections. This run tends to confirm that degradation occurs primarily during the navigation season, when discharges exceed the mean annual flow.

IV.B.5 **Bed Evolution in the Controlled Reach Below Omaha.** Figures IV.25-IV.31 show the computed bed elevations from Gibson Bend (RM 610.5) to the Iowa-Missouri border (RM 553.0). As noted earlier, the mathematical model actually extended an additional 30 miles downstream, so as to ensure that the influence of the approximate downstream boundary condition would not extend up into Iowa.

Bed response below Omaha is heavily influenced by the sediment and water inflow of the Platte River (RM 591.0 in the model). In particular, the general trend of aggradation from Omaha down to Calumet Bartlett Bend would appear to be entirely due to the Platte; when the model is run without the Platte, degradation occurs both above and below Omaha. Moreover, observations of water surface changes from 1957 to 1979 (see Fig. 39 of Reference 5) clearly show a change from degradation (decline in water level) to aggradation (rise in water level) between Blair and Omaha. While it is still an open question as to what causes Omaha to act as an apparent degradation control point, the computations of this study present strong evidence that the Platte is providing the control.

The oscillatory behavior of bed elevations at Lower Plattsmouth and Calumet Bartlett Bends reflects the seasonal variations of mainstem and tributary discharges. Figures III.13 and III.14 show that below the Platte confluence, the water discharge varies from 52,662 cfs to 40,163 to 19,163 cfs at four-month intervals. Bed response is especially sensitive to these changes because of the concomitant important changes in the Platte's sediment inflow. Using the sediment rating curve coefficients of Table III.4, it can be shown that the Platte's sediment load varies by a factor of 20 from high flow to low flow. During the first trimester of each year, the Platte's heavy

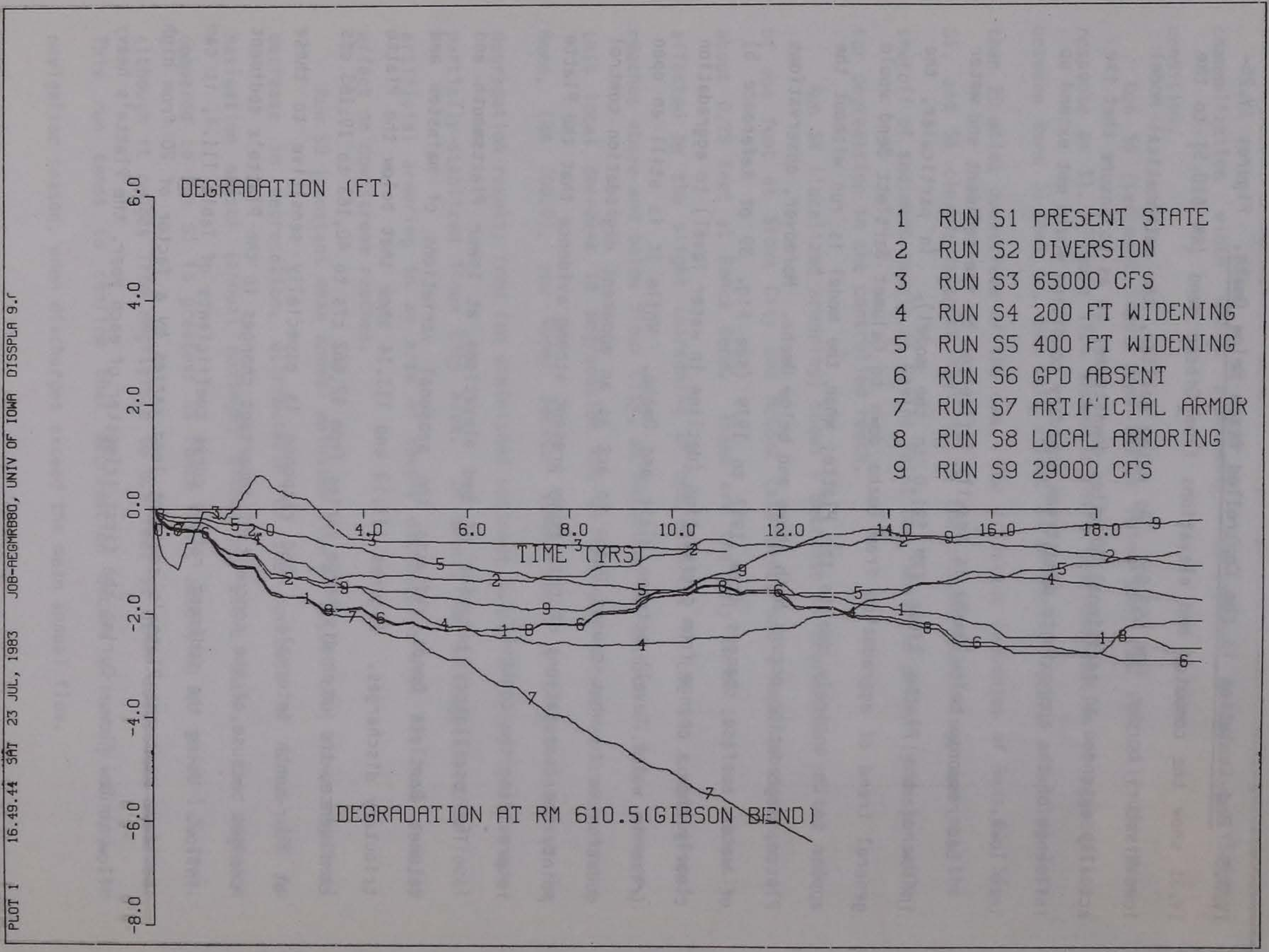


Figure IV.25 Bed Evolution with Time, RM 610.5

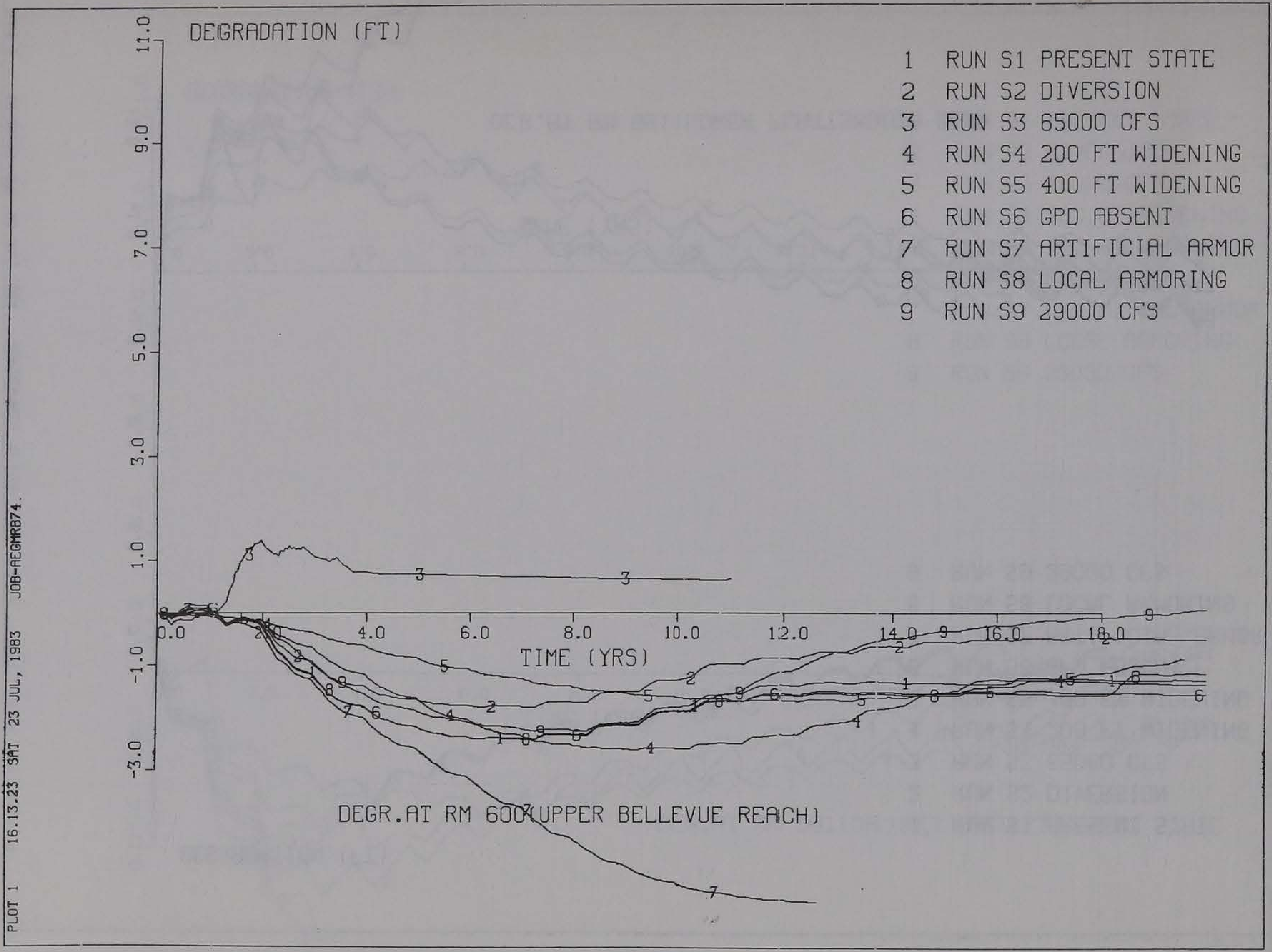


Figure IV.26 Bed Evolution with Time, RM 600.0

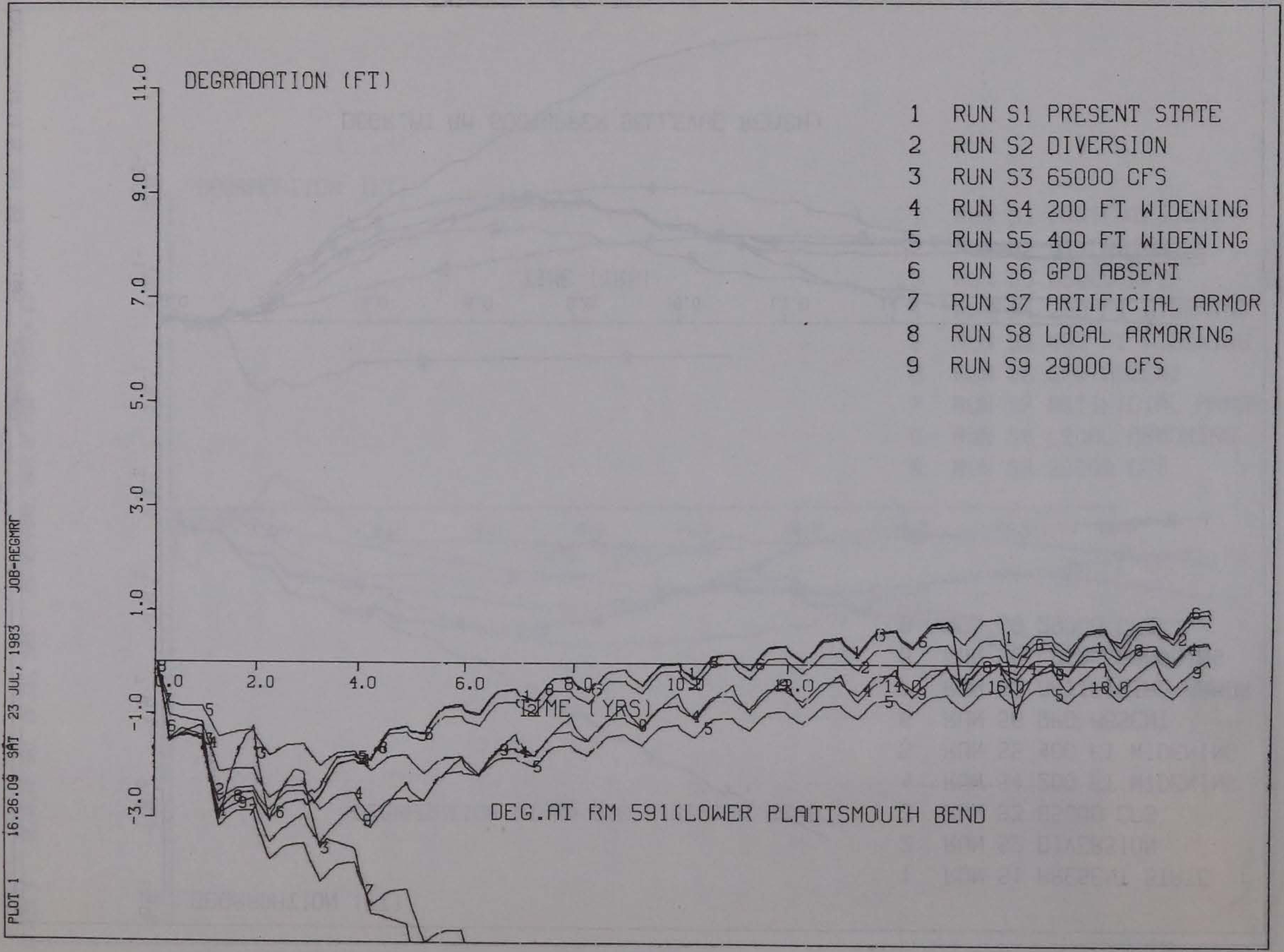


Figure IV.27 Bed Evolution with Time, RM 591.0

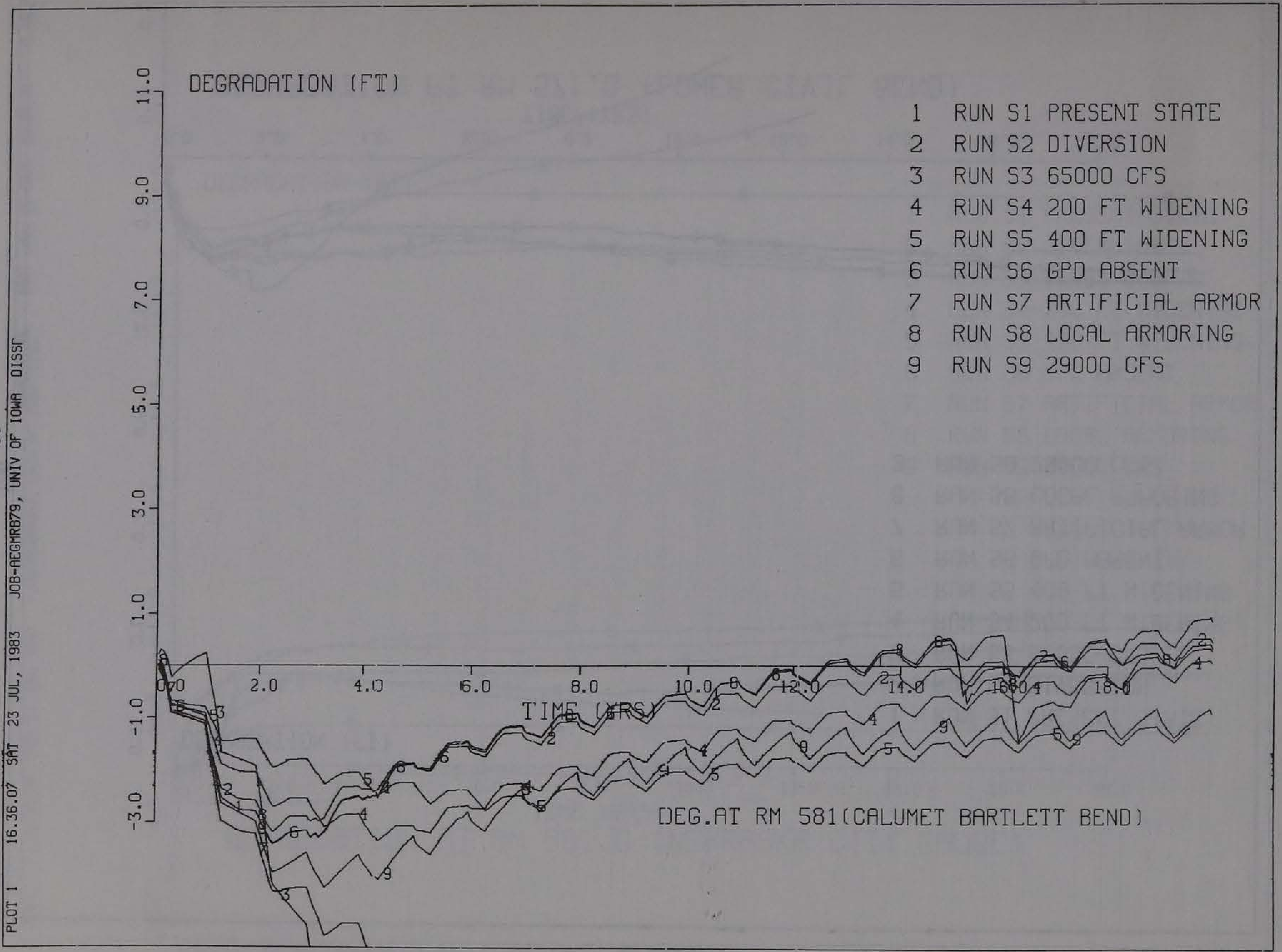


Figure IV.28 Bed Evolution with Time, RM 581.0

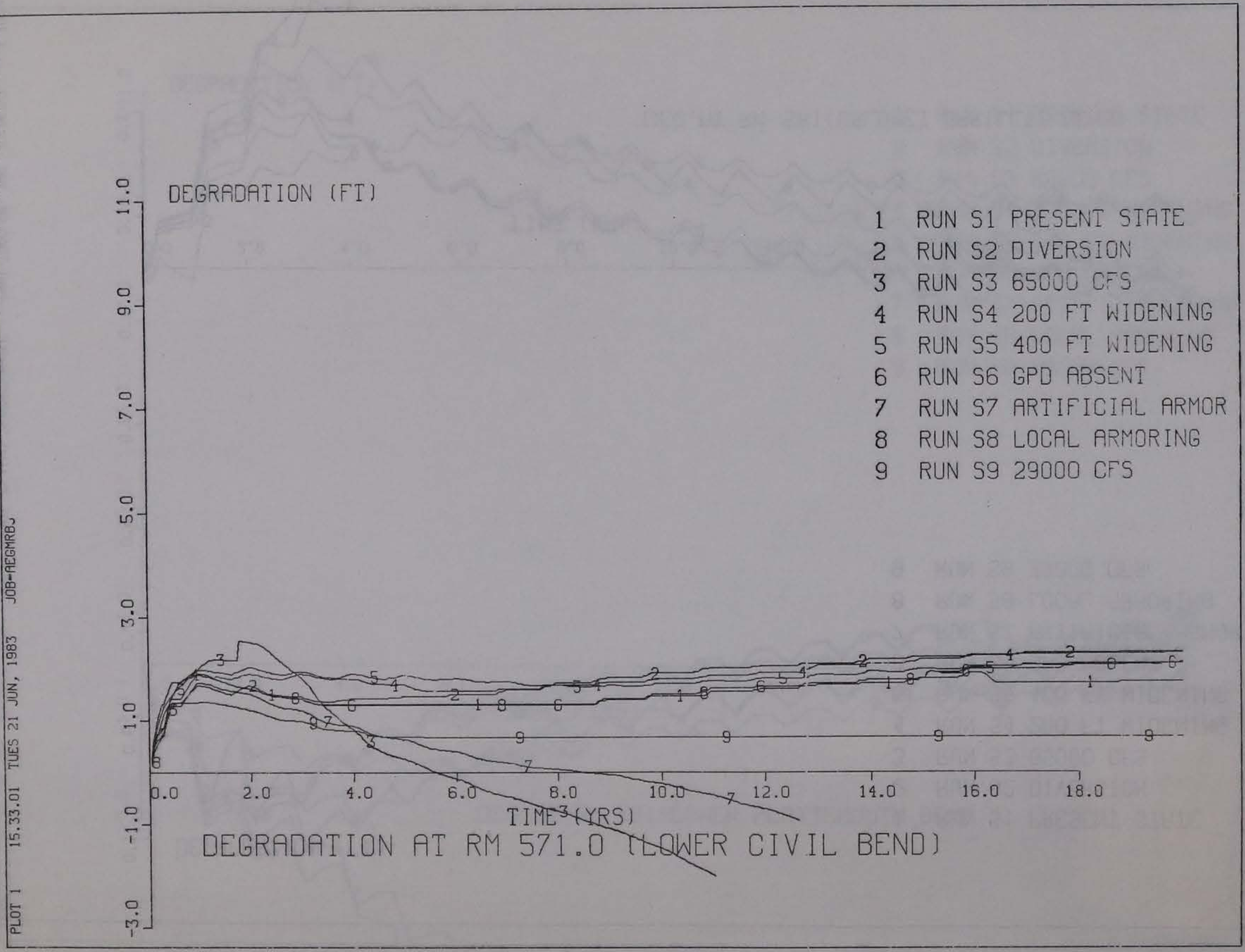


Figure IV.29 Bed Evolution with Time, RM 571.0

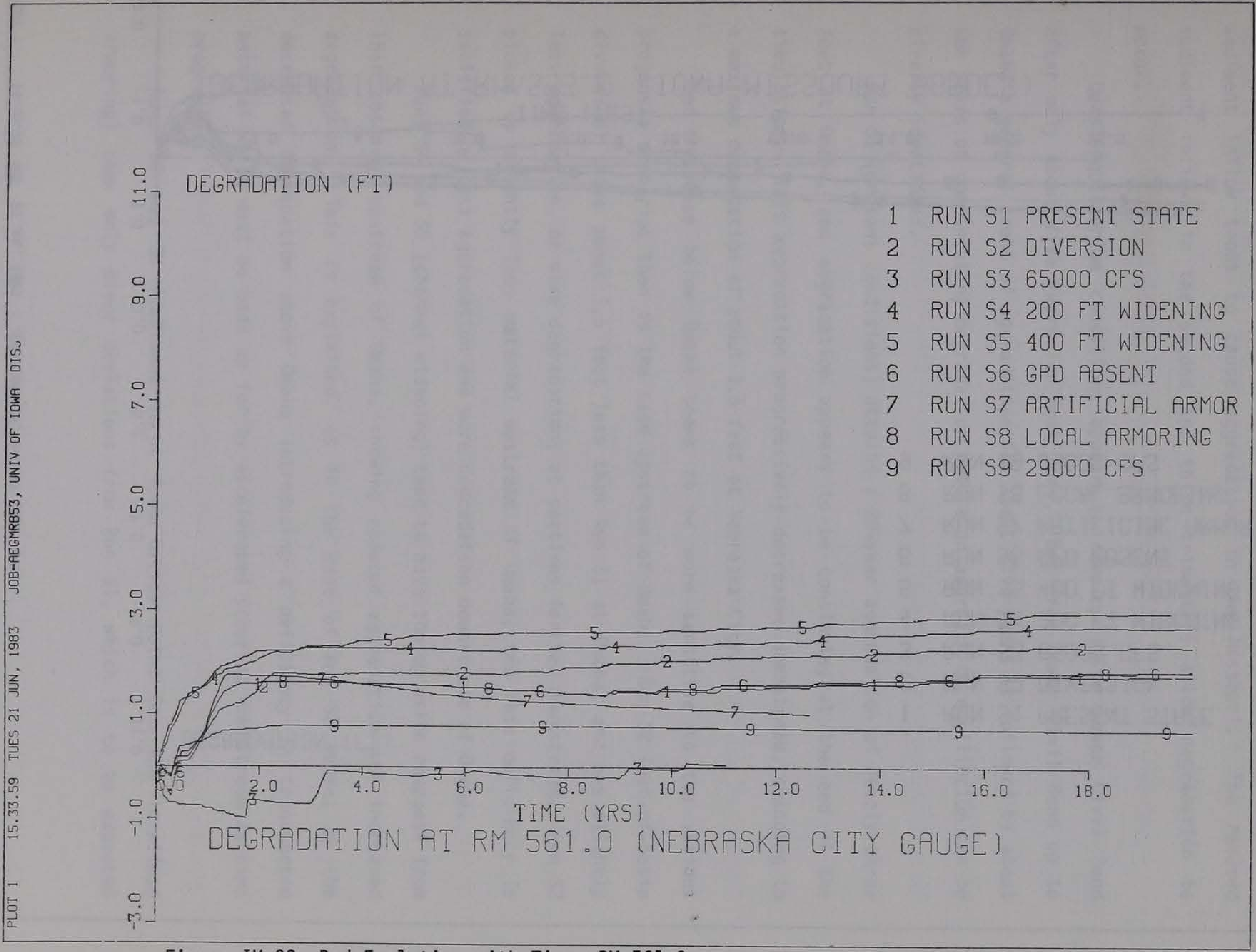


Figure IV.30 Bed Evolution with Time, RM 561.0

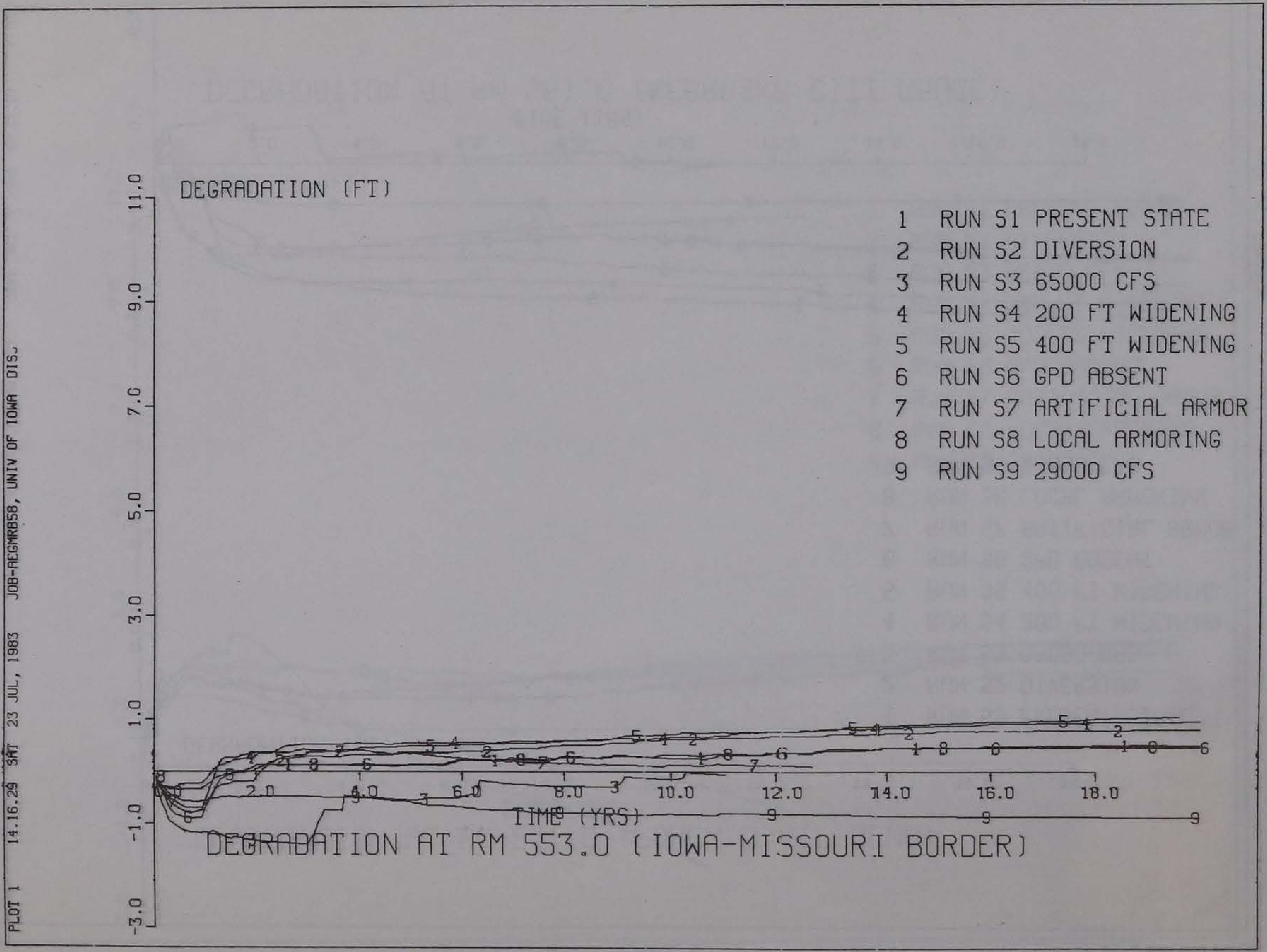


Figure IV.31 Bed Evolution with Time, RM 553.0

sediment inflow tends to cause aggradation in the Missouri. The reduced sediment inflows in the second and third trimesters allow degradation to occur.

Quasi-equilibrium conditions appear to develop below Lower Civil Bend after only about five years for most runs. But from Lower Civil Bend up to Omaha a general trend of aggradation for about five years is followed by about ten years of compensating degradation before an approach to equilibrium can be clearly identified.

Run S1 (present conditions) attains a 20-year aggradation of nearly three feet at Omaha, and aggradation appears to be continuing at the end of the simulation. This aggradation progressively decreases downstream, changing to a maximum degradation of about 1.5 feet at Nebraska City.

Bed response below Omaha seems to be more sensitive to the various prognosis scenarios than is the case upstream of Omaha. Run S2 (out-of-basin diversion) shows about 1.5 feet less than Run S1 at Omaha, and has slightly less aggradation, or more degradation, at sections farther downstream. Run S2 picked up slightly less material upstream of Omaha, and this deficiency is satisfied by less aggradation and more degradation downstream of Omaha.

Runs S4 and S5 (channel widening) tend to have the opposite response from that observed upstream of Omaha, showing reduced aggradation and increased degradation. This is explained, as in the case of Run S2 above, by the decreased degradation above Omaha introducing a deficiency in transported material which must be made up for by accelerated scouring downstream as time progresses.

Runs S6 and S8 (sediment input from Gavins Point Dam and localized armoring) show only minor deviations from Run S1, which is to be expected since both scenarios involve modifications which are so far upstream as to be irrelevant for bed response below Omaha.

Run S9 (constant discharge at mean annual flow) tends to show nearly equilibrium behavior below Omaha, resulting in bed elevation changes of less than one foot at the end of the simulations. This shows once again the sensitivity of bed evolution to changes in peak discharges.

IV.B.6 Analysis of Runs S3 and S7. Runs S3 (constant 65,000 cfs discharge) and S7 (artificial armoring) failed to yield consistent and useful results. However they are of great value in bringing out an area of deficiency in the methodology of IALLUVIAL: treatment of rapid aggradation. The problem originates at Lower Plattsmouth Bend, where the Platte River influence is most important. The extremely high discharge of Run S3 causes several feet of degradation throughout the model upstream of the Platte in the first few years, as can be seen on Figures IV.11-IV.24. This results in a fairly rapid coarsening of the bed material and increase in armoring factor which, through Eqs. (1), (2), and (6), rapidly reduces the sediment transport capacity. Thus a large portion of the heavy sediment inflow from the Platte cannot be carried away by the flow, and must be deposited. In the present formulation of IALLUVIAL, neither the armoring factor nor the median bed material size are significantly changed by deposition of finer material over underlying coarser material. Accordingly, deposition of the Platte's sediment load continues indefinitely, building a sort of dam which, after 10 years, causes upstream water levels to overflow the top of the sections as defined in the model, aborting the calculation.

The 1983-1984 continuation of this study will be devoted to the resolution of various methodology and numerical analysis problems in IALLUVIAL, including the above-described deposition anomaly. Meanwhile it would appear that Run S3 yielded valid results sufficiently far upstream from the Platte, say above RM 680. The maximum degradation over ten years is about five feet, at Upper Blencoe Bend. A certain equilibrium appears to be reached between RM 710.0 and RM 680.0, but upstream of this reach the degradation is still continuing at ten years. However one must be prudent in attaching too much importance to even these limited observations, in view of the known deposition problems downstream.

Run S7 (artificial armoring) was subject to the same kind of problem as Run S3; the artificial increase in coarser sediment size fractions provoked more rapid armoring (as expected), thus initiating the unbounded deposition at the Platte, as described above. Upstream of Upper Blencoe Bend (RM 680.0), the effect of artificial armoring is roughly comparable to that of Runs S2 (out-of-basin diversion) and S4 (200-foot widening) in reducing degradation by the order of one foot or less. But once again, prudence is advisable in evaluating this run.

Runs S3 and S7 may not have been successful in terms of their specific purposes in this study, but they are indirectly extremely valuable in pointing out the need for further work on deposition methodology in IALLUVIAL. This must be considered as a priority area of investigation, for as long as the methodology is known to be inadequate in cases of extreme deposition, caution must be exercised in interpreting the results when only slight deposition occurs.

IV.B.7 Analysis of Run S10. Run S10, as described in Section IV.A.10, simulates the effect of a single-year hydrograph corresponding to the 1952 flood. Figure IV.32 shows the computed bed evolution with time at selected sections along the Missouri.

Earlier difficulties encountered when deposition occurred under high flow conditions, described in Section IV.B.6, made it seem prudent to neglect the effect of tributary sediment inflows (in particular those of the Platte) for this run. The effect of this shut-off of the Platte's sediment load can be clearly seen on Curve 6 of Fig. IV.32, wich shows that at RM 571.0 (20 miles downstream of the Platte), degradation occurred even during the quite low flow periods of the 1952 hydrograph (see Fig. IV.2). The transport capacity was greater than the incoming sediment supply, requiring that the capacity be satisfied by removing material from the bed, and quite rapidly: three feet of degradation in a single year. Of course this is unrealistically high, for in actual conditions the Platte would be delivering a considerable sediment load. Curve 5 shows that removal of the Platte control also caused accelerated degradation at RM 630.0, where 1.5 feet occurred, more or less evenly distributed throughout the year.

The curves for the remaining sections shown on Fig. IV.32 show an initial period of degradation caused by the lack of any armoring in the initial state, then an approximately equilibrium state until the high flows occur at about 0.53 years. During the three weeks or so of extremely high flows (see again Fig. IV.2) Curves 3 and 4 (Sioux City and Upper Blencoe Bend) show about an additional half-foot of degradation, then stabilize once more until the end of the year. Curves 1 and 2, at Gavins Point Dam and the last section of the uncontrolled reach, as well as the remaining sections not plotted, show basically the same behavior.

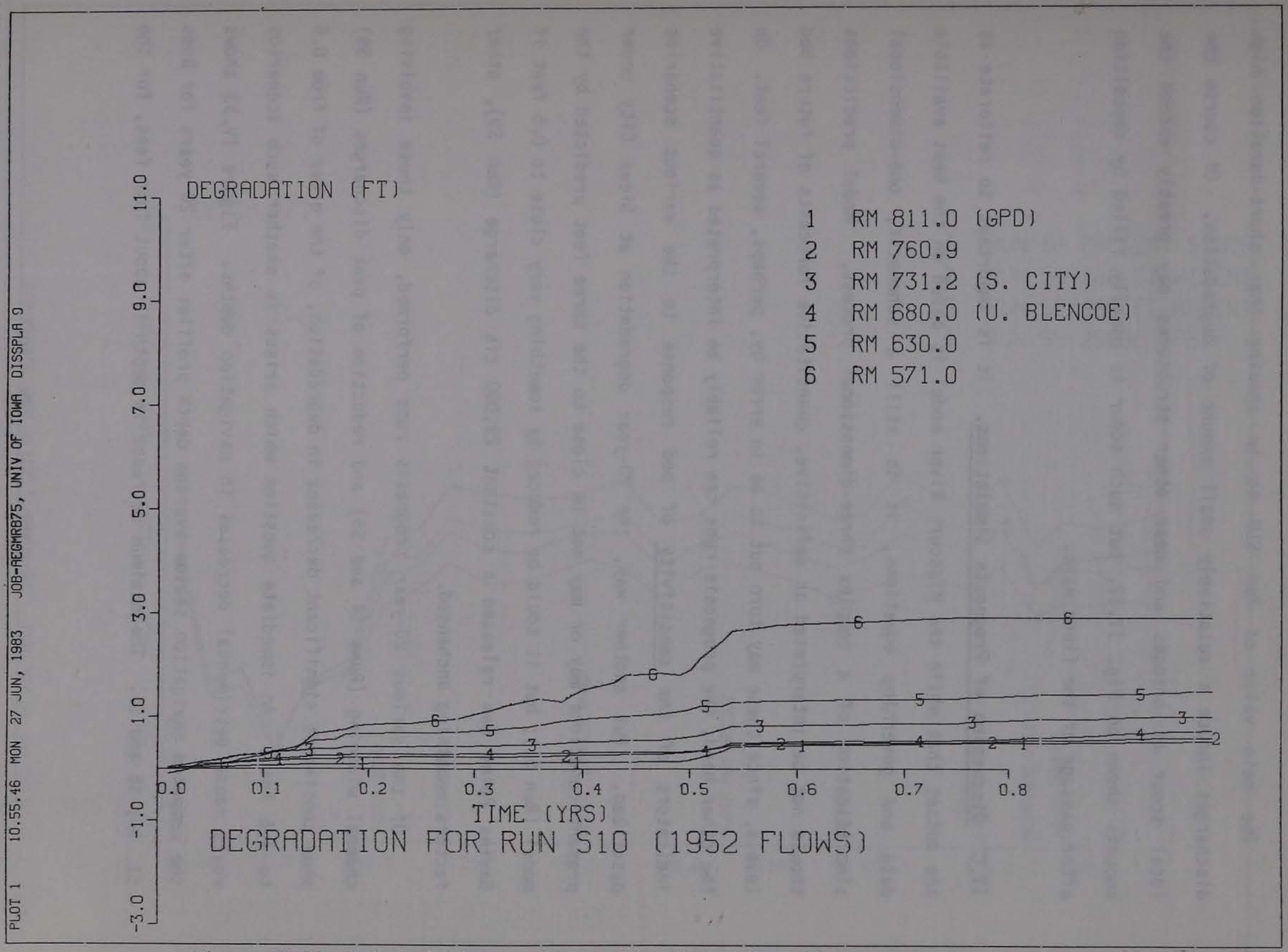


Figure IV.32 Bed Evolution at Selected Sections, Run S10

The main value of Run S10 is in showing that short-duration high discharges induce a relatively small amount of degradation. Of course the local scour at bridges and near other structures may greatly exceed the amounts shown on Fig. IV.32, but such scour is usually filled by deposition after passage of the flood wave.

IV.C **Discussion of Prognosis Simulations.** It is important to reiterate at the outset that while the Missouri River model is based on the best available data and governing equations, it is still a schematic, one-dimensional simplification of a complex three-dimensional process. Model predictions should not be interpreted as definitive, quantitative forecasts of future bed levels, since these may turn out to be in error by, perhaps, several feet. On the other hand, the prognosis runs can reliably be interpreted as quantitative indicators of the sensitivity of bed response to the various scenarios described. Put another way, the 20-year degradation at Sioux City under present condtions may or may not be close to the three feet predicted by the model (Run S1); but it could be reduced by something very close to 0.5 feet if Gavins Point Dam released a constant 29,000 cfs discharge (Run S9), other factors remaining unchanged.

Of the various 20-year prognosis runs performed, only those involving channel widening (Runs S4 and S5) and reduction of peak discharges (Run S9) show consistent significant decreases in degradation, of the order of from 0.5 to 1.5 feet. An immediate question which arises is whether such scenarios would cause detrimental decreases in navigation depths. Figure IV.33 shows the computed navigation season average depth profiles after 20 years for Runs S1, S4, S5 and S9. The maximum decrease in depth is about four feet, for the

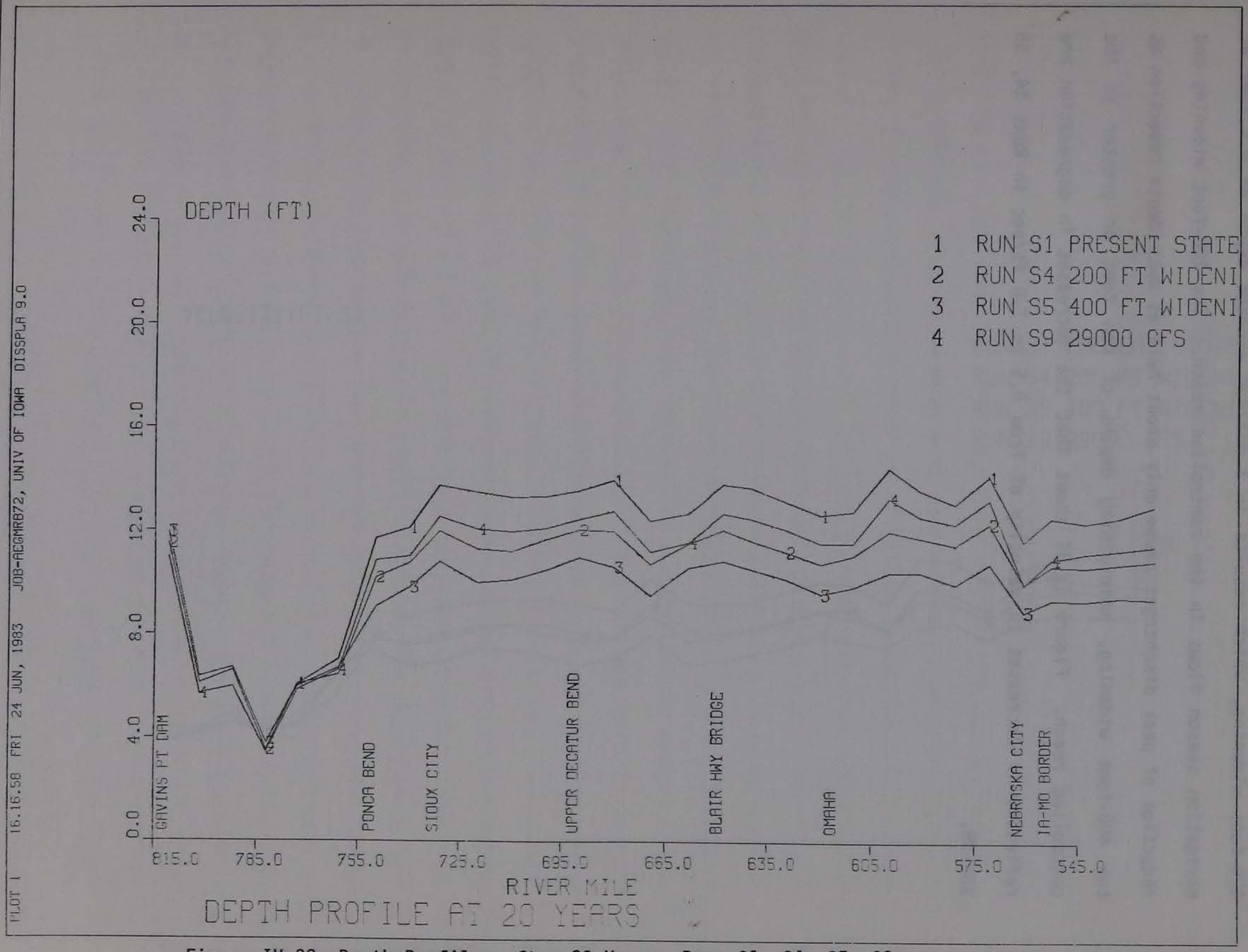


Figure IV.33 Depth Profiles after 20 Years, Runs S1, S4, S5, S9

400-foot widening, which results in a minimum average depth of 9.4 feet at navigation season flows in the controlled reach. The 200-foot widening and reduction of peak discharges cause only about half as much depth reduction as the 400-foot widening, maintaining depths of ten feet or greater in the controlled reach. Figure IV.34 shows that the decreases in degradation are reflected in decreases in velocity of from 0.5 to 1.0 ft/sec in Runs S4, S5 and S9.

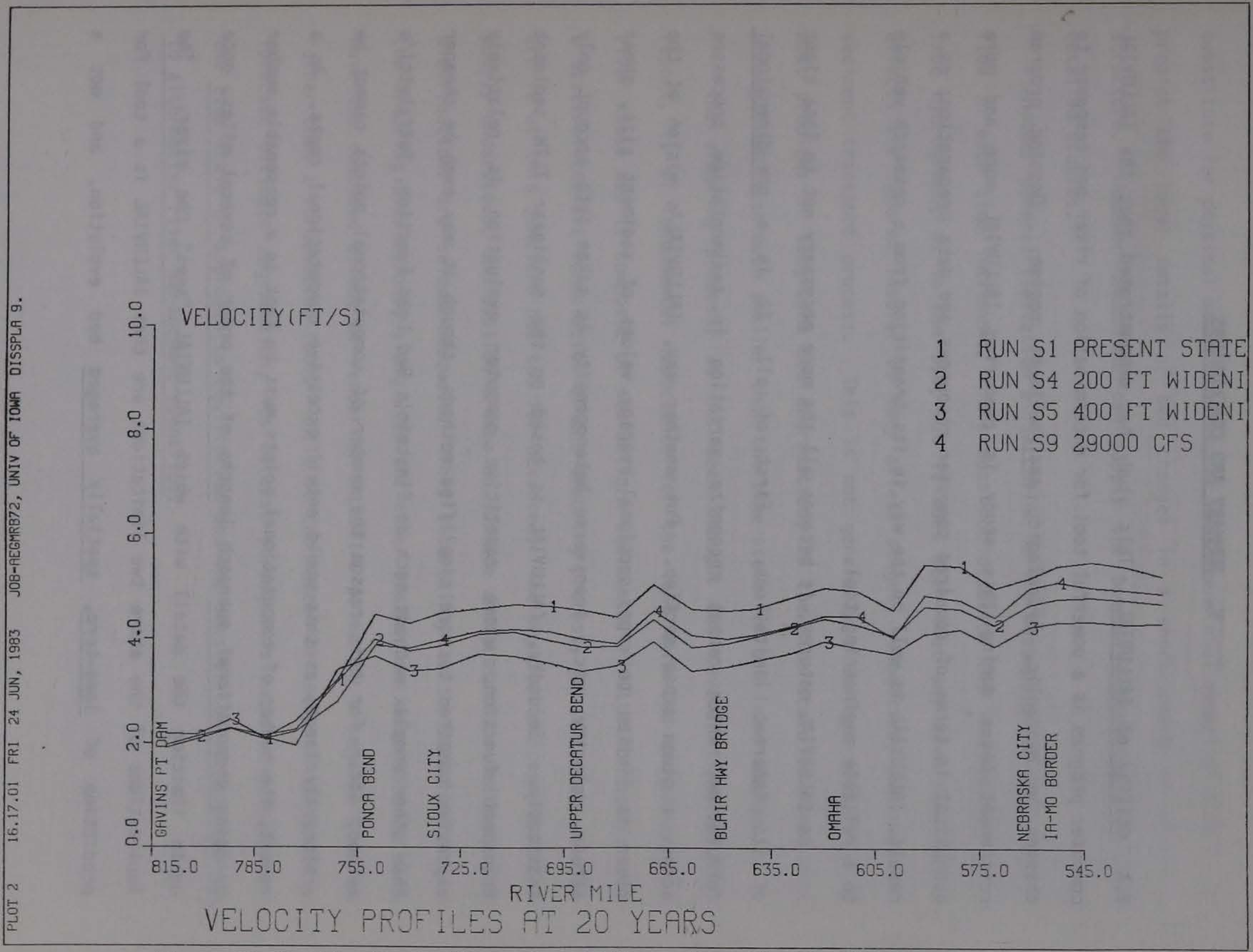


Figure IV.34 Velocity Profiles after 20 Years, Runs S1, S4, S5, S9

V. SUMMARY AND CONCLUSIONS

V.A Utility of IALLUVIAL. This study has demonstrated that the IALLUVIAL computer program is a powerful tool for determination of river bed response to changes in hydraulic, hydrologic, and sediment regime. Ongoing program refinement begun during this study is rendering IALLUVIAL more and more economical in terms of required computer resources and data preparation; as a result, IALLUVIAL is well on the way in its transition from a research vehicle to a reliable engineering tool.

As IALLUVIAL matures, it becomes all the more necessary not to lose sight of its inherent limitations. First of all, it is a one-dimensional formulation, which cannot recognize variation in sedimentation processes across a given cross section. Put another way, IALLUVIAL's vision of the river is limited to cross-sectional-average values of sediment size, shear stress, velocity, etc.; transverse heterogeneity is taken into account only indirectly. Secondly, IALLUVIAL is based on the nonlinear TLTM sediment transport function, whose repetitive computer evaluation is relatively expensive compared to more simplified methods, though it may even be cheaper than other complex methods such as Einstein's Bed Load Function, Toffaletti's method, etc. For this reason the number of computational points cannot be arbitrarily large, as this would entail excessive computational costs. As a result, the number of computational points must be kept to a reasonable number by using computational subreach lengths of the order of several miles, once again limiting the detail with which IALLUVIAL "sees" the river. The implications of the above two limitations are that IALLUVIAL is a tool for prediction of long-term, spatially averaged bed evolution, and not a substitute for physical model studies, or two-dimensional numerical models, to predict the local details of bed changes in a short reach or around a structure. However IALLUVIAL can supply the boundary conditions for such detailed studies.

Another general limitation of IALLUVIAL is its assumption of quasi-steady flow in each time increment. This does not disallow the introduction of a true hydrograph, as in Run S10, but it does mean that any wave propagation effects are ignored insofar as they affect stages, velocities, and thus the sediment transport process. This is not generally a serious deficiency in most problems of long-term bed degradation, as the time scale of flood wave propagation is so much smaller than the time scale for bed level changes.

The armoring process, as has been brought out several times in this report, is of fundamental importance for the long term bed evolution in a river whose bed is composed of non-uniform sediments. IALLUVIAL incorporates a state-of-the-art formulation of the armoring process, yet the state-of-the-art is at this juncture not too far advanced. The physical process itself is poorly understood, and available data on surface and subsurface sediment size distributions are seldom adequate. This uncertainty as to the viability of the armoring simulations, along with the other limitations described earlier, have the combined effect of rendering IALLUVIAL primarily a sensitivity tool rather than a forecasting tool. While it can indeed be used with prudence to forecast ultimate degradation, its natural strength is rather in indicating the time scale of approach to equilibrium and the sensitivity of bed response to alternative river management scenarios.

V.B. <u>Prognosis of Missouri River Bed Evolution</u>. The single most important conclusion to be drawn from the prognosis simulations of Chapter IV is that the worst of the degradation appears to be over. Field observations and previous IALLUVIAL simulations show about seven feet of degradation at Sioux City for the period 1955-1975; Run S1 of the present study predicts about three additional feet of degradation for the period 1980-2000, under present conditions. The maximum predicted additional degradation is about four feet near Upper Blencoe Bend, Rm 680.0. Equilibrium conditions are attained after about ten years below Omadi Bend (RM 720.0), but slowing degradation is predicted to continue to and beyond twenty years between Ponca and Omadi Bend. These ultimate degradation amounts must not be taken as definitive for the reasons given in the previous section; nonetheless, IALLUVIAL's close agreement with actual degradation over the past twenty years justifies some confidence in these predictions.

The most interesting of the prognosis runs were S4 and S5, simulating the effects of a 200-foot and 400-foot widening of the navigation channel. Run S4 predicted a reduction of from half a foot to one foot in ultimate degration, while Run S5 showed up to a two-foot reduction, i.e. a near-elimination of further degradation. These results, among others, suggest that it is primarily the channel narrowing, and not the shut-off of sediment supply by Gavins Point Dam, which causes degradation below Ponca Bend.

Run S9 was also of considerable interest, showing that release of water from Gavins Point Dam at a constant rate, rather than the present modulation scheme for the navigation and non-navigation seasons, could reduce the ultimate degradation by up to one foot, at the expense of a decrease of about one foot in water depths during the navigation season.

The uncontrolled reach between Gavins Point Dam and Ponca Bend appears to be essentially in equilibrium, except in the twenty miles just below the Dam, where an additional two feet of degradation may occur. From Omaha down to Plattsmouth, the sediment brought in by the Platte River acts as an effective control, effectively preventing degradation and even causing some deposition. Below Plattsmouth, degradation again occurs, reaching an ultimate additional one to two feet after less than ten years.

Since available bed-sediment data were insufficiently detailed to provide a coherent picture of subsurface bed material composition, the prognosis runs assumed vertical homogeneity of sediments. This allowed for no possible control of degradation by coarser subsurface material, so in this sense this study may have predicted the upper limit of ultimate degradation.

V.C **Future Research Needs.** During the course of this study, several data inadequacies and deficiencies in IALLUVIAL's formulation became apparent. This is not surprising; part of the development of any mathematical model destined to become a reliable engineering tool is its confrontation with reality on a prototype engineering problem. The following paragraphs discuss some of the areas needing further attention, with no attempt to set priorities or estimate the effort required.

Bed Sediment Data. This study has shown how important it is to have bed material size distributions including the small amounts of coarse material; not only on the surface but below it. While this study was indeed fortunate to have access to the extensive bed-sediment data made available by the Corps of Engineers, many assumptions and simplifying procedures had to be employed to develop an adequately detailed description of the study reach. Future bed-sediment sampling programs should be designed with the needs of a one-dimensional model in mind, and size distribution analyses should include the coarse fractions.

Multi-Channel Flow above Ponca State Park. In the one-dimensional framework of IALLUVIAL, river cross-sections are presented simply as relations giving the water-surface width and flow area as functions of water surface elevation. The detailed shape of the cross-section is used to construct these functions, but is "forgotten" during the actual computation. In particular, when the hydraulic radius is needed in the calculation, it is reconstituted as the ratio of the flow area to surface width, i.e., average depth. This procedure, while adequate for the well-defined controlled sections below Ponca, can be expected to underestimate the actual depths (and thus sediment transport capacity) in the multiple-channel, uncontrolled reach above Ponca. A fully adequate treatment of such reaches must await the anticipated extension of IALLUVIAL to quasi-two-dimensional capability. In the meantime, it should be possible to improve the way local depths are taken into account in the present one-dimensional formulation, and thus render prognosis simulations more realistic in the uncontrolled reach.

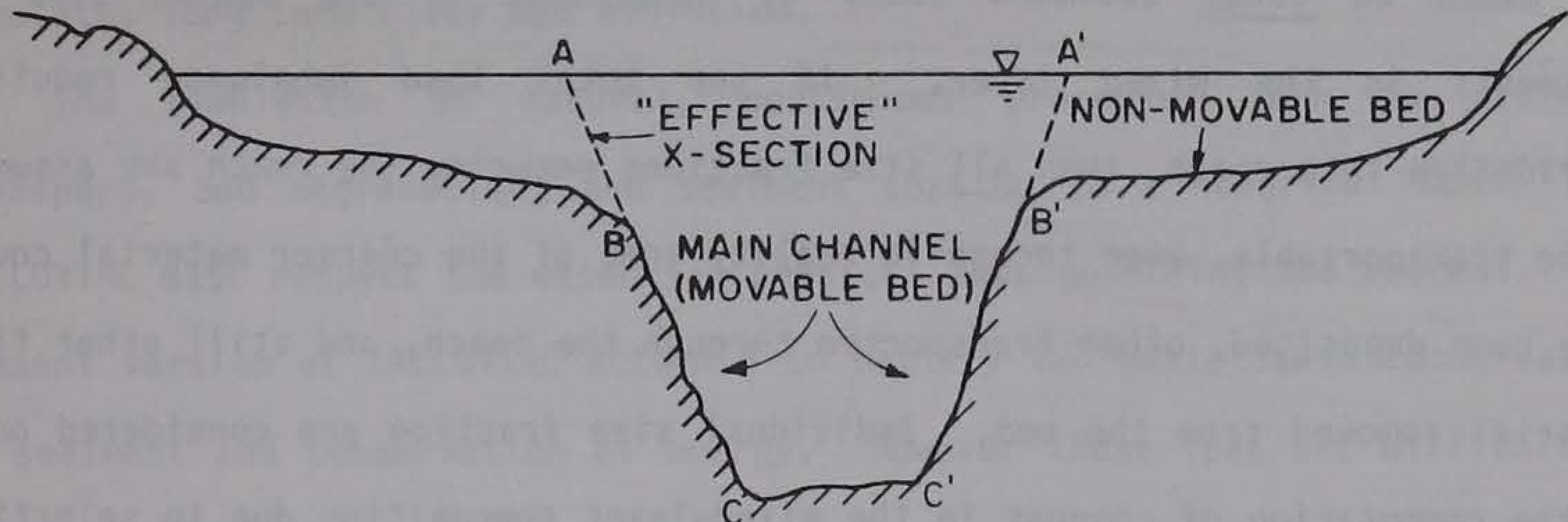


Figure V.1 Schematic Multi-Channel Cross-Section

The proposed approach would involve dividing the cross-sections into two parts--the main channel with a movable bed and the two side channels with non-movable beds (see Figure V.1). When flood discharge flows over the top (BB') of the main channel, the computation of water surface elevation would take into account the entire cross-section including the side channels, but the sediment discharge would be calculated from the mean depth and velocity of the extended main channel or the "effective" cross-section (ABCC'B'A') as shown in Figure V.1. The development of armoring due to continued bed aggradation would be assumed to occur only in the main channel.

Conservation of Sediment by Size Fraction. In IALLUVIAL, scour and deposition are based on total sediment load, as determined by the median size of sediments in the mixed layer. If the total load imbalance requires degradation in a reach, then all size fractions entering the reach are assumed to be transportable, even though in reality some of the coarser material could have been deposited, other transported through the reach, and still other fine material removed from the bed. Individual size fraction are considered only in the computation of changes in the mixed-layer composition due to selective removal or addition of material.

The above procedure, while not rigorous physically, has proven to be generally adequate for Missouri River computations. However, when tributary and bank erosion sediment supply are important, or when the bed material is less uniform than in the Missouri, it is necessary to introduce a rigorous accounting of sediment by size fraction. This could be done in IALLUVIAL by computing sediment load by size fraction, yet constraining the total amount of scour or deposition to be that given by the present total-load calculation procedure. This would require careful analysis of the conditions under which the Total Load Transport Model could be applied to individual size fractions, and would involve testing of developed procedures on both schematic and Missouri River data sets.

Degradation Time Scale. the computational scheme in IALLUVIAL is based on subdivision of time and distance into short intervals called time steps (usually about 15 days) and reach lengths (five to ten miles). At a given time the physics of flow, sediment transport, and degradation are applied to each reach individually, thereby taking into account local conditions in computing the overall response of the river to water and sediment loads in a given time step. The repetition of this process over many time steps simulates long term river bed evolution.

The simulation of natural, continuous processes such as sediment transport, bed degradation, and sediment sorting in a numerical model like IALLUVIAL must respect the essential physical laws governing the process. The present version of IALLUVIAL attempts to satisfy two basic laws: conservation of sediment and conservation of energy. However these laws are difficult to satisfy exactly when finite time steps and reach lengths are employed. In particular, conservation of sediment is violated whenever time steps are larger than about one day. This violation is minor in most cases, but its cumulative effect is to underestimate the amount of degradation which can occur in a given period of time--or, equivalently, to overestimate the time needed to attain a given amount of degradation.

The obvious solution to this problem, which is to reduce the time step to, say, one day, is not a viable one because of the greatly increased computational costs this would entail. An alternative solution, which should be explored, is to maintain the usual large time step of about 15 days for the relatively expensive computation of flow conditions, but use a much smaller step for the reach-by-reach degradation process described above. Use of this procedure would require a careful analysis of conditions under which bed level changes, armoring, and sediment sorting can be momentarily uncoupled from changes in water flow conditions.

A second apparent source of time-scale distortion in IALLUVIAL involves the rate at which degradation, initiated locally by the shut-off of sediment supply by Gavin's Point Dam and/or the channel constriction at Ponca State

Park, propagates downstream. In nature, bed perturbations (such as an advancing degradation wave) proceed downstream at a speed which depends on the flow conditions, sediment size distribution, and water and sediment properties. But in IALLUVIAL bed perturbations must necessarily be spread over an entire computational subreach, meaning that the perturbation can advance at a rate no faster than one subreach length per time step, or about 120 miles/year, for example, in the numerical model. Figure V.2 shows schematically how the degradation computed for a subreach may reflect the proper volume of material removed, but spread the effects of degradation too far downstream.

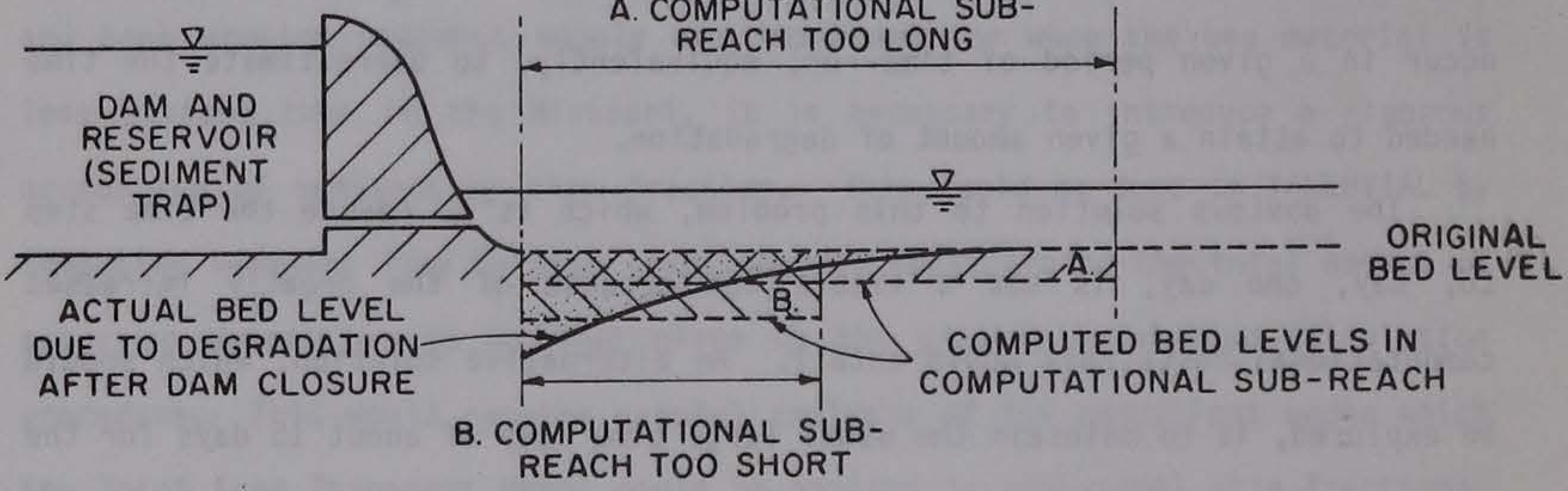


Figure V.2 Schematic Representation of Physical and Numerical Degradation Waves

This discrepancy between the actual propagation speed and the numerical propagation speed imposed in the computational model introduces another source of distortion of time in Missouri River degradation prognosis computations. The solution to this problem would involve developing a modified version of the present reach-by-reach calculation which would specifically incorporate, and be constrained to agree with, physical bed-perturbation propagation speeds as estimated using recent research results.

Incorporation of these two improvements into IALLUVIAL would complement its demonstrated ability to simulate channel degradation with improved reliability as to prediction of the time scales involved.

Critical Assessment of Armoring Formulation. Reference has often been made in this report to the critical role of bed armoring in arresting degradation. As discussed in Section V.A, IALLUVIAL's armoring formulation cannot be considered as optimum or definitive at this juncture. The authors are currently involved in a study of ways to improve the armoring formulation, under the sponsorship of the Omaha District, U.S. Army Corps of Engineers.

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APPENDIX A. IALLUVIAL INPUT DATA STRUCTURE

Superscript digits refer to notes at the end of the Appendix. Cards which are always required are marked by an asterisk (*).

	Card No.	Variable Name	Format, Columns	Variable Description and Remarks
*	1	TITLE	15A4(1-60)	Title of the study or run
*	2	N	I5(1-5)	Number of computational points, or cross-sections
		N1	I5(11-15)	Number of sediment size intervals
		NT	I5(16-20)	Number of time steps
		MAXMA	I5(21-25)	Max. no. of elevations used to define cross sections
		NTRIB	I5(41-45)	Number of tributaries; NTRIB ≥ 1
		NBANK	I5(46-50)	Number of reaches with erodible bank materials
		IBED	I5(51-55)	0 if vertically homogeneous bed material; 1 otherwise
*	3	MAXBED^1	I5(1-5)	Max. no. of nonhomogeneous vertical layers in a reach
		IDREJ	I5(11-15)	0 if no dredging; 1 otherwise
		NTY	I5(16-20)	No. of time steps in a 360-day year
*	4	KDIA	I5(1-5)	Required value = 0
		IDIA	I5(6-10)	Required value = 0
		IUF	I5(11-15)	Required value = 0
		INPR	I5(16-20)	Frequency of printed output, in time steps
		IROCK	I5(21-25)	0 if no rock outcrops; 1 otherwise
		IBUG^2	I5(36-40)	0 for normal output; 1 for extensive diagnostic messages
		ICHB	I5(41-45)	0 for no width changes with time; 1 otherwise
		ICOFF	I5(46-50)	0 for no cutoffs with time; 1 otherwise
		NRES^3	I5(56-60)	Results file reference number; 0 for no results file

	Card No.	Variable Name	Format, Columns	Variable Description and Remarks
*	5	IRES	I5(1-5)	Required value = 1
		ISED	I5(6-10)	Required value = 1
		INDEX	I5(11-15)	Required value = 1
		INDEX1	I5(16-20)	Required value = 0
		INDSS	I5(21-25)	Required value = 1
		ILIMIT	I5(26-30)	Required value = 5
		IEQ	I5(31-35)	Required value = 1
		IDSWS[4]	I5(36-40)	0 if downstream w.s. elev. given as input; 1 otherwise
*	6	ALFA	F10.4(1-10)	Parameter C2 in Eq. (4) of Ref. (4)
		BETA	F10.4(11-20)	Parameter C3 in Eq. (8) of Ref. (4)
		C21	F10.4(21-30)	Required value = 1.0
		C22	F10.4(31-40)	Required value = 1.0
		FMIX	F10.4(41-50)	Required value = 1.0
		CARM[5]	F10.4(51-60)	Parameter C1 in Eq. (8)
*	7	STR[6]	F14.7(1-14)	Energy slope for d.s. boundary and initial estimate
	8[7]	DMZ(I),I=1,N	6F10.4	Depth of rock outcrop below initial bed, by point
*	9	IUPS	I5(1-5)	0 for constant upstream sediment inflow; 1 for upstream sediment inflow rating curve
	10[8]	CPPMUP	F14.8(1-14)	Upstream sediment concentration, ppm
*	11	LOCTR(L), L=1,NTRIB	12I5	Locations (point numbers) of tributaries, upstream to downstream. LOCTR(1) = N always
	12[9]	AC(L),BC(L) L=1,NTRIB	2F14.8	Sediment rating curve coefficients, Eq. (13). One card for each tributary
*	13	PTRIB(L,K) K=1,N1; L=1,NTRIB	6F10.2	Probability distribution function for tributary sediment loads; K varies first
	14[10]	IBSED	I5(1-5)	0 if eroded bank material same as bed; 1 otherwise
		QMIN	F10.1(6-15)	Water discharge (cfs) below which no bank erosion occurs

	Card No.	Variable Name	Format, Columns	Variable Description and Remarks
	15[10]	LOCBER(M), M=1,NBANK	12I5	Number of reaches subject to bank erosion, upstream to downstream
	16[11]	PBANK(M,K) K=1,N1;M=1,NBANK	6F10.2	Cummulative distribution function for eroded bank material; k varies first, M varies upstream to downstream
	17[10]	BEROS(M), M=1,NBANK	6F10.2	Bank erosion rates, ft^3/mile/day, in reaches LOCBER(M)
*	18	GAMA	F10.4(1-10)	Unit weight of sediment (use 165.0)
*	19	DS(K),K=1 N1+1	6F10.4	Sediment sizes (mm) delimiting the N1 size intervals

Card types 20,21,22 are read for each of N computation points, I=1, N-1, downstream to upstream; types 20,21 are read for I=N.

*	20	RMILE(I)	F10.2(1-10)	River mile of computational point I[12]
		MA(I)	I10(11-20)	Number of levels used to define cross section; MA(I) $\leq$ MAXMA
*	21	STAGE(I,L)	F10.3(1-10)	Reference elevation, ft[13]
		AREA(I,L)	F10.3(11-20)	Cross-sectional area, ft^2 [13]
		R1(I,L)	F10.3(21-30)	Hydraulic radius, ft[13]
		B1(I,L)	F10.3(31-40)	Surface width, ft
		L=1,MA(I)		(lowest to highest level, one level per card)
*	22	CDF(K), K=1, N1+1	6F10.4	Cumulative distribution function for bed sediment in the reach between points I and I+1; CDF(K) corresponds to DS(K)
	23[14]	NBEL(I) I=1,N-1	12I5	Number of elevations at which bed material changes in reach I, I from downstream to upstream
	24[14]	THBED(I), I=1,N-1	6F10.3	Constant thickness (ft) of subsurface layers in reach I
	25[14]	PBED(I,K,J), K=1,N1;J=1,NBEL; I=1,N-1		Probability distribution function for sediment in subsurface layer J of reach I
*	26	SSC(N,K),[15] K=1,N1	8F10.4	Sediment concentration (ppm) by size fraction at the upstream boundary

Card No.	Variable Name	Format, Columns	Variable Description and Remarks
* 27	IARMOR	I5(1-5)	0 for direct specification of armoring size; 1 otherwise
	MIND	I5(6-10)	If IARMOR=0, number of smallest sediment size fraction in armor coat
	QMAX	F10.0(11-20)	If IARMOR=1, and IQMAX=0, constant discharge used to determine armoring size, cfs
	IQMAX	I5(21-25)	If IARMOR=1, 0 for determination of armor size based on QMAX, 1 if based on local discharge

The input data structures for width changes, cutoffs, and dredging are presently being revised. The user should therefore adopt IDREJ=ICOFF=0 to suppress use of these features.

28[16]	ITDAT	I4	Date (day number) associated with the list of time-dependent data to follow
	TFREAD	F4.0	Water temperature (°F) on day ITDAT
	QTRIB(L), L=1,NTRIB	9F8.0	Tributary water discharges (cfs) on day ITDAT (recall QTRIB(1) = mainstem inflow)
	YREAD[17]		Downstream water level on day ITDAT (ft)

Notes

1. Used only if IBED=1.
2. The diagnostic messages are lengthy and of use only to the user who knows the detailed workings of the program.
3. NRES is the FORTRAN reference number of a sequential file onto which is written, without format, all results at each time step. This file can be used for off-line analysis of the computation. See Appendix E for the structure of this file.
4. If IDSWS=1, the program uses TLTM to compute the water surface elevation at the downstream boundary, for an imposed energy slope of STR (see Card 7).
5. The Missouri River model uses $C_1 = 0.5$.
6. The Missouri River model uses STR=0.00189.
7. Card 8 is read only if IROCK=1.
8. Card 10 is read only if IUPS=0.
9. AC has units of tons/day; BC is dimensionless. AC(1), BC(1) are read only if IUPS=1.
10. Card(s) read only if NBANK ≠ 0.
11. Cards 10 are read only if NBANK ≠ 0 and IBSED=1.
12. River miles increase from downstream to upstream, and must represent actual distances along the mainstem.
13. If AREA(I,MA(I) is left blank, both the areas and hydraulic radii (average depths) will be calculated automatically by the trapezoidal rule. Otherwise the user must furnish consistent values.
14. Card(s) read only if IBED=1.
15. SSC(N,K) is not used, but must be read.
16. IALLUVIAL obtains time-dependent data by linear interpolation (in time) between successive data lists of type 27 cards. At least two type 27 cards are required; ITDAT < 0 on the first, ITDAT > NT*360/NTY on the last.
17. TFREAD is used only if IDSWS=0.

APPENDIX B. IALLUVIAL MEMORY STRUCTURE

Justification

Any computer program which is used as a vehicle for developing new, innovative techniques is destined to go through two distinct phases of evolution. In the early stages of research, when new formulations are being tried and modified, the program is used as a test-bed. It is adapted as necessary to conform to expedient data input needs and special output requirements, incorporating tentative procedures which may or may not be retained depending on their performance. As a result the program takes on the appearance of a Rube Goldberg contraption, with redundant operations, a proliferation of working arrays, remnants of special procedures, etc. But if the new techniques prove to be successful, the program enters a mature phase of evolution in which the basic methods remain essentially unchanged, but are supplemented by generalizations and extensions, for practical use. The problem is that the program code at the end of the research phase is often poorly adapted to further orderly development, especially when programmers and users other than the original developer are involved.

IALLUVIAL is now in its second phase of evolution. Although it completed the development phase in relatively good shape thanks to the efforts of its developer, one aspect of the code presented a potential stumbling block to the incorporation of new methodologies: organization of working arrays, or tables. IALLUVIAL had some 115 arrays, some unused, all dimensioned locally and not always consistently. This meant that to perform a calculation in which some dimension of the problem increases (e.g., number of computational points, or number of sediment size intervals, etc.) one had to check very carefully to be sure that no pre-programmed limitation on this dimension would be exceeded, leading to disastrous results. If such a check revealed that some pre-programmed dimension had to be changed, this required reviewing all sixteen subroutines, making the change, and then recompiling them, a tedious process and one fraught with possibilities for making an error.

It can be argued that one can avoid this dimension problem by pre-programming dimensions which are larger than the maximum expected ones. However this procedure is flawed for two reasons. First, experience has shown that there always will be a larger dimension needed than had been previously anticipated. Second, excessive dimensioning wastes computer memory when it is not fully used. It is true that most computers available today can accomodate virtually any reasonable memory requirements; on the other hand, run priorities and computer resource billings both take memory use into account in most computing centers, so it remains desirable not to waste memory.

These considerations, along with the need to add several new arrays in conjunction with tributary, bank erosion, and vertical size distribution developments, made this an obvious time to restructure memory use in IALLUVIAL. The following sections give a general description of the principles used and their implementation in the program.

Principles of Method

The basic technique emplyed in IALLUVIAL, referred to as "dynamic allocation," involves the use of just one working array, called T. All working arrays are stored inside T, and dimensioned automatically at execution time according to the specific size of the problem being solved (number of points, number of channel segments, etc.) T is itself dimensioned once in the

MAIN program. Therefore to change the amount of required memory, the user need only change the dimension of T and recompile the MAIN, without having to worry about the dimensions of the 95 working arrays. Based on the general input data to the program, the space needed for each array can be calculated at execution time, and the position of each array inside T can then be computed. Through the use of the dummy argument feature of FORTRAN, the arrays can be used exactly as if they were dimensioned locally, using their proper names.

This system, which uses standard features of FORTRAN, allows the user to choose the way he uses memory to conform to the constraints of his computer center. He may dimension T by excess once and for all, and hopefully never have to change it, accepting the wasted space. Or he can tailor the dimension of T to the size of each model to be run using the formula described later on, thus using no more computer memory than actually needed. In either case, only one numerical dimension (instead of 95) is involved. (It should be noted that on certain computing equipment, even T can be dimensioned automatically, requiring no additional compilation of the MAIN).

Implementation in IALLUVIAL

In view of previous program documentation and the need not to disrupt ongoing program use, the changes to IALLUVIAL were made in such a way as to leave most of the code untouched. The principal structural change involved changing the old MAIN to SUBROUTINE SMAIN, and creating a new, shorter MAIN for the dynamic allocation. With reference to the program listing in Appendix C, it may be seen that array T is dimensioned numerically to a value which must also be assigned to the scalar MEMO as shown. This is essential for subsequent verification of memory size.

As soon as the MAIN reads the first data card, containing all information necessary to determine the required size of working arrays, it proceeds to compute the location of each array with T, stored consecutively one after another. Thus I1 = 1, meaning that the first word of the first array (VOLIN) coincides with the first word of T. Since the required length of VOLIN is the product of its two maximum dimensions, N • N1, the next array (REACH) has its first word stored just after the last word of VOLIN, i.e., I2 = I1 + N • N1, and so on. Thus to each working array corresponds a unique index I_{XX}, each displaced from the previous one by the required length of that array. Table C.1 shows the names of the working arrays, the corresponding indexes, the dimensions, and a brief description of each.

At the completion of this operation, the position inside T of each working array has been assigned. At this point it is essential to verify that T is large enough, i.e., that the position of the last word of the last array is less than the dimension of T, MEMO.

The final stage in the dynamic allocation involves establishing the correspondance between the computed locations in T and the names of the arrays, i.e., T(I1) is equivalent to VOLIN (1,1), T(I28) = W(1), etc. This is done through a matching of argument lists in a call to SUBROUTINE SMAIN from the MAIN (note that actually this is broken into two calls, to SMAIN and ENTRY SMAIN1, to avoid having too long an argument list). This call, which transfers control to SMAIN for the duration of the computation, establishes once and for all the desired correspondance. In all subsequent use of the working arrays, their proper names are used exactly as before. The arrays are dummy-dimensioned using the same scalar variables used to compute their space allocation in T, no further dimensioning is required.

A potential drawback to this procedure is the need to transmit all arrays from one subroutine to another by argument lists, rather than in common blocks, which cannot be dummy-dimensioned on some computers. However, the expense of transmitting these long argument lists in repetitive calls is easily avoided by making one initial call to transmit the list once and for all, then calling an entry point (with no arguments) for all subsequent calls, as has been done in IALLUVIAL. For example one call to DAHYSO transmits all needed array addresses; all subsequent calls are to ENTRY HYSORT with no arguments.

Estimation of Required Memory The program itself, exclusive of space required for array storage (array T), required about 95K bytes of core storage when compiled in IBM FORTRAN H, option 2. The additional space required for array storage, i.e. the value of MEMO, can be estimatd by the following formula:

$$MEMO = N(38+17N1+7MAXMA+2NYR) + N1(2NTRIB) + 5NTRIB + NBANK(2+N1) + 3NYR + IDREJ(2NT+N+NNT) + 71$$

where MEMO is in 4-byte words, NYR is the number of years simulated, and all other variables are defined in appendix B, Cards 1 and 2. The Missouri River model of this study required MEMO = 10,000 words.

Table B.1
IALLUVIAL Memory Structure

Variable Name	Dimensions 1	Dimensions 2	Dimensions 3	Description	I( )	MAIN	INFLOW	S MAIN	SEDBED	START	DACHAN	DADRED	WATPRO	RESIS1	TRASF	SECPRO	SLOAD	ARMOR	HYSORT	VSORT	SHIELD	TRIB	ERROR1
Q	N			Water discharge @ each point	I7		○	○		○			○	○			○	○				○	
QTR	NTRIB			Tributary water discharge	I86		○	○					○									○	
LOCTR	NTRIB			Location (node no.) of tributary	I89		○	○					○				○					○	
STAGE	N			Water surface elevation @ each point	I6		○	○		○			○			○							
VOLIN	N	N1		Depth of sediment entering mixing layer	I1			○											○	○			
REACH	NN			Reach length	I2			○		○	○	○	○				○						
DMZ	N			Depth of rock outcrop below initial bed	I3			○															
MA	N			No. of definition levels for each section	I9			○		○	○	○				○							
STAGE1	N	MAXMA		Levels @ which section properties defined	I10			○		○		○	○			○	○	○	○	○			
B1	N	MAXMA		Width @ section definition levels	I11			○		○	○					○							
SL1	NN			Initial bed slopes	I12			○															
R1	N	MAXMA		Hydraulic radius @ section definition levels	I13			○		○	○	○				○							
AREA	N	MAXMA		Cross-sectional area	I14			○		○	○	○				○							
AREAI	N	MAXMA		Initial cross-sectional area, before updating	I15			○															
RI	N	MAXMA		Initial hydraulic radius, before updating	I16			○															
STAGEI	N	MAXMA		Initial section definition levels	I17			○															
DS	N1P1			Particle size diamters defining size fractions	I18			○															
D50	NN			Median sediment size by reach	I19			○							○		○	○	○				
CDF	N1P1			cdf for initial bed sediment by reach	I20			○															
DMS	N			D_{50} by section, aberaging of adjacent reaches	I21			○		○			○	○									
P	N1			Porosity of sediment by size fraction	I22			○									○	○	○				
D	N1			Geometric mean sediment size of each fraction	I23			○					○	○	○		○	○	○				
PT	NN	N1		Sediment fraction in bed	I24			○				○			○		○	○	○	○			
PTT	NN	N1		Initial sediment fraction in bed	I25			○				○					○	○	○	○			
TF	72			Temperatures @ which water viscosity defined	I26			○															
W	N1			Fall velocity for each size fraction	I28			○															
SSC	N	N1		Susp. sed. conc^n by size interval	I29			○							○		○		○				
SS1	N1			Susp. sed. conc^n @ u/s section	I30			○															
PTI	NN	N1		Initial storage for PT	I31			○															
XAREA	N			Total cross-sectional area	I32			○		○			○	○		○							
R	N			Hydraulic radius	I33			○					○	○	○	○							
B	N			Width at water surface	I34			○		○		○	○			○							
CTO	N			Mean sed. conc^n per volume	I35			○					○	○	○		○		○			○	
SF	N			Energy slope	I36			○		○			○	○	○		○	○					
ACF	N			Fraction of bed surface, which is armored	I37			○					○	○			○	○	○				
CIN	N			Initial values of mean sed. conc^n	I38			○						○									
FR	N			Friction factor	I39			○					○										
GS	N1			Specific wt by size fraction	I40			○															
VAV	N			Mean water velocity	I47			○									○						
SE	N			Energy slope	I48			○															

*indicates use of the array in the indicated subroutine

Table B.1 (cont)

					T( )	MAIN	INFLOW	S MAIN	SEDBED	START	DACHAN	DADRED	WATPRO	RESIS1	TRASF	SECPRO	SLOAD	ARMOR	HYSORT	VSORT	SHIELD	TRIB	ERROR1
DW	N			Mean water depth	I49			○									○						
DELDS	N	N1		Bed Elev^n change due to suspended load	I50			○									○						
TDELD	N	N1		Bed Elev^n change due to total load	I51			○									○		○				
CDEP	N			Cumulative sum of TDELD	I52			○				○					○	○	○	○			
KA	N	N1		Scour limit index	I53			○									○						
BZ	N	N1		Mixed layer thickness	I54			○											○				
Y	N			Cumulative degradation at points	I55			○															
VOLOUT	N			Depth of degr. in a time step	I56			○									○	○	○				
RMILE	N			River mile	I57			○															
LLIM	N			Index of enhaustion of sediment supply	I62			○											○				
ELT	N	N1		Computed Wt to satisfy stability criterion	I63			○									○		○				
DH	N			Cumputed cumulative water surface elevation change	I66			○															
TI	N	N1		Mixed layer thickness, uncorrected	I73			○											○				
TH	N			Mixed layer thickness, corrected	I74			○											○				
TH1	N			Temporary storage for TH	I75			○											○				
PTP	N	N1		Sediment size fractions, previous time period	I76			○											○				
EL1	N			Intermediate working variable	I77			○				○					○	○	○				
EL2	N			Intermediate working variable	I78			○											○				
PTU	N	N1		Updated sediment size distribution	I79			○											○	○			
BML	N			Mixed layer bottom elevation	I80			○											○				
PQS	N	N1		% of QS in each size fraction	I81			○							○		○						
PDN	N	N1		% of deposition in each size fraction	I82			○							○		○						
CDEP1	N			Temporary storage for CDEP	I83			○									○						
TB	N	N1		Mixed layer thickness, corrected	I84			○									○		○				
ACF1	N			Temporary storage for ACF	I85			○									○	○					
QSTR	NTRIB			Tributary sediment discharge	I87			○									○					○	
TDELTR	NTRIB	N1		Depth of sediment supplied by tributary	I88			○									○					○	
PTRIB	NTRIB	N1		Tributary sed. discharge size distribution	I90			○									○					○	
AC	NTRIB			Coefficient in sed. discharge rating curve	I91			○														○	
BC	NTRIB			Exponent in sed. discharge rating curve	I92			○														○	
LOCBER	NBANK			Location (reach no.) of bank erosion	I93			○									○					○	
BEROS	NBANK			Bank erosion rate	I94			○									○					○	
NBEL	NN			No. of sed. layers in a reach	I95			○	○			○					○	○	○	○			
THBED	NN			Thickness of sediment layers in a reach	I96			○	○			○					○	○	○	○			
PBED	NN	N1	MAXBED	Fraction of sediment in each size interval, each layer	I97			○	○				○				○	○	○	○			
ICHBT	NT3651			No. of time intervals in which widths can change	I98			○				○											
ICOFFT	NT3651			No. of time intervals in which cutoffs can occur	I99			○				○											
ICHBL	NT3651	N		Location of width changes (node number)	I100			○				○											
ICOFFL	NT3651	NN		Location of cutoffs (reach no.)	I101			○				○											
NCHBL	NT3651			No. of nodes undergoing width change in a time step	I102			○				○											
NCOFFL	NT3651			No. of reaches undergoing cutoffs in a time step	I103			○				○											
PBANK	NBANK	N1		Size distirbution of eroded bank material	I104			○									○					○	
PTA	NN	N1		Updated size distribution of original material	I105			○									○	○					

Table B.1 (cont)

					T( )	MAIN	INFLOW	S MAIN	SEDBED	START	DACHAN	DADRED	WATPRO	RESIS1	TRASF	SECPRO	SLOAD	ARMOR	HYSORT	VSORT	SHIELD	TRIB	ERROR1
IDRT	NT			List of time steps in which dredging occurs	I106			○				○											
IDRL	NT	N		List of locations (reach no.) of dredging, each time step	I107			○				○											
NDRL	NT			No. of dredging reaches in each time period	I108			○				○											
VDREJ	N			Volumetric rate of dredging @ each reach	I109			○				○											
DARM	N			Cumulative depth of degradation for armoring	I110			○				○					○	○					
RA	N			Pseudonym for R	I33												○	○	○				
BB	N			Pseudonym for B	I34												○	○					
QSDP	N-1			Total load deficit in previous time step	I4			○									○						

APPENDIX C

IALLUVIAL SOURCE LISTING

```
C    ******************************************
C
C       PROGRAM  I  A  L  L  U  V  I  A  L
C
C    ******************************************
C
C     DEFINITION OF VARIABLES
C
C     SECTION I,       I=1,N
C     SIZE FRACTION K,  K=1,N1
C     ELEVATION L,      L=1,MA(I)
C     TIME INTERVAL IT, IT=1,NT
C
C     IRES= INDEX VARIABLE TO INDICATE METHOD OF COMP.FLOW RESISTANCE
C            IRES= 1 FOR IIHR METHOD ; IRES= 2 FOR A-L-K METHOD
C     ISED= INDEX VARIABLE TO INDICATE  METHOD OF COMPUTING SEDIMENT
C           DISCHARGE ; ISED= 1 FOR IIHR METHOD; ISED= 2 FOR EINSTEIN
C           METHOD
C     INDEX=INDEX VARIABLE TO INDICATE NO.OF SUBSECTIONS USED IN
C           BACKWATER CALCULATIONS (=1 FOR SINGLE CHANNEL,=2 FOR
C           2 SUBSECTIONS, =3 FOR 3 SUBSECTIONS )
C     INDEX1=INDEX VARIABLE TO INDICATE WHETHER NO. OF SUBCHANNELS
C            USED IN SEDIMENT CALCULATIONS IS THE SAME OR MORE THAN
C            THAT USED IN BACKWATER CALCULATIONS (=0,SAME; =1, MORE )
C     INDSS=INDEX VARIABLE TO SPECIFY UPSTREAM SEDIMENT DISCHARGE;
C           INDSS=0 IF COMPUTED BY THE PROGRAM AS EQUAL TO THE
C           TRANSPORT CAPACITY; =1 IF GIVEN AS INPUT
C     IDSWS=INDEX VARIABLE TO SPECIFY DOWNSTREAM WATER SURFACE
C            ELEVATION;IDSWS=0 IF GIVEN AS INPUT; =1 IF COMPUTED
C            INTERNALLY ASSUMING UNIFORM FLOW
C     N=NO. OF SECTIONS,IN LONGITUDINAL DIRECTION
C     N1=NO. OF SEDIMENT SIZE FRACTIONS
C     NT= NO. OF TIME INTERVALS
C     NTRIB=NUMBER OF TRIBUTARIES
C     NBANK= NUMBER OF REACHES WITH BANK EROSION
C     IBED = INDEX VARIABLE TO INDICATE VERTICAL VARIATION OF BED-MAT.
C              SIZE DIST. BELOW ORIGINAL CHANNEL BED; IBED=0 FOR NO
C              VARIATION; =1 FOR VARIATION.
C     NBED= NO. OF REACHES WHERE SEDIMENT-BED COMPOSITION VARIES
C             IN VERTICAL DIRECTION
C     NTP=NO.OF TIME INTERVALS AT WHICH BED-ELEVATION CHANGES WILL BE
C          PLOTTED AT A GIVEN SECTION
C     ICHB= INDEX VARIABLE FOR CHANGE IN CHANNEL WIDTH WITH TIME;
C              ICHB=0 FOR NO CHANGE; =1 FOR CHANGE.
C     ICOFF= INDEX VARIABLE FOR INCORPORATING CHANNEL CUTOFF AT
C                 SPECIFIED TIMES
C     IDREJ=INDEX VARIABLE FOR DREDGING; IDREJ=0 FOR NO DREDGING;
C                  =1 FOR DREDGING.
C     IBUG=INDEX VARIABLE FOR PRINTING DETAILED OUTPUT FOR DEBUGGING
C             IBUG=0 FOR NO PRINT; =1 FOR PRINTING .
C     ILIMIT=LIMITING NUMBER OF VIOLATIONS OF SPECIFIED CRITERIA FOR
C            RECOMPUTING BACKWATER PROFILE AND/OR SEDIMENT LOADS
C            IN EACH TIME PERIOD
C     IEQ= INDEX VARIABLE TO INDICATE EQUILIBRIUM OR NON-EQUILIBRIUM
C          SEDIMENT CALCULATIONS ( IEQ=1 FOR EQM., IEQ=0 FOR NON-EQM.)
C     IDELT=TIME INTERVAL,DAYS
C     NTY=NO. OF TIME STEPS IN ONE YEAR (360DAYS)
```

```
C     ITIME=TOTAL PERIOD,DAYS
C     GAMA=SPECIFIC WEIGHT(LBS/CFT) OF SEDIMENT
C     IFLAG=INDEX VARIABLE TO INDICATE RECOMPUTATION OF BACKWATER
C           PROFILE ( IFLAG=0: DO NOT RECOMPUTE; IFLAG=1: RECOMPUTE )
C     IFLAG1=INDEX VARIABLE TO INDICATE RECOMP. OF SEDIMENT LOADS
C            IN EACH TIME PERIOD (IFLAG1=0,DO NOT RECOMPUTE;
C            IFLAG1=1, RECOMPUTE )
C
C     MA(I)=NO.OF INDEX ELEVATIONS FOR COMPUTING GEOMETRIC PROPERTIES
C           AT SECTION I
C     STAGE(I)=WATER SURFACE ELEVATION AT SECTION I,IN TIME INT. IT
C     REACH(I)=LENGTH OF REACH(FT.) BETWEEN SECTIONS I AND I+1
C     Q(I)=TOTAL DISCHARGE(CFS.) AT SECTION I,IN TIME INTERVAL IT
C     STAGE1(I,L),AREA(I,L),R1(I,L),B1(I,L)=STAGE,AREA,HYD.RADIUS,AND
C           W.S.WIDTH ,RESPECTIVELY,OF THE WHOLE SECTION AT SECTION I,
C           ELEV. INDEX L
C     D50  (I)=MEDIAN SEDIMENT SIZE (MM) AT SECTION I
C     D65G(I)=D65(MM) AT SECTION I,SEGMENT J
C     DLIM(I)= MAXM. SEDIMENT DEPTH(FT) AT START ON BED AT SECTION I,   M
C                SEGMENT J
C     D(K),P(K),W(K)=SED.SIZE(MM.),POROSITY,AND FALL VELOCITY(FT/S),
C                   RESPECTIVELY,FOR SIZE FRACTION K
C     PT(I,K)=SED. FRACTION FOR SECTION I,SEGMENT J,SIZE K,IN THE BED
C     PTT(I,K)=INITIAL VALUE OF PT(I,K)
C     PTI(I,K)=INITIAL STORAGE FOR PT(I,K)
C     TF(I),VISC(I)= ARRAY OF TEMPERATURE AND VISCOSITY OF WATER ,
C                   RESPECTIVELY, AT INDEX I
C     TEMPF= TEMPERATURE(F) OF WATER IN TIME PERIOD IT
C     GS(K)=SPECIFIC WEIGHT(LBS/CFT),FOR SIZE FRACTION K
C     SSC(I,K)=SED.CONCN.(PPM) OF FRACTION K,AT SEGMENT J,SECTION I
C     SS1(K)=SSC(N,K)
C     B(I)=W.S.WIDTH
C     SF(I)=ENERGY SLOPE
C     CTO(I)=MEAN SED. CONCENTRATION PER VOLUME, AT SECTION I
C     FR(I)=FRICTION FACTOR
C     PSD(K)=FRACTION OF MATERIAL OF SIZE K IN THE DISCHARGE
C     RA(I)=HYD. RADIUS AT SECTION I,SEGMENT J
C     XA(I)=CROSS SECTION AREA AT SECTION I,SEGMENT J
C     BB(I)=W.S.WIDTH
C     D50G(I)=SED.DIA.(MM.)  AT SECTION I, SEGMENT J
C     QST(I)=TOTAL DISCHARGE OF SEGMENT J,AT SECTION I
C     VAV(I)=MEAN VELOCITY AT SECTION I,SEGMENT J
C     SE(I)=ENERGY SLOPE AT SECTION I, SEGMENT J
C     DW(I)=MEAN WATER DEPTH OF SEGMENT J, AT SECTION I
C     DELDB (I,K)=CHANGE IN BED ELEVATION AT SECTION I, SEGMENT J, FOR
C                 SED. FRACTION K,DUE TO BED LOAD
C     DELDS (I,K)=CHANGE IN BED ELEVATION AT SECTION I, SEGMENT J, FOR
C                 SED. FRACTION K,DUE TO SUSPENDED LOAD
C     TDELD (I,K)=CHANGE IN BED ELEVATION AT SECTION I, SEGMENT J, FOR
C                 SED. FRACTION K,DUE TO SUSPENDED LOAD AND BED LOAD
C     CDEP(I)=SUM IN K AND TIME OF TDELD(I,K)
C     CC(J)=SUM IN K OF TDELD(I,K)
C     AREA1(I,K)=CROSS SECTIONAL AREA AT SECTION I,SEGM. J,ELEV.IND.K
C     R11(I,K)=HYDRAULIC RADIUS AT SECTION I,SEGMENT J,ELEV.IND. K
C     BB11(I,K)=W.S. WIDTH       AT SECTION I,SEGMENT J,ELEV.IND. K
C
C     XAREA(I),XAREAL(I),XAREAR(I),XAREAM(I)=
C
```

```
C     D50L (I),D50R (I),D50M (I)=SED.DIA.(MM.). FOR LEFT, RIGHT AND
C               MAIN SUBSECTION,RESPECTIVELY
C
C     DYNAMIC ALLOCATION OF ARRAYS
C
C     ATTENTION : ARRAY T MUST ALWAYS BE DIMENSIONED T(MEMO)
C     ---------             ------
C
C              $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
                DIMENSION T(20000   ),TITLE(15)
                MEMO=20000
C              $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
C
      READ (5,1000) TITLE
 1000 FORMAT(15A4)
      WRITE(6,2000) TITLE
 2000 FORMAT('1',////,10X,70('*'),/,10X,'*',68X,'*',/,10X,'*',4X,
     $ 15A4,4X,'*',/,10X,'*',68X,'*',/,10X,70('*'),////)
C
C     READ DIMENSIONING PARAMETERS
C
      READ(5,1001) N,M1,N1,NT,MAXMA,NOBS,NX,IGR,NTRIB,NBANK,IBED,NBED
      READ(5,1001) MAXBED,NTP,IDREJ,NTY
 1001 FORMAT(12I5)
      NN=N-1
      NMA=N*MAXMA
      NN1=N*N1
      N1P1=N1+1
      NT3651=1
      NT3652=1
      IF (NTY.NE.0) NT3651=NT/NTY+1
      IF (NTY.NE.0) NT3652=NT/NTY+2
      NT1=1
      IF (NTP.NE.0) NT1=NT/NTP+2
C
C     DYNAMIC ALLOCATION OF WORKING ARRAYS WITHIN ARRAY T
C
      I1=1
      I2=I1+NN1
      I3=I2+NN
      I4=I3+N
      I5=I4+NN
      I6=I5
      I7=I6+N
      I8=I7+N
      I9=I8
      I10=I9+N
      I11=I10+NMA
      I12=I11+NMA
      I13=I12+NN
      I14=I13+NMA
      I15=I14+NMA
      I16=I15+NMA
      I17=I16+NMA
      I18=I17+NMA
```

```
      I19=I18+N1+1
      I20=I19+NN
      I21=I20+(N1+1)
      I22=I21+N
      I23=I22+N1
      I24=I23+N1
      I25=I24+NN*N1
      I26=I25+NN*N1
      I27=I26+72
      I28=I27
      I29=I28+N1
      I30=I29+NN1
      I31=I30+N1
      I32=I31+NN*N1
      I33=I32+N
      I34=I33+N
      I35=I34+N
      I36=I35+N
      I37=I36+N
      I38=I37+N
      I39=I38+N
      I40=I39+N
      I41=I40+N1
      I42=I41
      I43=I42
      I44=I43
      I45=I44
      I46=I45
      I47=I46
      I48=I47+N
      I49=I48+N
      I50=I49+N
      I51=I50+NN1
      I52=I51+NN1
      I53=I52+N
      I54=I53+NN1
      I55=I54+NN1
      I56=I55+N
      I57=I56+N
      I58=I57+N
      I59=I58
      I60=I59
      I61=I60
      I62=I61
      I63=I62+N
      I64=I63+NN1
      I65=I64
      I66=I65
      I67=I66+N
      I68=I67
      I69=I68
      I70=I69
      I71=I70
      I72=I71
      I73=I72
      I74=I73+NN1
      I75=I74+N
      I76=I75+N
```

```
      I77=I76+NN1
      I78=I77+N
      I79=I78+N
      I80=I79+NN1
      I81=I80+N
      I82=I81+NN1
      I83=I82+NN1
      I84=I83+N
      I85=I84+NN1
      I86=I85+N
      I87=I86+NTRIB
      I88=I87+NTRIB
      I89=I88+NTRIB*N1
      I90=I89+NTRIB
      I91=I90+NTRIB*N1
      I92=I91+NTRIB
      I93=I92+NTRIB
      I94=I93+NBANK
      I95=I94+NBANK
      I96=I95+NN
      I97=I96+NN
      I98=I97+(NN*N1*MAXBED)*IBED
      I99=I98+NT3651
      I100=I99+NT3651
      I101=I100+NT3651*N
      I102=I101+NT3651*NN
      I103=I102+NT3651
      I104=I103+NT3651
      I105=I104+NBANK*N1
      I106=I105+NN*N1
      I107=I106+NT*IDREJ
      I108=I107+NT*N*IDREJ
      I109=I108+NT*IDREJ
      I110=I109+N*IDREJ
      I111=I110+N
      IEND=I111
C
C     VERIFICATION OF SUFFICIENT MEMORY
C
      IF(IEND.LT.MEMO) GO TO 10
      CALL ERROR1( IEND,MEMO,N,M1,N1,NT,MAXMA,NOBS,NX,IGR)
C
C     MEMORY O.K. TRANSFER CONTROL AND ARRAY ADDRESSES TO SMAIN
C
10    WRITE(6,2002) IEND,MEMO
2002  FORMAT(T20,'MEMORY USED =',I8,' WORDS',3X,'MEMORY AVAILABLE=',I8)
      CALL SMAIN(TITLE,T(I1),T(I2),T(I3),T(I6),T(I7),
     1 T(I9),T(I10),T(I11),T(I12),T(I13),T(I14),T(I15),T(I16),
     2 T(I17),T(I18),T(I19),T(I20),T(I21),T(I22),T(I23),T(I24),T(I25),
     3 T(I26),         T(I28),T(I29),T(I30),T(I31),T(I32),T(I33),T(I34),
     4 T(I35),T(I36),T(I37),T(I38),T(I39),T(I40),T(I4))
       CALL SMAIN1 (T(I47),T(I48),T(I49),T(I50),T(I51),T(I52),
     6 T(I53),T(I54),T(I55),T(I56),T(I57),
     7 T(I62),T(I63),T(I66),
     8 T(I73),T(I74),T(I75),T(I76),T(I77),T(I78),T(I79),
     9 T(I80),T(I81),T(I82),T(I83),T(I84),T(I85),T(I86),T(I87),T(I88),
     8 T(I89),T(I90),T(I91),T(I92),T(I93),T(I94),T(I95),T(I96),T(I97),
     9 T(I98),T(I99),T(I100),T(I101),T(I102),T(I103),T(I104),T(I105),
```

```
     @ T(I106),T(I107),T(I108),T(I109),T(I110))
      STOP
      END
C
      SUBROUTINE INFLOW (Q,QTR,LOCTR,TEMPF,STAGE)
C
      DIMENSION Q(N),QTR(NTRIB),LOCTR(NTRIB),QTRIB(8),STAGE(N)
C
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
C
      IF (IT.EQ.1) ITDAT=0
C
C     READ NEW INFLOWS IF NEEDED
C
25    IF (ITIME.LE.ITDAT) GO TO 100
      DO 30 LT=1,NTRIB
            QTR(LT)=QTRIB(LT)
30    CONTINUE
      TEMPF=TFREAD
      STAGE(1)=YREAD
      ITIMEP=ITDAT
      READ (5,1000,END=900) ITDAT, TFREAD,QTRIB,YREAD
      GO TO 25
1000  FORMAT (I4,F4.0,9F8.0)
C
C     INTERPOLATE BETWEEN VALUES AT PREVIOUS TIME STEP AND THOSE
C     MOST RECENTLY READ
C
100   FTIME=ITIME
      FINT=(FTIME-ITIMEP)/(ITDAT-ITIMEP)
      DO 125 LT=1,NTRIB
             QTR(LT)=QTR(LT)+FINT*(QTRIB(LT)-QTR(LT))
125   CONTINUE
      TEMPF=TEMPF+FINT*(TFREAD-TEMPF)
      STAGE(1)=STAGE(1)+FINT*(YREAD-STAGE(1))
      ITIMEP=ITIME
C
C     COMPUTE WATER DISCHARGES AT ALL COMPUTATIONAL POINTS BY
C     ACCUMULATION OF TRIBUTARY INFLOWS
C
      Q(N)=QTR(1)
      LT=2
      LM=N
10    LM=LM-1
      IF (LM.EQ.0) GO TO 301
      Q(LM)=Q(LM+1)
      IF (LM.NE.LOCTR(LT)) GO TO 10
      Q(LM)=Q(LM)+QTR(LT)
      LT=LT+1
      GO TO 10
C
C      PRINT MAINSTEM DISCHARGES AT TRIBUTARY INFLOW POINTS
C
301    IF (IBUG.NE.0) WRITE (6,2000) IT,ITIME,NTRIM,
```

```
     1 (Q(LOCTR(K)),K=1,NTRIB)
2000  FORMAT (1X,'IT=',I4,' ITIME=',I4,' NTRIM=',I1,' FLOWS:',
     1(T35,12F8.0))
C
999   RETURN
900   WRITE (6,2001) ITIME, ITDAT
2001  FORMAT (/,20(1H*),' ERROR: ITIME=',I5,
     1'EXCEEDS LAST INFLOW DATA ITDAT=',I5)
      STOP
      END
C
C     ----------------------
C       SUBROUTINE  SMAIN
C     ----------------------
C
      SUBROUTINE SMAIN (TITLE,VOLIN,REACH,DMZ,STAGE,Q,
     1 MA,STAGE1,B1,SL1,R1,AREA,AREAI,RI,STAGEI,DS,D50,CDF,DMS,P,D,
     2 PT,PTT,TF,W,SSC,SS1,PTI,XAREA,R,B,CTO,SF,ACF,CIN,FR,GS,QSDP)
C
      INTEGER ICODE/'IAL1'/
      LOGICAL SECCAL
      DIMENSION VOLIN(N,N1),REACH(NN),TITLE(15),DMZ(N),
     1 STAGE(N),Q(N),MA(N),STAGE1(N,
     2 MAXMA),B1(N,MAXMA),SL1(NN),R1(N,MAXMA),AREA(N,MAXMA),AREAI(N,
     3 MAXMA),RI(N,MAXMA),STAGEI(N,MAXMA),DS(N1P1),D50(NN),CDF(
     4 N1P1),DMS(N),P(N1),D(N1),PT(NN,N1),PTT(NN,N1),TF(72),
     5 VISC(72),W(N1),SSC(N,N1),SS1(N1),PTI(NN,N1),XAREA(N),
     6 R(N),B(N),CTO(N),SF(N),ACF(N),CIN(N),FR(N),GS(N1),
     7 VAV(N),QSDP(NN),
     8 SE(N),DW(N),DELDS(N,N1)
      DIMENSION TDELD(N,N1),CDEP(N),KA(N,N1),             Y(N),
     1 VOLOUT(N),RMILE(N),LLIM(N),DELT(N,
     2 N1),DH(N),
     3 TI(N,N1),TH(N),TH1(N),PTP(N,
     4 N1),EL1(N),EL2(N),PTU(N,N1),BML(N),PQS(N,N1),PDN(N,
     5 N1),CDEP1(N),TB(N,N1),ACF1(N),BZ(N,N1),
     6 QTR(NTRIB),QSTR(NTRIB),TDELTR(NTRIB,N1),LOCTR(NTRIB),
     7 PTRIB(NTRIB,N1),AC(NTRIB),BC(NTRIB),LOCBER(NBANK),
     8 BEROS(NBANK),NBEL(NN),THBED(NN),PBED(NN,N1,MAXBED)
      DIMENSION ICHBT(NT3651),ICOFFT(NT3651),ICHBL(NT3651,N),
     1 ICOFFL(NT3651,NN),NCHBL(NT3651),NCOFFL(NT3651),
     2 PBANK(NBANK,N1),
     3 PTA(NN,N1),IDRT(NT),IDRL(NT,N),NDRL(NT),VDREJ(N),DARM(N)
      DATA VISC /1.92,1.89,1.85,1.82,1.79,1.76,1.72,1.69,1.66,1.64,
     &1.61,1.58,1.55,1.53,1.50,1.48,1.45,1.43,1.41,1.39,1.37,1.34,
     & 1.32,1.30,1.28,1.26,1.25,1.23,1.21,1.19,1.17,1.16,1.14,1.13,
     & 1.11,1.10,1.08,1.07,1.05,1.04,1.03,1.01,.999,.986,.974,.961,
     & .949,.938,.926,.915,.904,.893,.883,.873,.862,.852,.843,.833,
     & .824,.814,.805,.796,.788,.779,.771,.762,.754,.746,.738,.731,
     & .723,.716 /
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
      COMMON/DREJ/KDREJ
C
      RETURN
```

```
      ENTRY SMAIN1(VAV,SE,DW,DELDS,TDELD,CDEP,KA,BZ,Y,
     4 VOLOUT,RMILE,LLIM,DELT,DH,
     5 TI,TH,TH1,PTP,EL1,EL2,PTU,BML,PQS,PDN,CDEP1,TB,ACF1,
     6 QTR,QSTR,TDELTR,LOCTR,PTRIB,AC,BC,LOCBER,BEROS,NBEL,THBED,PBED,
     7 ICHBT,ICOFFT,ICHBL,ICOFFL,NCHBL,NCOFFL,PBANK,PTA,IDRT,IDRL,
     8 NDRL,VDREJ,DARM)
C
C
C     DATA INPUT
C
C     IFR=INDEX VARIABLE TO INDICATE MODE OF CALCULATING FR. FACTOR
C         IFR=0 FOR CONSIDERING FR.FR. AS FUN. OF QS IN CURRENT PERIOD
C         IFR=1 FOR CONSIDERING FR.FR. AS FUN. OF QS IN PREVIOUS PERIOD
C     IDIA=INDEX VARIABLE TO INDICATE PROCEDURE OF FINDING D50 AT
C              A SECTION FROM ADJACENT REACH VALUES
C             IDIA=0 FOR CALCULATING D50 BY AVERAGING ADJ. REACH VALUES
C             IDIA=1 FOR CALCULATING D50 AS THE U/S REACH VALUE
C     IUF=INDEX VARIABLE TO INDICATE PROC. TO SPECIFY W.S. ELEVATION
C                AT THE MOST D/S SECTION
C             IUF=0 FOR SPECIFIED W.S.ELEV. AT THE MOST D/S SECTION
C             IUF=1 FOR CALCULATING W.S.ELEV. FOR UNIFORM FLOW
C     INPR=INDEX VARIABLE TO INDICATE FREQUENCY(@ NO. OF TIME INTERVALS)
C               OF PRINTING RESULTS
C     KDIA=INDEX VARIABLE FOR CONSIDERING ARMORING EFFECT IN CALC. D50
C             KDIA=0 FOR NOT CONSIDERING ARMORING EFFECT
C             KDIA=1 FOR CONSIDERING ARMORING EFFECT
C     IGR=INDEX VARIABLE TO INDICATE PLOTTING OPTION
C             IGR=0 FOR NO PLOT ; IGR=1 FOR PLOT
C     IPLOT=INDEX VARIABLE FOR TYPE OF PLOTS; IPLOT=0 FOR PLOTTING
C             ABSOLUTE VALUES OF BED W.S. ELEVATIONS; =1 FOR PLOTTING
C             INCREMENTAL CHANGES IN BED AND W.S. ELEVATIONS
C     IROCK=INDEX VARIABLE FOR LIMITING DEGRADATION DUE TO ROCK OUTCROP
C             IROCK=0 FOR NO ADJUSTMENT DUE TO ROCK OUTCROP
C             IROCK=1 FOR ADJUSTMENT DUE TO ROCK OUTCROP
C
C     IOBS=INDEX VARIABLE FOR INCLUDING OBSERVED CHANGE IN W.S.
C            PROFILE IN PLOTS
C             IOBS=0 FOR NOT INCLUDING OBSERVED VALUES
C             IOBS=1 FOR INCLUDING OBSERVED VALUES
C     INPUT=INDEX VARIABLE TO DESCRIBE DATA INPUT
C             INPUT=0 FOR SIMLIFIED DATA INPUT FOR THE MO. RIVER
C             INPUT=1 FOR GENERAL DATA INPUT
C
C     READ CONTROL VARIABLES
C
      READ(5,2) KDIA,IDIA,IUF,INPR,    IROCK,IOBS,INPUT,IBUG,ICHB,ICOFF
     @  ,IPLOT,NRES
C
C      OPEN RESULTS FILE,WRITE GENERAL DATA ON IT
C
      IF (NRES.GT.0)  WRITE(NRES)ICODE
      IF (NRES.GT.0)  WRITE(NRES)TITLE
      IF (NRES.GT.0)WRITE(NRES)
     1N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     2 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      READ(5,1) IRES,ISED,INDEX,INDEX1,INDSS, ILIMIT,IEQ,IDSWS
C
C     READ CALIBRATION PARAMETERS AND DIVERSE PHYSICAL PARAMETERS
```

```
C
      READ(5,5) ALFA,BETA,C21,C22,FMIX,CARM
      READ(5,3) STR,RMDS
      SF(1)=STR
      IF(IROCK.EQ.1) READ(5,5) (DMZ(I),I=1,N)
      IDELT=360/NTY
      IFR=0
      WRITE(6,54) IRES,ISED,INDEX,INDEX1,INDSS, N,M1,N1,NT,ILIMIT,IEQ,
     *    IFR,IDIA,IUF,INPR,KDIA,IGR,IROCK,IOBS,INPUT,NTRIB,NBANK,
     *    IBED,NBED,MAXBED,MAXMA,NOBS,NX,NTP,IBUG,ICHB,ICOFF,IPLOT,
     *    IDREJ,NTY,IDSWS,IDELT,NRES
      WRITE(6,31) ALFA,BETA,C21,C22,FMIX,CARM
      WRITE(6,29) STR,RMDS
C
C      CALL TRIB TO READ TRIBUTARY DATA
C
      CALL TRIB(QTR,QSTR,TDELTR,LOCTR,PTRIB,AC,BC,Q,LOCBER,BEROS,
     @  PBANK,CTO,INPUT)
C
      NN1=N1+1
C
C     READ STANDARD SEDIMENT SIZES
C
      READ(5,51) GAMA
      READ(5,5) (DS(K),K=1,NN1)
      WRITE(6,20)
C
C      READ SECTION DATA, COMPUTE RIVER MILES,AREAS, HYDRAULIC
C      RADII (LAST AREA=0.0 INTERPRETED AS REQUEST TO CALCULATE
C      ALL AREAS )
C
      DO 100 I=1,N
4110  FORMAT (F10.2,I10)
      READ (5,4110) RMILE(I), MA(I)
      IF (I.GT.1) REACH(I-1)=(RMILE(I)-RMILE(I-1))*5280.0
      MM=MA(I)
      IF(MM.GT.MAXMA) CALL ERROR2(I,MM   ,MAXMA)
      WRITE (6,8) I,RMILE(I),MA(I)
      READ(5,4) (STAGE1(I,L),AREA(I,L),R1(I,L),
     1                     B1(I,L),L=1,MM)
      SECCAL=.TRUE.
      IF(AREA(I,MM).NE.0.) SECCAL=.FALSE.
      DO 312 L=1,MM
      IF(L.EQ.1.OR..NOT.SECCAL) GO TO 750
      AREA(I,L)=AREA(I,L-1)+0.5*(B1(I,L-1)+B1(I,L))
     1          *(STAGE1(I,L)-STAGE1(I,L-1))
      R1(I,L)=AREA(I,L)/B1(I,L)
750   AREAI(I,L)=AREA(I,L)
      RI(I,L)=R1(I,L)
      STAGEI(I,L)=STAGE1(I,L)
312   CONTINUE
      WRITE(6,16)(STAGE1(I,L),AREA (I,L),R1 (I,L),B1(I,L),L=1,MM)
      IF (I.EQ.N) GO TO 100
C
C     READ SEDIMENT CHARACTERISTICS FOR REACH
C
      READ(5,5) (CDF(K),K=1,NN1)
C
```

```
C     COMPUTE D50 FROM GIVEN CDF
C
      DO 25 K=1,NN1
         IF (CDF(K).GT.0.5) GO TO 35
25    CONTINUE
      K=NN1
35    D50(I)=DS(K-1)+(DS(K)-DS(K-1))*(0.5-CDF(K-1))/
     1 (CDF(K)-CDF(K-1))
C
C     TRANSLATE 'D50' FROM REACH TO SECTION
C
      IF (I.NE.1) DMS(I)=(D50(I)+D50(I-1))/2.0
      IF(IDIA.EQ.1) DMS(I)=D50(I)
      DO 108 K=1,N1
      P(K)=0.40
      D(K)=SQRT(DS(K)*DS(K+1))
      PT(I,K)=CDF(K+1)-CDF(K)
108   PTT(I,K)= PT(I,K)
      WRITE(6,1490) I,D50(I)
     1              ,(CDF(K),K=1,NN1)
      WRITE(6,61) (PT(I,K),K=1,N1)
C
C      INITIALIZE QSDP FOR REACH I
C
      QSDP(I)=0.0
100   CONTINUE
C
C      WRITE RIVER MILES ON RESULTS FILE
C
      IF(NRES.GT.0) WRITE(NRES) (RMILE(I),I=1,N)
      DMS(1)=D50(1)
      DMS(N)=D50(N-1)
C
C      GENERATE STANDARD TEMPERATURES FOR VISCOSITY TABLE
C
      N3=72
      TF(1)=32.0
      DO 203 I=2,N3
203   TF(I)=TF(I-1)+1.0
C
C      CALL SEDBED TO READ DATA ON VERTICAL VARIATION OF BED
C      SEDIMENT COMPOSITION
C
      IF(IBED.EQ.1) CALL SEDBED(NBEL,THBED,PBED)
C
C
C     CALCULATION OF UNIT WEIGHTS OF SEDIMENT FRACTIONS
C
      G1=30.0
      G2=65.0
      G3=93.0
      DO 211 K=1,N1
      A=D(K)
      IF(A.LE..004 ) GS(K)=G1
      IF(A.GT..004 .AND.A.LE..062 ) GS(K)=G2
      IF(A.GT..062                ) GS(K)= G3
211   CONTINUE
C
```

```
C        PRINT DIVERSE GENERAL DATA
C
204   WRITE(6,44) (REACH(I),I=1,NN)
      IF(IROCK.EQ.1) WRITE(6,30)
      IF(IROCK.EQ.1) WRITE(6,33)  (DMZ(I3),I3=1,N)
      WRITE(6,48) (P(K),K=1,N1)
      WRITE(6,79)  (DS(K),K=1,NN1)
      WRITE(6,62)
      WRITE(6,37) ( D(K),K=1,N1)
      WRITE(6,63) GAMA
      WRITE(6,121)
      WRITE(6,33) (TF(I),I=1,N3)
      WRITE(6,122)
      WRITE(6,37 ) (VISC(I),I=1,N3)
      WRITE(6,88)
C
C     CONVERSION OF VISC(I) TO (SQ.FT./S)
C
      DO 935 I=1,N3
935   VISC(I)=VISC(I)*1.E-5
C
C     CONVERSION OF SED. SIZE FROM MM TO FT.
C
      DO 111 K=1,NN1
      IF (K.NE.NN1) D(K)=D(K)/304.8
111   DS(K)=DS(K)/304.8
      DO 814 I=1,N
      DMS(I)=DMS(I)/304.8
      IF(I.EQ.N) GO TO 814
      D50(I)=D50(I)/304.8
814   CONTINUE
C
C
C      READ U/S SEDIMENT INFLOW DATA
C
       READ(5,6,END=9000)  (SSC(N,K),K=1,N1)
C
C     INITIAL SUBROUTINE CALLS TO TRANSMIT ARRAY ADDRESSES
C
       CALL DAWATP(REACH,STAGE,Q,STAGE1,D,XAREA,R,B,CTO,SF,FR,ACF,
     1 LOCTR,QTR,DMS)
       CALL DARESI(Q,DMS,D,XAREA,R,CTO,SF,ACF,CIN)
       CALL DATRAS(D50,D,PT,SSC,R,CTO,SF,PQS,PDN)
       CALL DASECP(STAGE,MA,STAGE1,B1,R1,AREA,XAREA,R,B)
       CALL DASLOA(REACH,P,D,PT,PTT,SSC,CTO,SF,ACF,R,B,DW,
     1 DELDS,TDELD,CDEP,KA,VOLOUT,DELT,PQS,PDN,CDEP1,TB,ACF1,
     2 LOCTR,QSTR,PTRIB,TDELTR,LOCBER,BEROS,PBANK,Q,PTA,   D50,
     3 THBED,NBEL,STAGE1,PBED,DARM,EL1,VAV,QSDP)
       CALL DAHYSO(VOLIN,STAGE1,D50,P,PT,PTT,SSC,CTO,SF,ACF,R,BZ,
     1 TDELD,VOLOUT,LLIM,DELT,TI,TH,TH1,PTP,EL1,EL2,PTU,BML,TB,NBEL,
     2 THBED,PBED,CDEP,D)
       CALL DAARMO(ACF,ACF1,PT,D,P,CDEP,PTT,VOLOUT,B,SF,D50,THBED,
     1             PTA,NBEL,STAGE1,PBED,Q,R,DARM,EL1)
       IF(ICHB.EQ.1.OR.ICOFF.EQ.1)CALL DACHAN (ICHBT,ICOFFT,ICHBL,
     @ ICOFFL,REACH,B1,AREA,NCHBL,NCOFFL,MA,R1)
       IF(IDREJ.EQ.1) CALL DADRED (IDRT,IDRL,NDRL,VDREJ,REACH,B,STAGE1
     @ CDEP,AREA,R1,NBEL,THBED,PT,PTT,PBED,DARM,EL1,MA)
C
```

```
C     BEGIN LOOP ON TIME STEPS
C
      IFLAG=0
      ITIME=0
      KYR=0
      DO 5000 IT=1,NT
      ITIME=ITIME+IDELT
C
C     LOAD NEW DISCHARGES,TEMPERATURE,AND D/S STAGE(IF IDSWS.NE.1)
C
      CALL INFLOW(Q,QTR,LOCTR,TEMPF,STAGE)
C
C     COMPUTE NEW TRIBUTARY SEDIMENT LOADS
C
      CALL TRIBQS
C
C      LOAD D/S BOUNDARY CONDITION
C
      IF (IDSWS.EQ.1) CALL START(STAGE,Q,STAGE1,DMS,B,XAREA,MA,B1,
     @ R1,REACH,SF,AREA)
      KDREJ=0
C
C      CALL DREDGE TO EXECUTE DREDGING
C
      IF (IDREJ.EQ.1) CALL DREDGE
C
C     CALCULATE VISCOSITY FROM GIVEN TEMPERATURE IN EACH TIME PERIOD
C
      DO 900 I=1,N3
      IF(TEMPF.LE.TF(I)) GO TO 910
900   CONTINUE
      CALL ERROR3(IT,ITIME,TEMPF,TF(N3))
      I=N3
910   VIS=VISC(I)
      VISLOG=ALOG10(VIS)
C
C     ESTIMATING FALL VELOCITY BY RUBEY EQN.
C
      DO 214 K=1,N1
      F11=36.0*VIS**2/(32.2*D(K)**3*1.65)
      F1=SQRT(2.0/3.0+F11)-SQRT(F11)
      W(K)=F1*SQRT(1.65*32.20*D(K))
      IF(IBUG.EQ.1) WRITE(6,34) K,W(K)
34    FORMAT(10X,'W(',I2,')=',F10.4,'  (FT/S)')
214   CONTINUE
C
C
C     CONVERSION OF CONCENTRATION FROM PPM TO CFT./CFT.
C
      DO 602 K=1,N1
602   SSC(N,K)=SSC(N,K)*10.E-6/2.65
C
102   IPRINT=2
      IF(IT.LE.2) INTP=1
      IF(IT.GT.2) INTP=INPR
      IF(ITIME.EQ.360) INTP=1
      IF((IT/INTP)*INTP.NE.IT) IPRINT=0
      IF(IT.EQ.NT) IPRINT=2
```

```
C
C     CALL TO WATPRO FOR BACKWATER COMPUTATION IN EACH TIME STEP
C
      CALL WATPRO
C
C     CALCULATION OF MAIN FLOW PROPERTIES AT EACH SECTION
C
      DO 700 I=1,N
      VAV(I)=Q(I)/XAREA(I)
      SE(I)=FR(I)*(VAV(I)**2)/(8.0*32.2*R(I))
      DW(I)=XAREA(I)/B(I)
700   CONTINUE
C
C      CALL TO SLOAD FOR SEDIMENT CONTINUITY COMPUTATION
C
      CALL SLOAD
C
C
C     MODIFICATION OF SECTION PROPERTIES AFTER SEDIMENTATION IN EACH
C         TIME PERIOD
C
      DO 726 I3=2,NN
726   Y(I3)=(CDEP(I3-1)+CDEP(I3))/2.0
      Y(1)=CDEP(1)
      Y(N)=CDEP(N-1)
C
C     MODIFICATION BECAUSE OF ROCK OUTCROP
C
      IF(IROCK.EQ.0) GO TO 737
      DO 736 I3=1,N
736   IF(Y(I3).GT.DMZ(I3)) Y(I3)=DMZ(I3)
737   CONTINUE
C
C     MODIFICATION BY CHANGING INDEX ELEVATIONS OF X-SECTIONS
C
      DO 720 I=1,N
      MM=MA(I)
      DO 720 L=1,MM
      STAGE1(I,L)=STAGEI(I,L)-Y(I)
720   CONTINUE
C
C     TRANSLATE D50(I)  AND ACF(I) FROM REACHES TO SECTIONS
C
      IF(IBUG.EQ.1) WRITE(6,711) (ACF(I),I=1,NN)
711   FORMAT(5X,'ACF :  ',8E12.5)
      ACF(1)=ACF(1)
      ACF(N)=ACF(N-1)
      DMS(1)=D50(1)
      DMS(N)=D50(N-1)
      DO 731 I=1,NN
      DH(I)=ACF(I)
      IF (I.EQ.1) GO TO 731
      DMS(I)=(D50(I)+D50(I-1))/2.0
      IF(IDIA.EQ.1) DMS(I)=D50(I)
      ACF(I)=( DH(I)+ DH(I-1))/2.
731   CONTINUE
      IF(IBUG.EQ.1) WRITE(6,711) (ACF(I),I=1,N )
C
```

```
      IF(IBUG.EQ.0) GO TO 5021
713   WRITE(6,82) ITIME
      DO 725 I=1,N
      WRITE(6,27) I
      DO 725 L=1,MM
      WRITE(6,84)STAGE1(I,L),AREA(I,L),R1(I,L)
725   CONTINUE
C
C     PRINT OUT RESULTS
C
 5021  YR=ITIME/365.0
      N2=NTP*IDELT
      NLINE=27
      N5=N/NLINE+1
      N6=1
      N7=N6+NLINE-1
      IF(N7.GT.N) N7=N
      IT1=IT*IDELT
      IDAY=IT1-KYR*360
      IF((IT1/360)*360.EQ.IT1) KYR=KYR+1
C
C      WRITE TIME HEADING ON RESULTS FILE
C
      IF(NRES.GT.0) WRITE(NRES) IT,ITIME,IDAY,KYR
      DO 811 I3=1,N5
      IF (IPRINT.NE.0) WRITE(6,70) ITIME,YR
      IF (IPRINT.NE.0) WRITE(6,71)
      DO 810 I1=N6,N7
      I=N+1-I1
      DMM=DMS(I)*304.8
      DEP=Q(I)/(B(I)*VAV(I))
      FFR=8.0*32.2*DEP*SE(I)/(VAV(I)**2)
      CBAR=CTO(I)*2.65E6
      IF(I.EQ.N) GO TO 809
      IF(IPRINT.NE.0.AND.LLIM(I).EQ.0) WRITE(6,75) VOLOUT(I)
      IF(IPRINT.NE.0.AND.LLIM(I).EQ.1) WRITE(6,76) VOLOUT(I)
809   IF (IPRINT.NE.0) WRITE (6,72)
     1 I,RMILE(I),B(I),STAGE(I),Q(I),DEP,VAV(I),
     2 SE(I),Y(I),DH(I), STAGE1(I,1),DMM,ACF(I),CBAR,FFR
      IF (NRES.LE.0) GO TO 810
C
C     WRITE CURRENT VALUES ON RESULTS FILE
C
      WRITE (NRES) B(I),STAGE(I),Q(I),DEP,VAV(I),SE(I),
     1Y(I),DH(I),STAGE1(I,1),DMM,ACF(I),CBAR,FFR
      WRITE (NRES) (PT(I,K),K=1,N1)
810   CONTINUE
      N6=N7+1
      N7=N6+NLINE-1
      IF(N7.GT.N) N7=N
      IF (N6.GT.N7) GO TO 105
811   CONTINUE
105   IF (NRES.GT.0) WRITE(NRES) (QTR(I),I=1,NTRIB),
     1(QSTR(I),I=1,NTRIB)
C
C     RECALCULATION OF SEDIMENT DIA. AFTER SEDIMENTATION IN EACH PERIOD
C
4560  DO 1110 I=1,NN
```

```
      CDF(1)=0.0
      DO 1112 K=2,NN1
      CDF(K)=CDF(K-1)+PT(I,K-1)
      IF(CDF(K).GE.0.50) GO TO 1113
1112  CONTINUE
1113  D50(I)=DS(K-1)+(0.50-CDF(K-1))/(CDF(K)-CDF(K-1))
     *   *(DS(K)-DS(K-1))
      IF(CDF(K).EQ.0.50) D50(I)=DS(K)
      D50MM=D50(I)*304.8
      IF(IBUG.EQ.1) WRITE(6,1111) I,D50MM,(PT(I,K),K=1,N1)
1111  FORMAT(5X,'I=',I3,2X,'D50=',F6.3,2X,'PT:  ',9F9.5)
1110  CONTINUE
C
C     TRANSLATES D50 FROM REACH TO SECTION
C
      DMS(1)=D50(1)
      DMS(N)=D50(N-1)
      DO 728 I=2,NN
      DMS(I)=(D50(I)+D50(I-1))/2.0
      IF(IDIA.EQ.1) DMS(I)=D50(I)
728   CONTINUE
C
C
C     CALCULATING MAXM. VALUE OF TIME INTERVAL WHICH WILL NOT VIOLATE
C        SEDIMENT CONTINUITY THROUGH REACHES
C
4999  DMIN=DELT(1,1)
      IF(IT.EQ.1) NVI=0
      DO 753 I1=1,NN
      DO 753 K1=1,N1
      DINT=FLOAT(IDELT)
      IF(DINT.GT.DELT(I1,K1)) NVI=NVI+1
      IF(DELT(I1,K1).GE.DMIN) GO TO 753
      DMIN=DELT(I1,K1)
753   CONTINUE
      IF(IPRINT.EQ.2) WRITE(6,43) DMIN,NVI
43    FORMAT(   /,15X,70('*'),/,15X,'*',68X,'*',/,15X,'*',68X,'*',
     * /,15X,'*',9X,'MAXM. VALUE OF TIME INTERVAL WHICH WILL NOT ',
     * 'VIOLATE',8X,'*',/,15X,'*',23X,'SEDIMENT CONTINUITY IS',
     * 23X,'*',/,15X,'*',28X,F6.2,2X,'DAYS',28X,'*',/,15X,'*',
     * 28X,13('-'),27X,'*',/,15X,'*',20X,'TOTAL NO. OF VIOLATIONS =',
     * I4,19X,'*',              /,15X,'*',68X,'*',/,15X,70('*'),///)
5000  CONTINUE
      WRITE(6,7)
C
C
1     FORMAT(10I5)
749   FORMAT(11I5)
2     FORMAT(12I5)
3     FORMAT(2F14.7)
4     FORMAT(4F10.3)
5     FORMAT(6F10.4)
6     FORMAT(8F10.4)
7     FORMAT('1')
8     FORMAT(//,5X,'SECTION',I3,' RMILE=',F7.2,
     @   ' MA=',I3,T40,'STAGE',9X,'AREA',11X,
     1      'HYD. RAD.',5X,'SURF. WIDTH',/,T05,93(1H-))
9     FORMAT(20X,'NO. OF SECTIONS=',I3,//)
```

```
10    FORMAT(///,20X,'NO. OF SUBCHANNELS =',I5,//)
11    FORMAT(10X,'WHOLE SECTION',//,6X,'STAGE',9X,'AREA',11X,'HYD. RA
     *D.',5X,'WAT.SUR.WIDTH',/)
12    FORMAT(/,5X,'DHO(L,I)',/)
13    FORMAT(/,5X,'D50(I)',/)
14    FORMAT(15A4)
15    FORMAT('1',////,10X,70('*'),/,10X,'*',68X,'*',/,10X,'*',4X,
     $ 15A4,4X,'*',/,10X,'*',68X,'*',/,10X,70('*'),////)
16    FORMAT((T37,4(F10.3,5X)))
17    FORMAT(/,15X,'D50 =',F6.4,1X,'MM.')
18    FORMAT(20X,'REACH LENGTHS(FT.) :',/)
19    FORMAT(25X,'REACH..',I3,':',2X,F10.2,/)
20    FORMAT(///)
21    FORMAT(20X,'DISCHARGE(CFS) :',/)
22    FORMAT(30X,8F10.0)
23    FORMAT(/,5X,'ITOB(L)',/)
30    FORMAT(/,5X,'DMZ(I)',/)
31    FORMAT(//,5X,'ALFA=',F6.3,2X,'BETA=',F6.3,2X,'C21=',F6.3,
     #  2X,'C22=',F6.3,2X,'FMIX=',F6.3,2X,'CARM=',F6.3,//)
33    FORMAT (15X,8F10.1)
51    FORMAT(3F10.4)
53    FORMAT(/,5X,'Q(N1)')
54    FORMAT(     //,5X,'IRES=',I1,2X,'ISED=',I1,3X,'INDEX=',I1,3X,
     @'INDEX1=',I1,3X,'INDSS=',I1,4X,'N=',I3,4X,'M1=',I2,4X,'N1=',I2
     @,2X,'NT=',I5,2X,'ILIMIT=',I2,2X,'IEQ=',I2,2X, 'IFR=',I2,//,
     @  5X,'IDIA=',I2,2X,'IOF=',I2,2X,'INPR=',I4,2X,'KDIA=',I2,
     @  2X,'IGR=',I2,2X,'IROCK=',I2,2X,'IOBS=',I2,2X,'INPUT=',I2,
     @ 2X,'NTRIB=',I2,2X,'NBANK=',I3,2X,'IBED=',I2,//,5X,'NBED=',
     @ I2,2X,'MAXBED=',I2,2X,'MAXMA=',I2,2X,'NOBS=',I2,2X,'NX=',I2,
     @ 2X,'NTP=',I4,2X,'IBUG=',I2,2X,'ICHB=',I2,2X,'ICOFF=',I2,
     @ 2X,'IPLOT=',I2,2X,'IDREJ=',I2,2X,'NTY=',I3,//,5X,'IDSWS=',I2,
     @ ' IDELT=',I3,2X,'NRES=',I3)
56    FORMAT(//////,5X,'MA(I)')
58    FORMAT(12X,1015)
68    FORMAT(25X,'SECTION...',I3,/)
74    FORMAT(/,20X,'TIME INTERVAL=',I4,2X,'DAYS',//)
88    FORMAT(///,28X,                   'SEDIMENT CONCENTRATION IS GIVEN
     *AT MOST UPSTREAM SECTION AS INPUT',/,28X,65('-'),//)
91    FORMAT(8F10.2)
92    FORMAT(8F10.7)
121   FORMAT(/,5X,'TF  (F)')
122   FORMAT(/,5X,'VISC(SQ.FT./S *E05)',/)
125   FORMAT(/,5X,'TEMPF')
27    FORMAT(//,20X,'SECTION...',I3,//,7X,'STAGE',7X,'AREA',9X,
     *'HYD.RAD.',/)
29    FORMAT(//,5X,'STR=',F10.7,4X,'RMDS=',F8.1,//)
36    FORMAT(/,5X,'SSC(I,K)')
37    FORMAT(15X,F10.4,1X,F10.4,1X,F10.4,1X,F10.4,1X,F10.4,1X,F10.4,
     *1X,F10.4,1X,F10.4,1X,F10.4)
38    FORMAT(/,5X,'BB(I)')
39    FORMAT(12X,I5)
40    FORMAT(/,5X,'DW(I)')
41    FORMAT(/,5X,'CDF(I,K):',(T17,10F10.4))
42    FORMAT(/,5X,'QST(I)')
44    FORMAT(/,T2,'REACH LENGTHS:',(T17,10F10.0))
45    FORMAT(/,5X,'D50G(I)')
46    FORMAT(/,5X,'VAV(I)')
47    FORMAT(/,5X,'IDELT ')
```

```
48     FORMAT(/,5X,'POROSITY:',(T17,10F10.4))
49     FORMAT(/////,10X,'NO.OF SECTIONS=',I3,//,10X,'NO.OF SEGMENTS=',
      *I2,//,10X,'NO. OF SED.SIZE FRACTIONS=',I2,///)
50     FORMAT(/,5X,'SF(I)')
57     FORMAT(/,5X,'STAGE(N1)')
59     FORMAT(/////////////,25X,75('*'),///,27X,'WATER SURFACE PROFILE RE
      *MAINS THE SAME AS IN THE PREVIOUS TIME PERIOD',///,25X,75('*'),//)
61     FORMAT((T53,11F6.3))
62     FORMAT(/,5X,'D(K)')
63     FORMAT(/,5X,'GAMA=',F10.3,1X,'LBS./CFT.',/)
64     FORMAT(/,5X,'VIS=',F10.7,2X, 'SQ.FT./SEC',/)
66     FORMAT(15X,F10.6,1X,F10.6,1X,F10.6,1X,F10.6,1X,F10.6,1X,F10.6,1X,
      *F10.6,1X,F10.6,1X,F10.6)
67     FORMAT(/////,10X,25('*'),4X,'WATER SURFACE PROFILE CALCULATIONS
      *AFTER',1X,I4,2X,'DAYS',4X,25('*'),///)
70     FORMAT('1',/ ,30X,'WATER SURFACE AND BED PROFILE AFTER',1X,I4,2X,
      *'DAYS',1X,'(',F6.2,1X,'YEARS )',/,30X,62('-'),/)
71     FORMAT( 1X,'SEC.',2X,'RM',3X,'B(FT.)',2X,'STAGE',2X,'Q(CFS.)'  ,
      *1X,'DEP(FT)',1X,
      *'V(FT/S)',1X,'EN.SLOPE',3X,'DZ(FT)',2X,'DH(FT)',1X,'BED EL(FT)',
      *2X,'D50(MM)' ,2X,'ACF',3X,'ADEP(FT.)',2X,'CBAR(PPM)',2X,'FRI.FR.',
      * /,1X,130(1H-))
72     FORMAT(1X,I3,1X,F5.1,2X,F5.0,2X,
      *                          F7.2,1X,F7.0,1X,F6.2,2X,F6.3,1X,F9.6,
      *1X,F7.3, 2X,F7.3,2X,F8.2,2X,F6.3,2X,F6.3,12X,F8.2,4X,F6.4)
75     FORMAT(102X,E12.4)
76     FORMAT(102X,E12.4,1X,'*')
79     FORMAT(/,1X,'PARTICLE SIZES:',(T17,10F10.4))
82     FORMAT(//// ,10X,'MODIFIED SECTION PROPERTIES AFTER', 1X,I4,1X,
      *'DAYS',/,10X,41('-'),/ )
84     FORMAT(3X,F10.3,3X,F10.3,3X,F10.3,3X,F10.3,3X,F10.3,3X,F8.3,3X,
      *F8.3,3X,F8.3,3X,F8.3)
413    FORMAT(/,5X,'SL1(I)  (BED SLOPE*10000)',/)
1490   FORMAT(/,T20,'REACH',I3,' D50=',F7.3,' CDF,PDF:',(T51,12F6.3))
C
9000   RETURN
       END
C
C        -------------------------------------
          SUBROUTINE SEDBED (NBEL,THBED,PBED)
C        -------------------------------------
C
C        THIS SUBROUTINE READS ADDITIONAL SEDIMENT CHARACTERISTICS
C         IN CASE OF VERTICAL VARIATION OF ORIGINAL BED MATERIAL
C
C       NBEL(I)= NO. OF ELEVATIONS AT WHICH SED.SIZE DISTR. CHANGES
C                  AT REACH I
C       THBED(I)= THICKNESS OF HOMOGENEOUS SED.SIZE DIST. IN REACH I
C       PBED(I,K,L)= SED.SIZE DISTR.(IN FRACTION) ATREACH I,
C                        FRACTION K IN SEDIMENT LAYER L
C
C
       DIMENSION NBEL(NN),THBED(NN),PBED(NN,N1,MAXBED)
       COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
      1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
C
       READ(5,10)  (NBEL(I),I=1,NN)
       WRITE(6,15)
```

```
      WRITE(6,20)  (NBEL(I),I=1,NN)
C
      READ(5,25)  (THBED(I),I=1,NN)
      WRITE(6,30)
      WRITE(6,35)  (THBED(I),I=1,NN)
C
      WRITE(6,40)
      DO 100 I=1,NN
      LL=NBEL(I)
      IF(LL.EQ.0) GO TO 100
      DO 100 L=1,LL
      READ(5,25)  (PBED(I,K,L),K=1,N1)
      WRITE(6,35)  (PBED(I,K,L),K=1,N1)
100   CONTINUE
C
10    FORMAT(12I5)
15    FORMAT(/,5X,'NBEL(I):',/)
20    FORMAT(10X,12I5)
25    FORMAT(6F10.3)
30    FORMAT(/,5X,'THBED(I)  :',/)
35    FORMAT(10X,8F10.3)
40    FORMAT(/,5X,'PBED(I,K,L)  :',/)
C
      RETURN
      END
C
C
C     ------------------------------------------------------------------
       SUBROUTINE START(STAGE,Q,STAGE1,DMS,B,XAREA,MA,B1,R1,REACH,
     1                  SF,AREA)
C     ------------------------------------------------------------------
C
C     THIS SUBROUTINE CALCULATES WATER SURFACE ELEVATIONS AT THE
C      DOWNSTREAM BOUNDARY ASSUMING UNIFORM FLOW
C
       DIMENSION STAGE(N),Q(N),STAGE1(N,MAXMA),DMS(N),B(N),
     @ XAREA(N),MA(N),B1(N,MAXMA),R1(N,MAXMA),REACH(NN),SF(N)
     @ ,AREA(N,MAXMA)
       COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
       COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
C
      I=1
      S1=STR
      A2=ALOG10(S1*1000.0)
      I1=MA(I)
      BTR=B1(I,I1)
      ITER=0
      D50F=DMS(I)
100   QU=Q(1)/BTR
      A1=ALOG10(QU/SQRT(1.65*32.2*D50F   **3))
      VFD=10.0**(-0.4812+0.3761*A1+0.3106*A2)
      VEL=VFD*SQRT(32.2*1.65*D50F  )
      ARE=Q(I)/VEL
      DO 150 L=1,I1
      IF(AREA(I,L).GT.ARE) GO TO 200
```

```
150   CONTINUE
200   C=(ARE-AREA(I,L-1))/(AREA(I,L)-AREA(I,L-1))
      STAGE(I)=STAGE1(I,L-1)+C*(STAGE1(I,L)-STAGE1(I,L-1))
      B(I)=B1(I,L-1)+C*(B1(I,L)-B1(I,L-1))
      BTR1=B(I)
      ERR=ABS(BTR1/BTR-1.0)
      ITER=ITER+1
      IF(ERR.LE.0.02) GO TO 500
      IF(ITER.GT.20) GO TO 500
      BTR=BTR1
      GO TO 100
500   CONTINUE
      RETURN
      END
C
C     ---------------------------------------------------------
       SUBROUTINE DACHAN (ICHBT,ICOFFT,ICHBL,ICOFFL,REACH,B1,
     @    AREA,NCHBL,NCOFFL,MA,R1)
C     ---------------------------------------------------------
C
C     THIS SUBROUTINE READS AND COMPUTES THE EFFECTS OF CHANNEL-WIDTH
C        CHANGES AND  CHANNEL CUTOFF AS FUNCTION OF TIME
C
      DIMENSION ICHBT(NT3651),ICOFFT(NT3651),ICHBL(NT3651,N),
     @ ICOFFL(NT3651,NN),B1(N,MAXMA),REACH(NN),AREA(N,MAXMA),
     @ NCHBL(NT3651),NCOFFL(NT3651),MA(N),R1(N,MAXMA)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
C
C     ICHBT(IT)=TIME INTERVALS IN WHICH CHANNEL WIDTHS ARE CHANGED
C     ICOFFT(IT)=TIME STEPS IN WHICH CUTOFFS ARE INCORPORATED
C     ICHBL(NI)=LOCATION (NODE NO.) OF CHANNEL-WIDTH CHANGES
C                      IN TIME INTERVAL IT
C     ICOFFL(NI)=LOCATION (REACH NO.) OF CUTOFFS IN TIME STEP IT
C     NCOFFT=TOTAL NO. OF TIME STEPS IN WHICH CUTOFFS ARE MADE
C     NCOFFL(I1)= TOTAL NO. OF CUTOFF-REACHES IN TIME STEP I1
C     NCHBT= TOTAL NO. OF TIME STEPS IN WHICH CHANNEL WIDTHS
C                ARE CHANGED
C     NCHBL(I1)= TOTAL NO. OF NODES OF CHANNEL-WIDTH CHANGES
C                    IN TIME STEP I1
C
C     READ PARAMETERS FOR CHANGING WIDTH
C
      IF(ICHB.EQ.0) GO TO 100
      WRITE(6,19)
      READ(5,10) NCHBT
      READ(5,10) (NCHBL(I1),I1=1,NCHBT)
      WRITE(6,12) NCHBT
      WRITE(6,14)
      WRITE(6,15) (NCHBL(I1),I1=1,NCHBT)
 10   FORMAT(12I5)
 12   FORMAT(//,10X,'NCHBT=',I3,//)
 14   FORMAT(//,5X,'NCHBL(I1)',/)
 15   FORMAT(15X,12I5)
C
```

```
      READ(5,10)  (ICHBT(I1),I1=1,NCHBT)
      WRITE(6,16)
      WRITE(6,15)  (ICHBT(I1),I1=1,NCHBT)
      WRITE(6,18)
      DO 50 I1=1,NCHBT
      L=NCHBL(I1)
      READ(5,10)  (ICHBL(I1 ,I),I=1,L)
 50   WRITE(6,15)  (ICHBL(I1,I),I=1,L)
 16   FORMAT(//,5X,'ICHBT(I1)',/)
 18   FORMAT(//,5X,'ICHBL(I1,I)',/)
 19   FORMAT(//,10X,'INPUT VALUES FOR CHANNEL-WIDTH CHANGES WITH ',
     & 'TIME :',//)
 100  CONTINUE
C
C     READ PARAMETERS FOR CHANNEL CUTOFF
C
      IF(ICOFF.EQ.0) GO TO 200
      WRITE(6,29)
      READ(5,10) NCOFFT
      READ(5,10)  (NCOFFL(I1),I1=1,NCOFFT)
      WRITE(6,22) NCOFFT
      WRITE(6,24)
      WRITE(6,15)  (NCOFFL(I1),I1=1,NCOFFT)
 22   FORMAT(//,10X,'NCOFFT=',I3,//)
 24   FORMAT(//,5X,'NCOFFL(I1)',/)
C
      READ(5,10)  (ICOFFT(I1),I1=1,NCOFFT)
      WRITE(6,26)
      WRITE(6,15)  (ICOFFT(I1),I1=1,NCOFFT)
      WRITE(6,28)
      DO 150 I1=1,NCOFFT
      L=NCOFFL(I1)
      READ(5,10)  (ICOFFL(I1,I),I=1,L)
 150  WRITE(6,15)  (ICOFFL(I1,I),I=1,L)
 26   FORMAT(//,5X,'ICOFFT(I1)',/)
 28   FORMAT(//,5X,'ICOFFL(I1,I)',/)
 29   FORMAT(//,10X,'INPUT VALUES FOR CHANNEL CUTOFF :',//)
 200  CONTINUE
C
C     ADJUSTMENT FOR CHANNEL-WIDTH CHANGES
C
       RETURN
C     **************
       ENTRY CHANGE
C     **************
      IF(ICHB.EQ.0) GO TO 500
      ITEST=0
      DO 210 I1=1,NCHBT
      IT1=ICHBT(I1)
      IF(IT1.EQ.IT) ITEST=ITEST+1
      IF(IT1.EQ.IT) GO TO 215
 210  CONTINUE
 215  IF(ITEST.EQ.0) GO TO 500
      L=NCHBL(I1)
      DO 220 I2=1,L
      I=ICHBL(I1 ,I2)
      MM=MA(I)
      READ (5,30)  (B1(I,MAI),MAI=1,MM)
```

```
      WRITE(6,32) IT1,I
      WRITE (6,35) (B1(I,MAI),MAI=1,MM)
      DO 220 MAI=1,MM
      AREA(I,MAI)=B1(I,MAI)*R1(I,MAI)
220   CONTINUE
30    FORMAT(8F10.1)
32    FORMAT(//,10X,60('*'),//,15X,'NEW CHANNEL WIDTHS (FT.),   ',
     @ 'IT=',I3,2X,'I=',I3,//,10X,60('*'),//)
35    FORMAT(10X,8F10.1)
500   CONTINUE
C
C     ADJUSTMENT FOR CHANNEL CUTOFF
C
      IF(ICOFF.EQ.0) GO TO 1000
      ITEST=0
      DO 310 I1=1,NCOFFT
      IT1=ICOFFT(I1)
      IF(IT1.EQ.IT) ITEST=ITEST+1
      IF(IT1.EQ.IT) GO TO 315
310   CONTINUE
315   IF(ITEST.EQ.0) GO TO 1000
      L=NCOFFL(I1)
      DO 320 I2=1,L
      I=ICOFFL(I1 ,I2)
      READ(5,30) REACH(I)
      WRITE(6,42) IT1,I
      WRITE(6,35) REACH(I)
320   CONTINUE
C
42    FORMAT(//,10X,65('*'),//,15X,'NEW REACH LENGTH (FT.) FOR',
     @ ' CUTOFF AT IT=',I3,2X,'REACH=',I3,//,10X,65('*'),//)
1000  CONTINUE
      RETURN
      END
C
C
C     ------------------------------------------------------------
       SUBROUTINE DADRED (IDRT,IDRL,NDRL,VDREJ,REACH,B,STAGE1,
     @  CDEP,AREA,R1,NBEL,THBED,PT,PTT,PBED,DARM,EL1,MA)
C     ------------------------------------------------------------
C
C     THIS SUBROUTINE READS AND COMPUTES THE EFFECT OF DREDGING
C
      DIMENSION IDRT(NT),IDRL(NT,N),NDRL(NT),VDREJ(N),REACH(NN),
     1 B(N),STAGE1(N,MAXMA),CDEP(N),DARM(N),AREA(N,MAXMA),
     2 R1(N,MAXMA),NBEL(NN),THBED(NN),PT(NN,N1),PTT(NN,N1),
     3 PBED(NN,N1,MAXBED),EL1(N),MA(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/DREJ/KDREJ
C
C     IDRT(IT)=TIME STEPS IN WHICH DREDGINGS ARE DONE
C     IDRL(NI)=LOCATION (REACH NO.) OF DREDGING IN TIME STEP IT
C     NDRT=TOTAL NO. OF TIME STEPS IN WHICH DREDGINGS ARE MADE
C     NDRL(IT)=TOTAL NO. OF REACHES OF DREDGING IN TIME STEP IT
```

```
C      VDREJ(I)=VOLUME OF DREDGING (CUBIC YARDS/DAY) IN REACH I
C
C      READ DREDGING PARAMETERS
C
       WRITE(6,49)
       READ(5,10) NDRT
       READ(5,10) (NDRL(I1),I1=1,NDRT)
       WRITE(6,52) NDRT
       WRITE(6,54)
       WRITE(6,15) (NDRL(I1),I1=1,NDRT)
 10    FORMAT(12I5)
 15    FORMAT(15X,12I5)
 30    FORMAT(8F10.1)
 49    FORMAT(//,10X,'INPUT VALUES FOR DREDGING :',//)
 52    FORMAT(//,10X,'NDRT=',I3,//)
 54    FORMAT(//,5X,'NDRL(I1)',/)
C
       READ(5,10) (IDRT(I1),I1=1,NDET)
       WRITE(6,56)
       WRITE(6,15) (IDRT(I1),I1=1,NDRT)
       WRITE(6,58)
       DO 350 I1=1,NDRT
       L=NDRL(I1)
       READ(5,10) (IDRL(I1,I),I=1,L)
 350   WRITE(6,15) (IDRL(I1,I),I=1,L)
 56    FORMAT(//,5X,'IDRT(I1)',/)
 58    FORMAT(//,5X,'IDRL(I1,I)',/)
 400   CONTINUE
       RETURN
C      ************
       ENTRY DREDGE
C      ************
C
C      COMPUTES THE EFFECT OF DREDGING ON GEOMETRIC PROPERTIES
C
       ITEST=0
       DO 810 I1=1,NDRT
       IT1=IDRT(I1)
       IF(IT1.EQ.IT) ITEST=ITEST+1
       IF(IT1.EQ.IT) GO TO 815
 810   CONTINUE
 815   IF(ITEST.EQ.0) GO TO 1000
       KDREJ=1
       L=NDRL(I1)
       DO 890 I2=1,L
       I=IDRL(I1,I2)
       READ(5,30) VDREJ(I)
       WRITE(6,62) IT1,I,VDREJ(I)
       DDREJ=VDREJ(I)/(REACH(I)*(B(I)+B(I+1))/2.0)*27.0*IDELT
       CDEP(I)=CDEP(I)+DDREJ
       DARM(I)=0.0
       MM=MA(I)
       DO 820 L=1,MM
 820   STAGE1(I,L)=STAGE1(I,L)-DDREJ
 62    FORMAT(//,10X,70('*'),//,15X,'VOLUME OF DREDGING AT IT=',I4,
      1 2X,'I=',I3,2X,'IS:',F12.0,2X,'CU.YDS./DAY ',//,10X,70('*'),//)
C
C      COMPUTE THE EFFECT OF DREDGING ON BED-MATERIAL SIZE DISTR.
```

```
C
      IF(IBED.EQ.1.AND.NBEL(I).NE.0) GO TO 855
      BELIN=STAGE1(I,1)+CDEP(I)
      DO 852 K=1,N1
      IF(EL1(I).GE.STAGE1(I,1)) PT(I,K)=PTT(I,K)
852   CONTINUE
855   IF(IBED.EQ.0) GO TO 890
      IF(NBEL(I).EQ.0) GO TO 890
      NB=NBEL(I)
      DO 860 L=1,NB
      T1=BELIN-L*THBED(I)
      IF(T1.GT.STAGE1(I,1)) GO TO 865
860   CONTINUE
865   CONTINUE
      DO 890 K=1,N1
      IF(EL1(I).GE.STAGE1(I,1)) PT(I,K)=PBED(I,K,L)
      PTT(I,K)=PT(I,K)
890   CONTINUE
1000  CONTINUE
      RETURN
      END
C
C     -----------------------------------------
C     SUBROUTINE WATPRO
C     -----------------------------------------
C
C     THIS SUBROUTINE COMPUTES WATER SURFACE PROFILE, AVERAGE VELOCITY
C     AND FRICTION SLOPE BY STANDARD STEP METHOD
C
C
C     DEFINITION OF VARIABLES
C
C     SF(I)=ENERGY GRADIENT AT SECTION I
C     CONVF=CONVEYANCE FACTOR FOR WHOLE SECTION
C     CONVFL,CONVFR,CONVFM=CONVEYANCE FACTORS FOR LEFT,RIGHT AND
C              MAIN SUBSECTION, RESPECTIVELY
C     VEL=VELOCITY FOR THE WHOLE SECTION
C     VELCOF=VELOCITY COEFFICIENT
C     VH=VELOCITY HEAD
C     THEAD1=TOTAL HEAD,OBTAINED BY ADDING VELOCITY HEAD TO STAGE
C     THEAD2=TOTAL HEAD,OBTAINED BY ADDING FRICTION HEAD
C     DY=CORRECTION TO BE APPLIED TO THE ASSUMED STAGE VALUE
C     ITER=NO. OF ITERATIONS REQUIRED FOR BACKWATER COMPUTATIONS
C     OLDH2=TEMPORARY LOCATION FOR STORING THEAD2 OF PREVIOUS SECTION
C     CL,CR,CM,A1,A2=INTERMEDIATE VARIABLES FOR BACKWATER CALCULATIONS
C
C     ------------------------------------------------------------
      SUBROUTINE DAWATP(REACH,STAGE,Q,STAGE1,D,XAREA,R,B,CTO,SF,FR,
     1    ACF,LOCTR,QTR,DMS)
C     ------------------------------------------------------------
C
      DIMENSION REACH(NN),STAGE(N),Q(N),STAGE1(N,MAXMA),D(N1),
     1 XAREA(N),R(N),B(N),CTO(N),SF(N),FR(N),DMS(N),ACF(N),
     2 LOCTR(NTRIB),QTR(NTRIB)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
```

```
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      VELCOF=1.0
      CON1=VELCOF/2.0/32.2
      ERR=0.05
      CON2=1./8./32.2
      CON3=32.2*1.65
      CON4=1./CON2
      RETURN
C     *************
      ENTRY WATPRO
C     *************
C
C     COMPUTATION STARTS AT THE CONTROL SECTION
C      (MOST DOWNSTREAM OR SECTION 1)
C
      I=1
C
C      TLTM ITERATION MANAGEMENT FOR SECTION '1'
C
C
C      CALL SECPRO TO OBTAIN SECTION PROPERTIES
C
 101  CALL SECPRO
      IF(IBUG.GT.0.AND.I.GT.1.AND.IPRINT.EQ.1) WRITE(6,55) I,ITER
C
C      CALL RESIS1 FOR TLTM CALCULATION
C
      CALL RESIS1
      FR(I)=FF
      XAREA(I)=R(I)*B(I)
      CONVF=SQRT(CON4*R(I)/FF)*XAREA(I)
      VEL=Q(I)/XAREA(I)
      VH=VEL*VEL*CON1
      THEAD1=STAGE(I)+VH
      IF (I.EQ.1) THEAD2=THEAD1
C
C     COMPUTATION STARTS AT THE NEXT SECTION
C
      IF(I.EQ.1) GO TO 135
      THEAD2=OLDH2 +(SF(I)+SF(I-1))*0.5*REACH(I-1)
      DEL= ABS(THEAD1-THEAD2)
 135  IF (IBUG.GT.0.AND.IPRINT.EQ.1)
     1 WRITE(6,50) I,XAREA(I),R(I),STAGE(I),Q(I),
     * SF(I),VEL,THEAD1,THEAD2,ALPHA
       IF(I.EQ.1) GO TO 140
       T1=THEAD1-THEAD2
       XSIGN=SIGN(1.,T1)
       IF(DEL.LT.ERR) GO TO 140
       IF(ITER.EQ.30) GO TO 140
       A1=2.0*VH/R(I)
       A2=3.0*SF(I)*REACH(I-1)/(2.0*R(I))
       DY=(THEAD1-THEAD2)/(1.0-A1+A2)
       IF(IBUG.GT.0.AND.IPRINT.EQ.1)
     1 WRITE (6,20) I,DY,R(I),VEL,SF(I),FF,CPM
       STAGE(I)=STAGE(I)-DY
       ITER=ITER+1
       GO TO 101
```

```
140   IF (IBUG.GT.0.AND.IPRINT.EQ.2)
     1   WRITE(6,52) I,R(I),VEL,Q(NI),SF(I),THEAD1,
     * THEAD2,FFCW,FU,CPPM,ITER
      IF (ITER.GT.30) CALL ERROR4(I,IT,ITIME,ITER,DEL)
C
C      BACKWATER ITERATION COMPLETED
C      DISTRIBUTE TOTAL SEDIMENT DISCHARGE AMONG SIZE FRACTIONS
C
      CALL TRASF
      I=I+1
C
C      INITIAL ESTIMATE OF STAGE OF NEXT U/S SECTION
C
      IF (I.LE.N) STAGE(I)=STAGE(I-1)+SF(I-1)*REACH(I-1)
      ITER=1
      OLDH2=THEAD2
      IF (I.LE.N) GO TO 101
20    FORMAT(5X,'I=',I3,2X,'DY=',F8.4,2X,'D=',F7.3,2X,'V=',F7.3,
     * 2X,'S=',F8.6,2X,'FF=',F7.4,2X,'CBAR=',F8.3)
50    FORMAT(/,5X,'I=',I3,2X,'A=',F10.2,2X,'R=',F5.2,2X,'H=',F9.4,2X,
     *'Q=',F9.2,2X,'SF=',F10.8,2X,'V=',F5.2,2X,'H1=',F9.4,2X,'H2=',
     *F9.4,2X,'ALPHA=',F6.3,/ )
52    FORMAT(5X,'I=',I4,2X,'D=',F6.3,2X,'V=',F6.3,2X,'Q=',F8.1,
     *  2X,'S=',F8.6,2X,'H1=',F8.3,2X,'H2=',F8.3,2X,'FCW=',F6.4,2X,
     *  'FU=',F6.4,2X,'CBAR=',F8.2,2X,'ITER=',I3,/)
55    FORMAT(/,15X,15('*'),2X,'I=',I3,2X,'ITERATION ....',I3,
     *  2X,15('*'),//)
C
C     RECALCULATING SEDIMENT DISCHARGE IN CASE OF TRIBUTARIES
C
      IF(NTRIB.EQ.1) GO TO 800
      DO 700 I2=2,NTRIB
      I4=LOCTR(I2)
      QMAIN=Q(I4)-QTR(I2)
      VL=QMAIN/(XAREA(I4))
      SLN=FR(I4)*VL**2.0*CON2/R(I4)
      A3=ALOG10(R(I4)/DMS(I4))
      A4=ALOG10(SLN)
      UST=SQRT(32.2*R(I4)*SLN)
      RS=UST*DMS(I4)/VIS
      CALL SHIELD(RS,SHP)
      VAR1=SQRT(CON3*DMS(I4))
      USC=SQRT(SHP)*VAR1
      TEMP=AMAX1(UST-USC,0.001)
      A12=ALOG10(VL/ VAR1)
      A17=ALOG10(TEMP/VAR1)
      QS=10.0**(-2.2786+A12*2.9719+A12*A17*1.006+A3*A17*0.2989)
      CTO(I4)=QS*DMS(I4)*VAR1/(VL*R(I4))
      IF(IT.EQ.1) ACF(I4)=0.0
      CTO(I4)=(1.0-ALFA*ACF(I4))*CTO(I4)
700   CONTINUE
800   CONTINUE
      RETURN
      END
C
C        ----------------------------------------------------
C              SUBROUTINE  RESIS1
C        ----------------------------------------------------
```

```
C
C     THIS SUBROUTINE CALCULATES SEDIMENT DISCHARGE AND FRICTION FACTOR
C     USING THE TOTAL LOAD TRANSPORT MODEL (TLTM) DEVELOPED AT IIHR
C
C     ----------------------------------------------------
      SUBROUTINE DARESI(Q,DMS,D,XAREA,R,CTO,SF,ACF,CIN)
C     ----------------------------------------------------
C
      DIMENSION Q(N),DMS(N),D(N1),XAREA(N),R(N),CTO(N),SF(N),
     1 ACF(N),CIN(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/ARM/MIND,QMAX,IARMOR
      NAMELIST/RATS/IT,I,IT2,S1,V1,D1,F11,F1,VAR1,W,A12,A3,WLOG,
     1             DMSLOG,A4,T1P,S1P,UST,A6,A10,RS,USC,TEMP,A17,QS,
     2             A1,RIGHT,V1,V2,T1,T,TT,S1OLD
C
      ERRP=0.01
      ERRA=0.05
      CON3=32.2*1.65
      CON5=32.2/1000.0
      CON4=8.0*32.2
      RETURN
C     *************
      ENTRY RESIS1
C     *************
C
      IT2=0
      S1=STR*1000.0
      IF(IT.GT.1) S1=SF(I)*1000.0
      V1=Q(I)/XAREA(I)
      D1=R(I)
      F11=36.0*VIS**2/(CON3*DMS(I)**3)
      F1=SQRT(2.0/3.0+F11)-SQRT(F11)
      VAR1=SQRT(CON3*DMS(I))
      W   =F1*SQRT(1.65*32.2*DMS(I))
      A12=ALOG10(V1/VAR1)
      A3    =ALOG10(D1/DMS(I))
      WLOG=ALOG10(W)
      DMSLOG=ALOG10(DMS(I))
C
C      BEGIN ITERATIVE SOLUTION
C
100   A4=ALOG10(S1)
      T1P=T1
      S1P=S1OLD
      UST=SQRT(D1*S1*CON5)
      A6=ALOG10(UST/W)
      A10=WLOG+DMSLOG-VISLOG
      RS=UST*DMS(I)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP)*VAR1
      TEMP=AMAX1(UST-USC,0.001)
      A17=ALOG10(TEMP/VAR1)
```

```
C
C       QS COMPUTED FROM EQ. 1, IIHR 250
C
      QS=10.0**(-2.2786+A12   *2.9719+A12   *A17   *1.0600+
     @ A3   *A17   *.2989)
 120  A1=ALOG10(QS)
C
C       U COMPUTED FROM EQ. 2, IIHR 250
C
212   RIGHT=10.0**(.9045+A1   *.1665+A1   *A6   *A10   *.0831+
     @ A6   *A10   *.2166+A3   *A4   *A6   *(-.0411))
C
C       ITERATION MANAGEMENT
C
214   V2=RIGHT*VAR1
      T1=V1-V2
      T=ABS(T1)
      TT=T/V1
      IF(T.LE.ERRA .OR.TT.LE.ERRP) GO TO 150
      IF (IT2.GT.60) GO TO 150
C
C       REGULA FALSI CORRECTION OF S1
C
      S1OLD=S1
      IF(IT2.GT.0) S1=S1-T1*(S1-S1P)/(T1-T1P)
      IF(IT2.EQ.0) S1=S1*(1.+0.3*SIGN(1.,T1))
      S1=AMAX1(S1,.001)
      IT2=IT2+1
      IF(IBUG.EQ.0) GO TO 100
      IF(IT.EQ.1) GO TO 100
      IF(IPRINT.EQ.0) GO TO 100
      CBAR=CTO(I)*2.65E6
      IF(IT2.EQ.1) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
      IF(IT2.EQ.5) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
      IF(IT2.EQ.10) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
      IF(IT2.EQ.100) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
15    FORMAT(5X,'IT2=',I4,2X,'V1=',F6.2,2X,'V2=',F6.2,2X,'S1=',2X,
     * E14.7,2X,'CBAR=',F9.2,2X,'QS=',E14.7)
      GO TO 100
C
C       ITERATION COMPLETED
C
 150  IF (IT2.LE.10) GO TO 152
      CALL ERRORS(I,IT,ITIME,IT2,TT)
      WRITE(6,RATS)
      IF(IT2.GT.60) STOP
C
C       COMPUTE TLTM FRICTION FACTOR
C
 152  SF(I)=S1/1000.0
      FF=CON4*D1*S1/(1000.0*V1**2)
      FU=FF
154   AA=0.0
      IC=0
      IF(IT.EQ.1) I8=N1-1
      IF(IT.GT.1) I8=MIND
      DO 153 IA=I8  ,N1
      IC=IC+1
```

```
153    AA=AA+D(IA)
       DA=AA/FLOAT(IC)
       IF(IPRINT.EQ.1) WRITE(6,25) I,D1,V1,S1,FF,CPM
C
C       COMPUTE COLEBROOK-WHITE FRICTION FACTOR
C
       CRI=2.*ALOG10(2.0*D1/DA)+1.14
       IF(IBUG.EQ.1) WRITE(6,23) D(IA),DA,CRI,D1,S1,DMS(I)
23     FORMAT(5X,'D=',E14.7,2X,'DA=',E14.6, 2X,'CRI=',E14.7,2X,
      @ 'D1=',E14.6,2X,'S1=',E14.6,2X,'D50=',E14.6)
       FFCW=1.0/(CRI)**2
       IF(IPRINT.EQ.1) WRITE(6,22) FF,FFCW
C
C       COMPUTE COMPOSITE FRICTION FACTOR (EQ.5 IIHR 250)
C
       FF=C21*(1.-ACF(I))*FF+C22*ACF(I)*FFCW
       R(I)=D1
       SF(I)=FF*V1**2/(CON4*D1)
       S1=SF(I)*1000.0
C
C       UPDATE SEDIMENT DISCHARGE FOR COMPOSITE FRICTION FACTOR
C
156    A4=ALOG10(S1)
       UST=SQRT(32.2*D1  *S1  /1000.0)
       A6=ALOG10(UST/W)
       RS=UST*DMS(I)/VIS
       CALL SHIELD(RS,SHP)
       USC=SQRT(SHP)*VAR1
       TEMP=AMAX1(0.001,UST-USC)
       A17=ALOG10(TEMP/VAR1)
       QS=10.0**(-2.2786+A12   *2.9719+A12   *A17   *1.0600+
      @  A3   *A17   *.2989)
165    CTO(I)=QS*SQRT(CON3*DMS(I)**3)/(V1*D1)
       IF(IT.EQ.1) ACF(I)=0
       IF (IT.EQ.1) CIN(I)=CTO(I)
       CTO(I)=(1.-ALFA*ACF(I))*CTO(I)
155    CPPM=CTO(I)*2.65E6
       IF(IPRINT.EQ.1) WRITE(6,10) I,D1,V1,V2,SF(I),FF,CPPM,IT2,ACF(I)
10     FORMAT(//, 6X,'I=',I3,2X,'D=',F5.2,2X,'V1=',F5.2,2X,'V2=',F5.2,
      *2X,'SF=',F9.7,2X,'F=',F6.4,2X,'CBAR=',F9.2,2X,'IT=',I4,
      *2X,'ACF=',F9.7,/)
22     FORMAT(/,5X,'FF=',  F7.5,2X,'FFCW=',F7.5)
25     FORMAT(5X,'I=',I3,2X,'D1=',F7.3,2X,'V1=',F7.3,2X,'S1=',F8.6,
      *  2X,'FF=',F7.4,2X,'CBAR=',F8.3)
500    RETURN
       END
C
C          ----------------------------------------
C                  SUBROUTINE   TRASF
C          ----------------------------------------
C
C          THIS SUBROUTINE CALCULATES SEDIMENT DISCHARGE BY SIZE
C          FRACTION BY IIHR METHOD (EQ.20 IIHR 250)
C
C      ---------------------------------------------------
       SUBROUTINE DATRAS(D50,D,PT,SSC,R,CTO,SF,PQS,PDN)
C      ---------------------------------------------------
C
```

```
      DIMENSION D50(NN),D(N1),PT(NN,N1),SSC(N,N1),R(N),CTO(N),
     1 SF(N),PQS(N,N1),PDN(N,N1)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/BANK/IBSED,QMIN,IUPS
C
      RETURN
C     ************
      ENTRY TRASF
C     ************
C
      IF(I.EQ.N) GO TO 100
      SS=0
      X=0.0316*SQRT(R(I)/D50(I))
      UST=SQRT(32.2*R(I)*SF(I))
      DO 160  K=1,N1
      RS=UST*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D(K))
      PROB=1.00
      IF(UST.LE.USC) PROB=0.00
160   SS=SS+PT(I,K)*((D50(I)/D(K))**X)*PROB
      N2=N1-1
      DO 200 K=1,N1
      RS=UST*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D(K))
      PROB=1.00
      IF(UST.LE.USC) PROB=0.00
      PSI=0.0
      IF(SS.NE.0.0) PSI=PT(I,K)*((D50(I)/D(K))**X)/SS*PROB
      PQS(I,K)=PSI
      SSC(I,K)=CTO(I)*PSI
      IF(IBUG.EQ.1) WRITE(6,37) I,K,SSC(I,K)
37    FORMAT(/,5X,'SSC(',I2,',',I1,',',I2,')=',E14.6)
200   CONTINUE
      S2=0
      DO 250 K=1,N1
250   S2=S2+PQS(I,K)*(D(K)/D50(I))**X
      DO 260 K=1,N1
260   PDN(I,K)=PT(I,K)
100   IF(INDSS.EQ.1.AND.IUPS.EQ.0) CTO(N)=CPPMUP/(2.65E6)
      RETURN
      END
C
C     ------------------------------------------
C     SUBROUTINE SECPRO
C     ------------------------------------------
C
C
C     THIS SUBROUTINE COMPUTES CROSS SECTIONAL AREA,HYD.RADIUS AND WATER
C     SURFACE WIDTH AT SECTION I FOR A PARTICULAR ELEVATION
C
C     --------------------------------------------------------
```

```
      SUBROUTINE DASECP(STAGE,MA,STAGE1,B1,R1,AREA,XAREA,R,B)
C     ----------------------------------------------------------
C
      DIMENSION STAGE(N),MA(N),STAGE1(N,MAXMA),B1(N,MAXMA),
     1 R1(N,MAXMA),AREA(N,MAXMA),XAREA(N),R(N),B(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
C
      RETURN
C     *************
      ENTRY SECPRO
C     *************
C
C     DEFINITION OF VARIABLES
C
C     XAREA(I)=CROSS SECTION AREA OF THE WHOLE SECTION AT SECTION I
C     R(I)=HYD. RADIUS OF THE WHOLE SECTION AT SECTION I
C     B(I)=WATER SURFACE WIDTH OF WHOLE SECTION AT SECTION I
C
C     XAREAL(I),XAREAR(I),XAREAM(I)=CROSS SECTION AREAS AT SECTION I OF
C             LEFT,RIGHT AND MAIN SUBSECTION,RESPECTIVELY
C     RL(I),RR(I),RM(I)=HYD. RADIUS AT SECTION I FOR LEFT,RIGHT AND MAIN
C                         SUBSECTION,RESPECTIVELY
C     BBL(I),BBR(I),BBM(I)= WATER SURFACE WIDTH AT SECTION I FOR LEFT,
C                             RIGHT AND MAIN SUBSECTION, RESPECTIVELY
C
      A=STAGE(I)
      MM=MA(I)
      IF(A.LE.STAGE1(I,1)) GO TO 200
      DO 150 L=1,MM
      D=STAGE1(I,L)
      IF(IBUG.EQ.1) WRITE(6,10) A,D,MM,L
 10   FORMAT(10X,'A=',F10.2,2X,'D=',F10.2,2X,'MM=',I2,2X,'L=',I2)
      IF(D.GT.A) GO TO 170
 150  CONTINUE
      L=MM
 170  C=(A-STAGE1(I,L-1))/(STAGE1(I,L)-STAGE1(I,L-1))
      XAREA (I)=AREA (I,L-1)+(AREA (I,L)-AREA (I,L-1))*C
      R(I)=R1(I,L-1)+(R1(I,L)-R1(I,L-1))*C
      B(I)=B1(I,L-1)+(B1(I,L)-B1(I,L-1))*C
      IF(IBUG.EQ.1) WRITE(6,30) I,A,STAGE1(I,1),XAREA(I),R(I),B(I)
      IF(A.GT.STAGE1(I,MM)) WRITE(6,20) I,IT,A,D
      GO TO 300
 200  WRITE(6,25) I,IT,A,D
 20   FORMAT( 5X, 8('*'),2X,'W.S. ELEV. EXCEEDS TOP ELEV. OF ',
     @   'X-SECTION AT I=',I3,2X,'IT=',I4,2X,'WSE=',F8.2,2X,
     @   'D=',F8.2,2X,8('*'))
 25   FORMAT( 5X, 8('*'),2X,'W.S. ELEV. BELOW BOTTOM OF ',
     @   'X-SECTION AT I=',I3,2X,'IT=',I4,2X,'WSE=',F8.2,2X,
     @   'D=',F8.2,2X,8('*'))
 30   FORMAT(5X,'I=',I4,2X,'WSE=',F9.3,2X,'BEL=',F8.3,2X,'A=',
     @ F8.1,2X,'R=',F8.3,2X,'B=',F8.3)
      STOP
 300  RETURN
```

```
      END
C
C
C     -----------------------------------------------------
C     SUBROUTINE SLOAD
C     -----------------------------------------------------
C
C     THIS SUBROUTINE APPLIES SEDIMENT CONTINUITY EQUATION AND
C     CALCULATES DEPTHS OF DEGR./AGGR.
C
C     DEFINITION OF VARIABLES
C
C
C     SSC(I,K)= SUSPENDED SEDIMENT CONCENTRATION AT SECTION I ,
C               SEGMENT J, SED. FRACTION K
C     BB(I)=WIDTH OF SECTION I,SEGMENT J
C     W(K)= FALL VELOCITY OF SEDIMENT PARTICLE OF FRACTION K
C     ERVEL(I,K)=EROSION VELOCITY AT SECTION I, SEG.J,SED.FR. K
C     CB(I,K)= SEDIMENT CONCENTRATION IN BED LAYER AT SECTION I,
C                SEGMENT J, SED. FRACTION K
C     EZ(I,K )= TRANSEVERSE DIFFUSION COEFFICIENT FOR SEDIMENT IN
C                 SECTION I, SEGMENT J, FOR SED. FR. K
C     N= NO. OF SECTIONS(IN LONGITUDINAL DIRECTION)
C     NN=NO. OF REACHES=N-1
C     M1= NO. OF SEGMENTS
C     N1=NO. OF SEDIMENT SIZE FRACTIONS
C     REACH(I)= LENGTH OF REACH BETWEEN SECTIONS I AND I+1
C     MANG(I)= MANNING'S COEFFICIENT AT SECTION I,SEGMENT J
C     VAV(I)= AVERAGE VELOCITY AT SECTION I,SEGMENT J
C     DELT=TIME INTERVAL(DAYS)
C     P(K)= POROSITY FOR SEDIMENT FRACTION K
C     SI=PARAMETER FOR TRANSEVERSE SEDIMENT TRANSFER
C     CC,CD,TEST=INTERMEDIATE VARIABLES FOR SUSP. SEDIMENT CALCULATIONS
C     KA(I,K)=INDEX VARIABLE TO INDICATE WHETHER LIMITING SCOURING
C        DEPTH IS REACHED AT SECTION I,SEGMENT J, SED.FR. K(=0,LIMITING
C               DEPTH NOT REACHED; =1, LIMITING DEPTH REACHED )
C
C      NOTE: RA AND BB ARE PSEUDONYMS FOR R AND B
C
C     ---------------------------------------------------------
      SUBROUTINE DASLOA(REACH,P,D,PT,PTT,SSC,CTO,SF,ACF,RA,BB,
     1 DW,DELDS,TDELD,CDEP,KA,VOLOUT,DELT,PQS,PDN,CDEP1,
     2 TB,ACF1,LOCTR,QSTR,PTRIB,TDELTR,LOCBER,BEROS,PBANK,Q,PTA,
     3    D50,THBED,NBEL,STAGE1,PBED,DARM,EL1,VAV,QSDP)
C     ----------------------------------------------------------
C
      DIMENSION REACH(NN),P(N1),D(N1),PT(NN,N1),PTT(NN,N1),
     1 SSC(N,N1),CTO(N),SF(N),ACF(N),RA(N),BB(N),
     2 DW(N),DELDS(N,N1),TDELD(N,N1),CDEP(N),
     3 KA(N,N1),VOLOUT(N),DELT(N,N1),PQS(N,N1),
     4 PDN(N,N1),CDEP1(N),TB(N,N1),ACF1(N),QSTR(NTRIB),
     5 PTRIB(NTRIB,N1),TDELTR(NTRIB,N1),LOCTR(NTRIB),
     6 LOCBER(NBANK),BEROS(NBANK),PBANK(NBANK,N1),Q(N),
     7 PTA(NN,N1),      D50(NN),THBED(NN),NBEL(NN),STAGE1(N,MAXMA),
     8 PBED(NN,N1,MAXBED),DARM(N),EL1(N),VAV(N),QSDP(NN)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
```

```
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/SLOHYS/I,K
      COMMON/BANK/IBSED,QMIN,IUPS
      COMMON/ARM/MIND,QMAX,IARMOR
C
      CON3=1.65*32.2
      THETA=1.0
      THETA1=1.0-THETA
      RETURN
C     ***********
      ENTRY SLOAD
C     ***********
C
C      LOOP ON REACHES, U/S TO D/S
C
603   DO 1000 I1=2,N
      I=N+1-I1
      I5=I
      I6=I+1
      QSTU=Q(I+1)/((BB(I)+BB(I+1))*0.5)
      DELCTO=CTO(I+1)-CTO(I)
      IF(I.EQ.N-1)  DELCTO=0.0-CTO(I)
      QSD=THETA*DELCTO+THETA1*QSDP(I)
      QSDP(I)=DELCTO
C
C      LOOP ON SEDIMENT SIZE FRACTIONS FOR EACH REACH
C
604   DO 800 K=1,N1
      VAR1=SQRT(CON3*D(K))
599   KA(I,K)=0
      WFAC=1.00
C
C      COMPUTATION OF TRANSPORT CAPACITY BY SIZE FRACTION
C      IN EACH REACH
C
      DO 200 I2=I5,I6
      UST=SQRT(32.2*RA(I2)*SF(I2))
      RS=UST*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP)*VAR1
      F11=36.0*VIS**2/(CON3*D(K)**3)
      F1=SQRT(2.0/3.0+F11)-SQRT(F11)
      WI   =F1*VAR1
      A3=ALOG10(RA(I2)/D(K))
      A4=ALOG10(SF(I2)*1000.0)
      A12=ALOG10(VAV(I2)/VAR1)
      TEMP=AMAX1(UST-USC,0.001)
      A17=ALOG10(TEMP/VAR1)
      QSK=10.0**(-2.2786+A12*2.9719+A12*A17*1.0600+A3*A17*0.2989)
      IF(INDSS.EQ.1.AND.I2.EQ.N) QSK=CPPMUP/2.65E6
     @ *PTRIB(1,K)
      IF(I2.EQ.I5) QSIK=QSK
200   CONTINUE
C      QSK= U/S LOAD FRACTION K
C      QSIK= D/S LOAD FRACTION K
C      QSD= GLOBAL DEFICIT, REACH I ( +VE FOR AGGR. )
```

```
C        WFAC= 1 FOR GLOBAL DEGR. ,K DEGR
C        WFAC= 0 FOR OPPOSITE GLOBAL -K TREND
C        0<WFAC<1 FOR GLOBAL AGGR. , K DEGR
C
      IF(QSD.GT.0.0) WFAC=1.00-QSIK/QSK
      IF(QSD.GT.0.0.AND.WFAC.LT.0.0) WFAC=0.0
      IF(QSD.LT.0.0.AND.QSIK.LT.QSK) WFAC=0.0
      IF(ABS(QSD).LE.0.377E-6) WFAC=0
C
C        COMPUTATION OF DEGRADATION OR DEPOSITION IN
C        REACH I FOR FRACTION K , ADJUSTED FOR INCONSISTENCY
C        WITH GLOBAL TREND USING WFAC
C
      IF(QSD.LE.0.0)DELDS(I,K)=QSD*PQS(I,K)*QSTU/((1.-P(K))*REACH(I))
     1*IDELT*86400.0*WFAC
      IF(QSD.GT.0.0 ) DELDS(I,K)=QSD*PDN(I,K)*QSTU/((1.0-P(K))
     *  *REACH(I))*IDELT*86400.0*WFAC
520   TDELD(I,K)=-DELDS(I,K)
C
C     ADUSTMENT FOR TRIBUTARY SEDIMENT INFLOWS
C
      DO 700 I2=1,NTRIB
      I4=LOCTR(I2)-1
      IF(I4.NE.I) GO TO 700
      IF(INDSS.EQ.0.AND.I2.EQ.1) QSTR(I2)=CTO(I)*Q(N)
      TDELTR(I2,K)=QSTR(I2)*IDELT*86400.0/((BB(I4)+BB(I4+1))
     1 /2.0*REACH(I4))*PTRIB(I2,K)/(1.0-P(K))
      TDELD(I4,K)=TDELD(I4,K)-TDELTR(I2,K)
700   CONTINUE
C
C     ADJUSTMENT FOR BANK EROSION
C
      IF(NBANK.EQ.0) GO TO 800
      WF=0.0
      IF(Q(I).GT.QMIN) WF=1.00
      DO 725 I3=1,NBANK
      I4=LOCBER(I3)
      IF(I4.NE.I) GO TO 725
      EROS=BEROS(I3)*IDELT*REACH(I4)/5280.0/(1.0-P(K))/((BB(I4)
     1 +BB(I4+1))*0.5*REACH(I4))*WF
      IF(IBSED.EQ.0) PBANK(I3,K)=PTT(I4,K)
      TDELD(I4,K)=TDELD(I4,K)-EROS*PBANK(I3,K)
725   CONTINUE
C
800   CONTINUE
C
C     CHECK CONTINUITY IN CASE OF TRIBUTARIES OR BANK EROSION
C
      IF(NTRIB.EQ.1.AND.NBANK.EQ.0) GO TO 790
      IF(QSD.GE.0.0) GO TO 790
      DO 740 I2=1,NTRIB
      I3=LOCTR(I2)-1
      IF(I3.EQ.I) GO TO 746
740   CONTINUE
742   DO 745 I2=1,NBANK
      I3=LOCBER(I2)
      IF(I3.EQ.I) GO TO 746
745   CONTINUE
```

```
      GO TO 790
746   QSDI=0.
      DO 747 L=1,N1
747   QSDI=QSDI+TDELD(I,L)
      QSDO=QSDI
      DO 765 L=1,N1
      IF(TDELD(I,L).GE.0.0) GO TO 765
      IF(PQS(I,L).NE.0.0) GO TO 765
      I8=MIND
      IF(IT.EQ.1) I8=N1-1
      IF(L.GE.I8  ) GO TO 765
      QSDI=QSDI-ABS(TDELD(I,L))
      TDELD(I,L)=0.0
765   CONTINUE
      DO 775 L=1,N1
      IF(TDELD(I,L).NE.0.0) TDELD(I,L)=TDELD(I,L)+
     @   (QSDI-QSDO)*PQS(I,L)
775   CONTINUE
790   CONTINUE
C
C      CALL HYSORT TO UPDATE MIXED LAYER SIZE
C      DISTRIBUTION FOR REACH I
C
      CALL HYSORT
C
C      COMPUTE TOTAL DEGRADATION IN REACH I
C
825   TOTAL=0
      II=0
      III=0
      DO 550 K=1,N1
550   TOTAL=TOTAL+TDELD(I,K)
      IF(ABS(TOTAL).LE.0.001 ) TOTAL=0.0
      AB=TOTAL/DW(I)
      IF(AB.GT..08) II=II+1
      IF(AB.GT..01) III=III+1
      IF(IT.EQ.1) GO TO 570
      CDEP(I)=CDEP(I)+TOTAL
      DARM(I)=DARM(I)+TOTAL
      GO TO 571
570   CDEP(I)=TOTAL
      DARM(I)=TOTAL
C
C      CALL ARMOR TO UPDATE ARMORING FACTOR FOR REACH I
C
571   CALL ARMOR
900   CONTINUE
1000  CONTINUE
C
C     CHECKING CRITERIA FOR RECOMPUTING BACKWATER PROFILE
C
      IF(IT.EQ.1) GO TO 1001
      IF(IFLAG.EQ.0) GO TO 1004
1001  DO 1002 I=1,NN
1002  CDEP1(I)=CDEP(I)
1004  IF(II.EQ.1.OR.III.GT.ILIMIT) GO TO 1015
      IFLAG=0
      LL=0
```

```
      DO 1010 I=1,NN
      A4=CDEP(I)-CDEP1(I)
      A4=ABS(A4)/DW(I)
      IF(A4.GT..01 ) LL=LL+1
      IF(A4.GT..08 ) IFLAG=1
1010  CONTINUE
      IF(LL.GT.ILIMIT) IFLAG=1
      IF(IFLAG.EQ.0) GO TO 1005
1015  IFLAG=1
C
C     PRINT OUT OF RESULTS
C
1005  IF(IBUG.EQ.0.OR.IPRINT.EQ.0) GO TO 1006
      WRITE(6,99) IFLAG
      WRITE(6,98) ITIME
1006  DO 500 I1=2,N
      I=N+1-I1
      IF(IBUG.EQ.1) WRITE(6,50) I,J
      DO 500 K=1,N1
      PCENT= PT(I,K) *100.0
      IF(DELT(I,K).EQ.0) DELT(I,K)=900.0
500   IF(ISED.EQ.1.AND.IBUG.EQ.1) WRITE(6,65) K,TDELD(I,K),PCENT
501   CONTINUE
      IF(IBUG.EQ.0.OR.IPRINT.EQ.0) GO TO 9999
      N4=N-1
      DO 502 I4=1,N4
      WRITE(6,86) I4,(TDELD(I4,K),K=1,N1)
      WRITE(6,87) I4,(PT(I4,K),K=1,N1)
      WRITE(6,88) I4,(PQS(I4,K),K=1,N1)
      WRITE(6,89) I4,(DELT(I4,K),K=1,N1)
502   WRITE(6,95)
86    FORMAT(10X,'I=',I3,3X,'DEGR/AGGR.',2X,9F9.5 )
87    FORMAT(10X,'I=',I3,3X,'  S.D.(BM)',2X,9F9.5 )
88    FORMAT(10X,'I=',I3,3X,'  S.D.(QS)',2X,9F9.5 )
89    FORMAT(10X,'I=',I3,3X,'DELT(DAYS)',2X,9F9.2 )
50    FORMAT(///,10X,'REACH....',I3,5X,'SEGMENT..',I2,/,10X,28('-'),//,
     *10X,'SED.FRACTION',15X,'CHANGE IN BED ELEVATION(FT.)'//32X,'BED LO
     *AD',11X,'SUSP. LOAD',12X,'TOTAL',10X,'PERCENTAGE',/)
65    FORMAT(15X,I2,50X,E14.6,8X,F8.4)
98    FORMAT(/////,10X,30('*'),4X,'SEDIMENT CALCULATIONS AFTER',1X,
     *I4,2X,'DAYS',4X,30('*'),///)
96    FORMAT(//,10X,'A4=',F8.4)
99    FORMAT(////,10X,'IFLAG=',I2)
95    FORMAT(/   )
9999  RETURN
      END
C
C
C     ---------------------------------------------------------------
        SUBROUTINE DAARMO (ACF,ACF1,PT,D,P,CDEP,PTT,VOLOUT,BB,SF,
     @    D50,THBED,PTA,NBEL,STAGE1,PBED,Q,RA,DARM,EL1)
C     ---------------------------------------------------------------
C
C     THIS SUBROUTINE CALCULATES ARMORING OF BED SURFACE
C
C     IARMOR=INDEX VARIABLE TO SPECIFY OR DETERMINE ARMORING
C               SEDIMENT SIZE; IARMOR=0, SPECIFY; =1 FOR
C               DETERMINING INTERNALLY
```

```
C     MIND= FRACTION NUMBER FOR THE MINIMUM SEDIMENT SIZE WHICH
C           (AND COARSER FRACTIONS) FORM ARMOR COAT
C     QMAX=MAXIMUM WATER DISCHARGE(CFS.) FOR DETERMINING NON-MOVING
C              ARMORING FRACTIONS
C     IQMAX=INDEX VARIABLE FOR SPECIFYING WATER DISCHARGE FOR ARMORING
C              CALCULATIONS; IQMAX=0 FOR USING SPECIFIED CONSTANT
C              QMAX IN EACH TIME STEP AND REACH; =1 FOR USING WATER
C              DISCHARGE FROM SPECIFIED HYDROGRAPH
C
C
C      NOTE: BB,RA ARE PSEUDONYMS FOR B,R
C
      DIMENSION P(N1),D(N1),PT(NN,N1),PTT(NN,N1),CDEP(N),
     1 VOLOUT(N),ACF(N),ACF1(N),BB(N),SF(N),D50(NN),THBED(NN),
     2 PTA(NN,N1),NBEL(NN),STAGE1(N,MAXMA),PBED(NN,N1,MAXBED)
      DIMENSION Q(N),RA(N),DARM(N),EL1(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/SLOHYS/I,L7
      COMMON/ARM/MIND,QMAX,IARMOR,IQMAX
      COMMON/DREJ/KDREJ
C
C      READ ARMORING INPUT PARAMETERS DURING PREPARATORY PHASE
C      OF RUN.
C
      READ(5,1000)  IARMOR,MIND,QMAX,IQMAX
 1000 FORMAT(2I5,F10.0,I5)
      DARMOR=0.
      IF(IARMOR.EQ.0) DARMOR=D(MIND)*304.8
      WRITE(6,43) IARMOR,MIND,QMAX,IQMAX,DARMOR
   43 FORMAT(/,T10,'BED ARMORING PARAMETERS: IARMOR=',I2,' MIND=',
     1        I3,' QMAX=',F10.2,' IQMAX=',I2,' DARMOR=',F10.3,/,
     2        T10,24(1H-))
      CON3=32.2*1.65
      RETURN
C***************************************
      ENTRY ARMOR
C***************************************
C
100   IF(IARMOR.EQ.0) GO TO 200
C
C     COMPUTE THE ARMORING SEDIMENT SIZE
C
105   S1=(SF(I)+SF(I+1))/2.0
      IF(IQMAX.EQ.1) GO TO 170
      A1=QMAX/(BB(I)+BB(I+1))*0.50/SQRT(CON3*D50(I)**3)
      A1=ALOG10(A1)
      A2=ALOG10(S1    *1000.0)
      VFD=10.0**(-0.4812+0.37610*A1+0.31060*A2)
      VEL=VFD*SQRT(CON3*D50(I))
      DEP=QMAX/(BB(I)+BB(I+1))*0.50/VEL
      USTAR=SQRT(32.2*DEP*S1)
170   IF(IQMAX.EQ.1) USTAR=SQRT(32.2*(RA(I)+RA(I+1))/2.0*S1)
      DO 180 K=1,N1
      RS=USTAR*D(K)/VIS
```

```
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*CON3*D(K))
      IF(USC.GT.USTAR) GO TO 185
180   CONTINUE
185   MIND=K
      DARMOR=D(MIND)*304.8
      IF(IBUG.NE.0) WRITE(6,16) MIND,DARMOR ,IT,I
16    FORMAT(//,10X,'MIND=',I2,3X,'DMIN=',F8.3,'MM.',3X,'IT=',I4,4X,
     @ 'I=',I3,/)
200   CONTINUE
C
C     ADJUSTING SIZE DISTRIBUTION OF ARMORING FRACTIONS IN CASE OF
C        VERTICAL VARIATION OF BED MATERIAL
C
      BEDEL=STAGE1(I,1)
      IF(IBED.EQ.0) GO TO 410
      IF(NBEL(I).EQ.0) GO TO 410
      IF(DARM(I).LE.0) GO TO 410
      CDEPP=CDEP(I)
      IF(I.GT.1) CDEPP=(CDEP(I)+CDEP(I-1))/2.0
      T1=STAGE1(I,1)-THBED(I)+CDEPP
      IF(T1.LE.BEDEL ) GO TO 410
208   NB=NBEL(I)
      DO 210 L=1,NB
      T1=STAGE1(I,1)-L*THBED(I)+CDEPP
      IF(T1.GT.BEDEL ) GO TO 215
210   CONTINUE
      L=NB
215   DO 260 K=MIND,N1
      ELL=STAGE1(I,1)-THBED(I)*L+CDEPP
      PIN=PTT(I,K)*THBED(I)+PBED(I,K,L)*(ELL-BEDEL )
      L2=L-1
      IF(IBUG.EQ.1) WRITE(6,94) K,L2
94    FORMAT(5X,'K=',I3,2X,'L2=',I6)
      IF(L2.EQ.0) GO TO 255
      DO 245 LA=1,L2
245   PIN=PIN+PBED(I,K,LA)*THBED(I)
255   PTA(I,K)=PIN/DARM(I)
260   CONTINUE
400   CONTINUE
      IF(IBUG.EQ.1) WRITE(6,81) PTA(I,K),I,K
81    FORMAT(5X,'PTA=',F10.6,2X,'I=',I3,2X,'K=',I2)
C
C      COMPUTING FRACTION OF ARMORED AREA
C
      IF(IBED.EQ.1) GO TO 450
410   DO 420 K=MIND,N1
420   PTA(I,K)=PTT(I,K)
450   CONTINUE
      AC=0
      DO 455 K=1,N1
455   AC=AC+PT(I,K)/D(K)
      FARM=0
      DO 500 IA=MIND,N1
500   FARM=FARM+(1.0-P(IA))*PTA(I,IA)/D(IA)
      ACF(I)=FARM*CARM*DARM(I)
      IF(VOLOUT(I).GE.0.0) GO TO 550
      BC=0
```

```
      DO 560 IA=MIND,N1
  560 BC=BC+PT(I,IA)/D(IA)
      ACF(I)=0.0
      IF(AC.NE.0.0) ACF(I)=BC/AC
      IF(IBUG.EQ.1) WRITE(6,83) I,BC,ACF(I),PT(I,MIND),PT(I,N1)
  550 ACF(I)=AMIN1(AMAX1(0.0,ACF(I)),1.00)
      IF(IT.EQ.1) GO TO 600
      IF(DARM(I).GE.0.0.AND.ACF(I).EQ.0.0) GO TO 600
      IF(ACF(I).LT.ACF1(I).AND.KDREJ.EQ.0) ACF(I)=ACF1(I)
  600 ACF1(I)=ACF(I)
      IF(IBUG.EQ.1) WRITE(6,82) ACF(I),I
   82 FORMAT(5X,'ACF=',F10.4,2X,'I=',I3)
   83 FORMAT(5X,'I=',I3,2X,'BC=',E14.6,2X,'ACF=',E14.6,2X,'PT(MIND)=',
     @ E14.6,2X,'PT(N1)=',E14.6)
      RETURN
      END
C
C
C     ------------------------------------------
C     SUBROUTINE   HYSORT
C     ------------------------------------------
C
C     THIS SUBROUTINE RECOMPUTES BED-MATERIAL SIZE DISTRIBUTION DUE TO
C     DEGRADATION/AGGRADATION IN EACH TIME PERIOD
C
C     -------------------------------------------------------------
      SUBROUTINE DAHYSO(VOLIN,STAGE1,D50,P,PT,PTT,SSC,CTO,SF,ACF,
     1 RA,BZ,TDELD,VOLOUT,LLIM,DELT,TI,TH,TH1,PTP,EL1,EL2,
     2 PTU,BML,TB,NBEL,THBED,PBED,CDEP,D)
C     -------------------------------------------------------------
C
C
C      NOTE: RA IS A PSEUDONYM FOR R
      DIMENSION VOLIN(N,N1),STAGE1(N,MAXMA),D50(NN),P(N1),PT(NN,
     1 N1),PTT(NN,N1),SSC(N,N1),CTO(N),SF(N),ACF(N),
     2 RA(N),BZ(N,N1),TDELD(N,N1),VOLOUT(N),LLIM(N),DELT(N,
     3 N1),TI(N,N1),TH(N),TH1(N),PTP(N,N1),EL1(N),
     4 EL2(N),PTU(N,N1),BML(N),TB(N,N1),NBEL(NN),THBED(NN),
     5 PBED(NN,N1,MAXBED),CDEP(N),D(N1)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/SLOHYS/I,K
C
      RETURN
C     ************
      ENTRY HYSORT
C     ************
C
C     WARNING:ARMORING FACTOR APPROACHING UNITY
C
      IF (ACF(I).GT.0.98) WRITE (6,2000) ACF(I),I,ITIME,IT
 2000 FORMAT (T5,'WARNING:ARMORING FACTOR =',F5.3,' IN REACH',
     1 I3,' AT TIME',I6,' IT=',I5)
      ACF(I)=AMIN1(0.98,ACF(I))
```

```
      NA=N-1
      IADJ=0
      VOLOUT(I)=0
      TH(I)=0
      TOTAL=0
      LLIM(I)=0
C
      DM=(RA(I)+RA(I+1))*0.5
      SM=(SF(I)+SF(I+1))*0.5
      THA=DM*SM/(1.65*D50(I))
      THA=THA*0.333333
C
C      MIXED LAYER THICKNESS COMPUTED BY EQ.6, IIHR 250
C
      TM=DM*(0.079865+2.23897*THA-18.1264*THA**2+70.90*THA**3
     #  -88.3293*THA**2*THA**2)*0.50*FMIX
      DMM=DM*0.1
      IF(TM.LT.DMM) TM=DMM
      FR1=TM/DM
      IF(IBUG.EQ.1) WRITE(6,12) I,TM,DM,FR1
12    FORMAT(5X,'I=',I4,2X,'TM=',E14.6,2X,'DM=',E14.6,2X,'H/D=',F6.3)
C
C     ADJUSTMENT OF SIZE DIST. IF MIXED- LAYER THICKNESS IS
C       MORE THAN THE TOP-LAYER SEDIMENT BED THICKNESS
C
      IF(IBED.EQ.0.OR.IT.GT.1) GO TO 315
      IF(NBEL(I).EQ.0) GO TO 315
      IF(TM.LE.THBED(I)) GO TO 315
      LL=NBEL(I)
      DO 300 L=1,LL
      T1=THBED(I)*L
      IF(TM.GT.T1) GO TO 305
300   CONTINUE
      L=LL
305   L2=L-1
      DO 310 K=1,N1
      PT(I,K)=PT(I,K)*THBED(I)/TM+(TM-THBED(I)*L)/TM*PBED(I,K,L)
      IF(L2.EQ.0) GO TO 310
      DO 306 L1=1,L2
306   PT(I,K)=PT(I,K)+THBED(I)/TM*PBED(I,K,L1)
310   CONTINUE
315   CONTINUE
C
C
      DO 75 K=1,N1
      DELT(I,K)=0
      PTP(I,K)=PT(I,K)
      IF(IT.EQ.1) PTU(I,K)=PT(I,K)
75    TOTAL=TOTAL+TDELD(I,K)
      DO 100 K=1,N1
      TI(I,K)=TM*(1.0-P(K))*PT(I,K)
      TB(I,K)=TI(I,K)*(1.-BETA*ACF(I))
70    CONTINUE
      IF(IBUG.EQ.1) WRITE(6,56) I,K,TB(I,K),TDELD(I,K)
56    FORMAT(/,10X,'TB(',I2,',',I1,',',I2,')=',E14.6,2X,'TDELD=',E14.
      TB(I,K)=AMAX1(0.,TB(I,K))
      TH(I)=TH(I)+TB(I,K)
      IF(TDELD(I,K).LT.0.0) GO TO 76
```

```
      IF(IADJ.EQ.0) GO TO 72
      IF(IT.EQ.1.AND.TDELD(I,K).GT.TB(I,K)) SSC(I,K)=
     * TB(I,K)/TDELD(I,K)*SSC(I,K)
 72   CONTINUE
      IF(IT.EQ.1.AND.TDELD(I,K).GT.TB(I,K)) LLIM(I)=1
      IF(IT.EQ.1.AND.TDELD(I,K).NE.0) DELT(I,K)=IDELT*
     *  TB(I,K)/TDELD(I,K)
      IF(TDELD(I,K).EQ.0) DELT(I,K)=900.0
      DELT(I,K)=AMIN1(DELT(I,K),9000.)
      IF(IT.EQ.1.AND.TDELD(I,K).GT.TB(I,K)) TDELD(I,K)=TB(I,K)
      IF(IT.EQ.1) GO TO 90
      ABC=TH1(I)*PT(I,K)
      IF(IADJ.EQ.0) GO TO 74
      IF(TDELD(I,K).GT.ABC) SSC(I,K)=ABC/TDELD(I,K)*SSC(I,K)
 74   CONTINUE
      IF(TDELD(I,K).GT.ABC) LLIM(I)=1
      IF(TDELD(I,K).NE.0) DELT(I,K)=IDELT*ABC/TDELD(I,K)
      DELT(I,K)=AMIN1(DELT(I,K),9000.)
      TDELD(I,K)=AMIN1(TDELD(I,K),ABC)
      IF(TDELD(I,K).GE.0.0) GO TO 90
 76   CONTINUE
      DELT(I,K)=AMIN1(DELT(I,K),9000.)
      IF(IT.EQ.1) GO TO 90
      IF(I.LT.NA) TBB=TH1(I+1)*PTP(I+1,K)
      IF(I.EQ.NA) TBB=TH1(I)*PTP(I,K)
 90   VOLOUT(I) =VOLOUT(I)+TDELD(I,K)
 100  CONTINUE
      IF(IADJ.EQ.0) GO TO 125
      CTO(I)=0.
      DO 120 K=1,N1
 120  CTO(I)=CTO(I)+SSC(I,K)
      IF(IBUG.EQ.1) WRITE(6,16) VOLOUT(I),I,J
 16   FORMAT(5X,'*** VOLOUT =',E14.7,2X,'I=',I2,2X,'J=',I2)
 125  CONTINUE
      IF(VOLOUT(I).LT.0) GO TO 800
      CCC=0
      IF(IT.EQ.1) TH1(I)=TH(I)
      DIN=TH(I)+VOLOUT(I)-TH1(I)
      EL1I=STAGE1(I,1)-TH1(I)
      EL2I=EL1I-DIN
      BEL=BML(I)
      IF(IT.EQ.1) BEL=EL2I
      DO 200 K=1,N1
C
      LINDEX=0
      LDEP=0
      IF(IBED.EQ.1) CALL VSORT(BEL,EL1I,EL2I,DIN,PTT,PT,PTU,VOLIN,
     # NBEL,THBED,PBED,LINDEX,STAGE1,CDEP,LDEP)
C
      IF(LINDEX.EQ.1) GO TO 135
      IF(IT.EQ.1) GO TO 130
      IF(EL2I.GT.EL1I) GO TO 130
      IF(BEL    .GE.EL1I) VOLIN(I,K)=DIN*PTT(I,K)
      IF(EL1I.GE.BEL    .AND.BEL    .GT.EL2I) VOLIN(I,K)=(EL1I-BEL    )
     #  *PTU(I,K)+(BEL    -EL2I)*PTT(I,K)
      IF(EL2I.GT.BEL    ) VOLIN(I,K)=DIN*PTU(I,K)
 130  IF(IT.EQ.1) VOLIN(I,K)=DIN*PTT(I,K)
      IF(EL2I.GT.EL1I) VOLIN(I,K)=DIN*PT(I,K)
```

```
135    CONTINUE
       VOLIN(I,K)=AMAX1(VOLIN(I,K),0.0)
       BZ(I,K)= TH1(I)*PT(I,K)-TDELD(I,K)+VOLIN(I,K)
       BZ(I,K)=AMAX1(BZ(I,K),0.0)
200    CCC=CCC+BZ(I,K)
       EL1(I)=EL1I
       EL2(I)=EL2I
       EMIN=EL1I
       IF(EL2I.LT.EL1I) EMIN=EL2I
       BEL=AMIN1(BEL,EMIN)
       TH1(I)=0
       DO 220 K=1,N1
149    TH1(I)=TH1(I)+TB(I,K)
       PT(I,K)=BZ(I,K)/CCC
       IF(I.NE.NA) GO TO 220
       IF(IT.EQ.1) GO TO 220
       IF(BEL.LT.BML(I)) PTU(I,K)=PT(I,K)
       IF(IBUG.EQ.1) WRITE(6,151) I,K,PT(I,K)
151    FORMAT(/,10X,'PT(',I2,',',I1,',',I2,')=',F10.4)
220    CONTINUE
       BML(I)=BEL
       GO TO 900
800    CC1=0
       IF(IT.EQ.1) TH1(I)=TH(I)
       DIN=TH1(I)-VOLOUT(I)-TH  (I)
       EL1I=STAGE1(I,1)-TH1(I)
       EL2I=EL1I+DIN
       BEL=BML(I)
       IF(IT.EQ.1) BEL=EL1I
       DO 850 K=1,N1
C
       LINDEX=0
       LDEP=1
       IF(IBED.EQ.1) CALL VSORT(BEL,EL1I,EL2I,DIN,PTT,PT,PTU,VOLIN,
     # NBEL,THBED,PBED,LINDEX,STAGE1,CDEP,LDEP)
C
       IF(LINDEX.EQ.1) VOLIN(I,K)= -VOLIN(I,K)
       IF(LINDEX.EQ.1) GO TO 832
       IF(IT.EQ.1) GO TO 830
       IF(EL2I.GT.EL1I) GO TO 830
       IF(BEL   .GE.EL1I) VOLIN(I,K)=DIN*PTT(I,K)
       IF(EL1I.GE.BEL.AND.BEL.GT.EL2I) VOLIN(I,K)=-((EL1I-BEL)
     #  *PTU(I,K)+(BEL   -EL2I)*PTT(I,K))
       IF(EL2I.GT.BEL   ) VOLIN(I,K)=DIN*PTU(I,K)
830    IF(IT.EQ.1) VOLIN(I,K)=DIN*PTT(I,K)
       IF(EL2I.GT.EL1I) VOLIN(I,K)=DIN*PT(I,K)
832    CONTINUE
       VOLIN(I,K)=AMAX1(VOLIN(I,K),0.0)
       BZ(I,K)=TH1(I)*PT(I,K)-TDELD(I,K)-VOLIN(I,K)
       BZ(I,K)=AMAX1(BZ(I,K),0.0)
850    CC1=CC1+BZ(I,K)
       EL1(I)=EL1I
       EL2(I)=EL2I
       EMIN=EL1I
       IF(EL2I.LT.EL1I) EMIN=EL2I
       IF(EMIN.LT.BEL) BEL=EMIN
       TH1(I)=0.
       DO 860 K=1,N1
```

```
858   TH1(I)=TH1(I)+TB(I,K)
      PT(I,K)=BZ(I,K)/CC1
      IF(I.NE.NA) GO TO 860
      IF(IT.EQ.1) GO TO 860
      IF(BEL.LT.BML(I)) PTU(I,K)=PT(I,K)
860   CONTINUE
      BML(I)=BEL
900   RETURN
      END
C
C     -----------------------------------------------------------------
       SUBROUTINE VSORT (BEL,EL1I,EL2I,DIN,PTT,PT,PTU,VOLIN,
     @      NBEL,THBED,PBED,LINDEX,STAGE1,CDEP,LDEP)
C     -----------------------------------------------------------------
C
C     THIS SUBROUTINE ADJUSTS MIXED-LAYER COMPOSITION IN CASE OF
C       VERTICAL VARIATION IN SEDIMENT-BED SIZE DISTRIBUTION
C
      DIMENSION PTT(NN,N1),PT(NN,N1),PTU(N,N1),VOLIN(N,N1),
     1 NBEL(NN),THBED(NN),PBED(NN,N1,MAXBED),STAGE1(N,MAXMA),
     2 CDEP(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IOF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/SLOHYS/I,K
C
      IF(NBEL(I).EQ.0) GO TO 1000
      IF(LDEP.EQ.1) DIN= -DIN
      LINDEX=1
      NB=NBEL(I)
      L1=0
      L2=0
      LB=0
      IF(I.EQ.1) CDEPP=CDEP(I)
      IF(I.GT.1) CDEPP=(CDEP(I)+CDEP(I-1))/2.0
      DO 200 L=1,NB
      T1=STAGE1(I,1)-L*THBED(I)+CDEPP
      IF(NB.GT.1) GO TO 50
      IF(T1.GT.EL1I) L1=L
      IF(T1.GT.EL2I) L2=L
      IF(T1.GT.BEL) LB=L
      IF(K.EQ.1.AND.IBUG.EQ.1) WRITE(6,49) I,EL1I,EL2I,BEL,T1
49    FORMAT(5X,'I='I3,2X,'EL1I=',E14.7,2X,'EL2I=',E14.7,2X,
     @ 'BEL=',E14.7,2X,'T1=',E14.7)
50    IF(NB.EQ.1) GO TO 200
      T2=STAGE1(I,1)-(L+1)*THBED(I)+CDEPP
      IF(EL1I.LT.T1.AND.EL1I.GT.T2) L1=L
      IF(EL1I.LT.T1.AND.L.EQ.NB) L1=L
      IF(EL2I.LT.T1.AND.EL2I.GT.T2) L2=L
      IF(EL2I.LT.T1.AND.L.EQ.NB) L2=L
      IF(BEL.LT.T1.AND.BEL.GT.T2) LB=L
      IF(BEL.LT.T1.AND.L.EQ.NB) LB=L
200   CONTINUE
      IF(L1.GT.0.AND.L2.GE.L1) PTU(I,K)=PBED(I,K,L1)
C
      LL=L2-1
```

```
      IF(EL2I.GT.BEL) GO TO 990
      IF(EL2I.GT.EL1I) GO TO 990
      IF(BEL.LT.EL1I) GO TO 250
C     THE CASE FOR BEL GT.EL1I
      IF(L1.EQ.0.AND.L2.EQ.0) VOLIN(I,K)=DIN*PTT(I,K)
      IF(L1.EQ.0.AND.L2.EQ.0) GO TO 250
      IF(L1.GT.0) GO TO 220
      EL1=STAGE1(I,1)-THBED(I)+CDEPP
      EL2=STAGE1(I,1)-L2*THBED(1)+CDEPP
      VIN=(EL1I-EL1)*PTT(I,K)+(EL2-EL2I)*PBED(I,K,L2)
      IF(LL.EQ.0) GO TO 215
      DO 210 LA=1,LL
210   VIN=VIN+THBED(I)*PBED(1,K,LA)
215   VOLIN(I,K)=VIN
220   IF(L1.EQ.0.AND.L2.GT.0) GO TO 250
C
      IF(L1.EQ.L2) VIN=DIN*PBED(I,K,L1)
      IF(L1.EQ.L2) GO TO 235
      EL1=STAGE1(I,1)-THBED(I)*L1+CDEPP
      EL2=STAGE1(I,1)-THBED(I)*L2+CDEPP
      IF(L2.GT.L1) VIN=(EL1I-EL2)*PBED(I,K,L1)+(EL2-EL2I)*
     @  PBED(I,K,L2)
      LM=L1+1
      IF(LL.LT.LM) GO TO 235
      DO 230 LA=LM,LL
230   VIN=VIN+THBED(I)*PBED(I,K,LA)
235   VOLIN(I,K)=VIN
      GO TO 1000
C
250   CONTINUE
C     THE CASE FOR BEL LT. EL1I
      IF(BEL.GT.EL1I) GO TO 1000
      IF(EL2I.GT.BEL) GO TO 990
      IF(L1.EQ.0.AND.L2.EQ.0) VOLIN(I,K)=(EL1I-BEL)*PTU(I,K)+
     @  (BEL-EL2I)*PTT(I,K)
      IF(L1.EQ.0.AND.L2.EQ.0) GO TO 1000
      VIN=(EL1I-BEL)*PTU(I,K)
      EL2=STAGE1(I,1)-L2*THBED(I)+CDEPP
      EL3=STAGE1(I,1)-(LB+1)*THBED(I)+CDEPP
      IF(LB.EQ.L2) VOLIN(I,K)=VIN+(BEL-EL2I)*PBED(I,K,L2)
      IF(LB.EQ.L2) GO TO 1000
C
      LL4=L2-LB
      IF(LL4.EQ.1.AND.LB.EQ.0) VOLIN(I,K)=VIN+(BEL-EL3)*
     1 PTT(I,K)      + (EL3-EL2I)*PBED(I,K,L2)
      IF(IBUG.EQ.1) WRITE(6,252) I,L1,L2,LB,PTU(I,K),PTT(I,K),
     1 PBED(I,K,L2),K
252   FORMAT(5X,'I=',I3,2X,'L1=',I2,2X,'L2=',I2,2X,'LB=',I2,2X,
     1 'PTU=',E14.6,2X,'PTT=',E14.6,2X,'PBED=',E14.6,2X,'K=',I2)
      IF(LL4.EQ.1.AND.LB.EQ.0) GO TO 1000
      IF(LB.GT.0) VIN=VIN+(BEL-EL3)*PBED(I,K,LB)+(EL2-EL2I)*
     @ PBED(I,K,L2)
      LN=LB+1
      IF(LL.LT.LN) GO TO 400
      DO 260 LA=LN,LL
260   VIN=VIN+THBED(I)*PBED(I,K,LA)
400   VOLIN(I,K)=VIN
      GO TO 1000
```

```
C
990   IF(EL2I.GT.BEL) VOLIN(I,K)=DIN*PTU(I,K)
      IF(EL2I.GT.EL1I) VOLIN(I,K)=DIN*PT(I,K)
1000  RETURN
      END
C
C     --------------------------------------------
      SUBROUTINE SHIELD(RS,SHP)
C     --------------------------------------------
C
C     THIS SUBROUTINE APPROXIMATES SHIELD'S CURVE
C
      IF(RS.GE..3.AND.RS.LE.2.0) SHP=.118*(RS**(-.973))
      IF(RS.GT.2.0.AND.RS.LE.4.0) SHP=.090*(RS**(-.585))
      IF(RS.GT.4.0.AND.RS.LE.10.0) SHP=.0434*(RS**(-.119))
      IF(RS.GT.10..AND.RS.LE.30.0) SHP=.0275*(RS**(.0792))
      IF(RS.GT.30..AND.RS.LE.500.) SHP=.0194*(RS**(.181))
      IF(RS.GT.500.0) SHP=.060
      RETURN
      END
C
C     -------------------------------------------------------
       SUBROUTINE TRIB (QTR,QSTR,TDELTR,LOCTR,PTRIB,AC,BC,Q,
     1     LOCBER,BEROS,PBANK,CTO,INPUT)
C     -------------------------------------------------------
C
C     THIS SUBROUTINE COMPUTES THE COTRIBUTION OF TRIBUTARIES
C        AND BANK EROSION
C
      DIMENSION QTR(NTRIB),QSTR(NTRIB),TDELTR(NTRIB,N1),
     1 LOCTR(NTRIB),PTRIB(NTRIB,N1),AC(NTRIB),BC(NTRIB),Q(N),
     2 LOCBER(NBANK),BEROS(NBANK),PBANK(NBANK,N1),CTO(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/BANK/IBSED,QMIN,IUPS
C
C     IBSED= INDEX VARIABLE FOR INDICATING SIZE DISTR. OF BANK EROSION;
C              IBSED=0 FOR ASSUMING SAME DISTR. AS BED MATERIAL; =1
C              FOR SPECIFYING THEIR VALUES AS INPUT
C     QMIN= MINIMUM WATER DISCHARGE(CFS.) ABOVE WHICH BANK EROSION
C              OCCURS
C     IUPS=INDEX VARIABLE TO SPECIFY UPSTREAM SEDIMENT INFLOW;
C          IUPS=0 FOR CONSTANT SED.CONCN.; =1 FOR FUNCTION
C          OF WATER DISCHARGE
C     NOTE : UPSTREAM SEDIMENT INFLOW IS TREATED IN THE SAME WAY
C     ----             AS FOR TRIBUTARIES
C
       READ(5,10) IUPS
       IF(INDSS.EQ.1.AND.IUPS.EQ.0) READ(5,35) CPPMUP
       WRITE(6,12) IUPS
       IF(INDSS.EQ.1.AND.IUPS.EQ.0) WRITE(6,17) CPPMUP
       READ(5,10) (LOCTR(I2),I2=1,NTRIB)
       WRITE(6,15)
       WRITE(6,20) (LOCTR(I2),I2=1,NTRIB)
10     FORMAT(12I5)
```

```
12        FORMAT(//,10X,'IUPS=',I2,//)
15        FORMAT(//,10X,'TRIBUTARY LOCATIONS (NODE NUMBERS) :',//)
17        FORMAT(/, 5X,'MEAN SEDIMENT CONCN. AT U/S BOUNDARY=',F7.1,
     1  2X,'P.P.M.',/)
20        FORMAT(15X,10I8)
C
22        FORMAT(//,10X,'TRIBUTARY WATER DISCHARGES(CFS.) :',//)
25        FORMAT(6F10.2)
30        FORMAT(15X,10F9.0)
C
C         READ TRIB.SED.DISCH. COEFFICIENTS AC,BC IN QS=AC*Q**BC
C              QS IN TONS/DAY, Q IN CFS.
C
          DO 102 I2=1,NTRIB
          IF(I2.GT.1) GO TO 101
          IF(INDSS.EQ.0) GO TO 102
          IF(IUPS.EQ.0) GO TO 102
101       READ(5,35) (AC(I2),BC(I2))
102       CONTINUE
          WRITE(6,36)
          DO 104 I2=1,NTRIB
          IF(I2.GT.1) GO TO 103
          IF(INDSS.EQ.0) GO TO 104
          IF(IUPS.EQ.0) GO TO 104
103       WRITE(6,40) (AC(I2),BC(I2))
104       CONTINUE
35        FORMAT(2F14.8)
36        FORMAT(//,10X,'SEDIMENT DISCHARGE COEFFICIENTS (FOR TRIBUTARIE',
     @  'S) :',//)
40        FORMAT(15X,2F14.8)
C
C
C         READ SIZE DISTR. OF TRIB. SED. INFLOWS
C
410       WRITE(6,28)
          DO 500 I2=1,NTRIB
          READ(5,25) (PTRIB(I2,K),K=1,N1)
500       WRITE(6,32) (PTRIB(I2,K),K=1,N1)
28        FORMAT(//,10X,'SIZE DISTRIBUTION OF TRIB. SED. INFLOWS :',//)
32        FORMAT(15X,10F8.3)
C
C         READ PARAMETERS FOR BANK EROSION
C
          IF(NBANK.EQ.0) GO TO 900
          READ(5,61) IBSED,QMIN
          WRITE(6,65) IBSED,QMIN
          READ(5,10) (LOCBER(I3),I3=1,NBANK)
          WRITE(6,70)
          WRITE(6,20) (LOCBER(I3),I3=1,NBANK)
          IF(IBSED.EQ.0) GO TO 700
          WRITE(6,68)
          DO 600 I2=1,NBANK
          READ(5,25) (PBANK(I2,K),K=1,N1)
600       WRITE(6,32) (PBANK(I2,K),K=1,N1)
700       CONTINUE
61        FORMAT(I5,F10.1)
65        FORMAT(//,10X,'IBSED=',I2,4X,'QMIN=',F10.1,' CFS.',//)
68        FORMAT(//,10X,'SIZE DISTR. OF BANK EROSION :',//)
```

```
70     FORMAT(//,10X,'LOCATION OF BANK EROSION (REACH NUMBER) :',//)
C
C      READ BANK EROSION RATE,BEROS (IN CFT./MILE/DAY)
C
       READ(5,25) (BEROS(I3),I3=1,NBANK)
       WRITE(6,72)
       WRITE(6,74) (BEROS(I3),I3=1,NBANK)
72     FORMAT(//,10X,'BANK EROSION COEFFICIENT (CFT/MILE/DAY) :',//)
74     FORMAT(15X,8F10.1)
900    CONTINUE
       RETURN
C    **********************************
       ENTRY TRIBQS
C    **********************************
C      TRIBQS CALLED AT BEGINNING OF EACH TIME STEP TO LOAD
C      QSTR, TRIBUTARY SEDIMENT INFLOWS
C
C      COMPUTING SED.DISCH. OF TRIBUTARIES
C
       DO 400 I2=1,NTRIB
       IF(I2.GT.1) GO TO 240
       I=LOCTR(I2)
       IF(INDSS.EQ.1.AND.IUPS.EQ.0) CTO(I)=CPPMUP/(2.65E6)
240    CONTINUE
       IF(I2.GT.1) GO TO 250
       IF(INDSS.EQ.0) GO TO 300
       IF(INDSS.EQ.1.AND.IUPS.EQ.0) QSTR(I2)=CPPMUP/2.65E6
     @ *QTR(I2)
       IF(INDSS.EQ.1.AND.IUPS.EQ.0) GO TO 300
250    QSTR(I2)=AC(I2)*QTR(I2)**(BC(I2))*2000.0/(62.5*86400.0)
       IF(I2.GT.1) GO TO 300
       I=LOCTR(I2)
       IF(INDSS.EQ.1.AND.IUPS.EQ.1) CTO(I)=QSTR(I2)/QTR(I2)
300    CONTINUE
400    CONTINUE
       IF (IBUG.NE.0) WRITE (6,2000) (QSTR(I2),I2=1,NTRIB)
2000   FORMAT (9X,'TRIBUTARY SEDIMENT LOADS:',(T35,12F8.2))
       RETURN
       END
C
C     ------------------------------------------------------------
      SUBROUTINE ERROR1(IEND,MEMO,N,M1,N1,NT,MAXMA,NOBS,NX,IGR)
C     ------------------------------------------------------------
C
      IERR=1
      WRITE(6,2000) IERR
2000  FORMAT(/,1X,110(1H*),' ERROR',I2)
      WRITE(6,2001) IEND,MEMO,N,M1,N1,NT,MAXMA,NOBS,NX,IGR
2001  FORMAT(T20,'REQUIRED MEMORY=',I7,' (WORDS) EXCEEDS DIMENSION ',
     1 'OF ARRAY T(',I7,')',/,T20,'N,M1,N1,NT,MAXMA,NOBS,NX,',
     2 'IGR=:',8I5)
      STOP
C
      ENTRY ERROR2(I,MM,MAXMA)
      IERR=2
      WRITE(6,2000) IERR
      WRITE(6,2002) I,MM,MAXMA
2002  FORMAT(T20,'SECTION',I3,':NO. OF DEFINITION LEVELS',I3,
```

```
     1 ' EXCEEDS MAXIMUM ALLOTTED ,MAXMA=',I4)
      STOP
C     *************
      ENTRY ERROR3(IT,ITIME,TEMPF,TFLAST)
C     *************
      IERR=3
      WRITE (6,2000) IERR
      WRITE (6,2003) TEMPF,TFLAST,IT,ITIME
2003  FORMAT (T20,'WATER TEMPERATURE=',F10.3,' EXCEEDS MAXIMUM
     1        ALLOWED=',F10.3,' IT=',I5,' ITIME=',I5)
      RETURN
C     *************
      ENTRY ERROR4(I,IT,ITIME,ITER,DEL)
C     *************
      IERR=4
      WRITE (6,2000) IERR
      WRITE (6,2004) ITER,I,IT,ITIME,DEL
2004  FORMAT (T20,'BACKWATER ITERATIONS XECEED',I4,'SECTION',I4,
     1        ' IT=',I4,' ITIME=',I4,' DELTA =',F10.3)
      RETURN
C     *************
      ENTRY ERROR5(I,IT,ITIME,IT2,TT)
C     *************
      IERR=5
      WRITE (6,2000) IERR
      WRITE (6,2005) IT2,I,IT,ITIME,TT
2005  FORMAT (T20,'TLTM ITERATIONS EXCEED',I4,' SECTION',I4,'IT=',
     1        I4,' ITIME=',I4,' TT=',F10.3)
      RETURN
      END
```

APPENDIX D

RUN S1 RESULTS

Results Headings Legend:

SEC. = computational section number

RM = river mile (1960)

B(FT) = water surface width, ft

STAGE = water surface elevation, ft msl

Q(CFS.) = water discharge, cfs

DEP(FT) = average flow depth, ft

V(FT/S) = average water velocity, ft/sec

EN.SLOPE = energy slope, ft/ft

DZ(FT) = cumulative change in bed elevation, ft (positive for degradation)

DH(FT) = not used

BED EL(FT) = thalweg elevation, ft msl

D50(MM) = median bed-material size, mm

ACF = armoring factor (fraction of bed area armored)

ADEP(FT.) = bed elevation change in most recent time step, ft (positive for degradation)

CBAR(PPM) = mean sediment concentration, ppm by weight

FRI. FR. = friction factor

```
  ****************************************************************
  *                                                              *
  *     ISWRRI RUN 1 PROGNOSIS RUN WITH PRESENT CONDITIONS       *
  *                                                              *
  ****************************************************************

          MEMORY USED =   26585 WORDS   MEMORY AVAILABLE=   85000

IRES=1  ISED=1   INDEX=1   INDEX1=0   INDSS=1    N= 30    M1= 1    N1= 8  NT= 240  ILIMIT= 5  IEQ= 1  IPR= 0
IDIA= 0  IUP= 0  INPR= 120  KDIA= 0  IGB= 0  IROCK= 0  IOBS= 0  INPUT= 1  NTRIB= 8  NBANK=  6  IBED= 0
NBED= 0  MAXBED= 0  MAXMA=16  NOBS= 0  NX= 0  NTP=   0  IBUG= 0  ICHB= 0  ICOFF= 0  IPLOT= 0  IDREJ= 0  NTY= 24
IDSWS= 1 IDELT= 15  NRES=  0

ALPA= 1.000  BETA= 1.000  C21= 1.000  C22= 1.000  FMIX= 1.000  CARM= 0.500


STR= 0.0001890    RADS=   523.0


     IUPS= 0

MEAN SEDIMENT CONCN. AT U/S BOUNDARY=     0.0  P.P.M.

     TRIBUTARY LOCATIONS (NODE NUMBERS) :

            30         29         27         22         16         15         12         6

     SEDIMENT DISCHARGE COEFFICIENTS (FOR TRIBUTARIES) :

                0.00265200      1.57899952
                0.00265200      1.57899952
                0.00136000      1.66999912
                0.00026490      2.12199974
                0.00019630      2.65529995
                0.00002654      2.66329956
                0.00004542      2.14219952
```

```
SIZE DISTRIBUTION OF TRIB. SED. INFLOWS :

          0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
          0.390    0.433    0.127    0.050    0.0      0.0      0.0      0.0
          0.390    0.433    0.127    0.050    0.0      0.0      0.0      0.0
          0.390    0.433    0.127    0.050    0.0      0.0      0.0      0.0
          0.650    0.284    0.066    0.0      0.0      0.0      0.0      0.0
          0.650    0.284    0.066    0.0      0.0      0.0      0.0      0.0
          1.000    0.0      0.0      0.0      0.0      0.0      0.0      0.0
          0.402    0.460    0.123    0.012    0.003    0.0      0.0      0.0

IBSED= 0     QMIN=    30000.0 CFS.


LOCATION OF BANK EROSION (REACH NUMBER) :

          29       28       27       26       25       24

BANK EROSION COEFFICIENT (CFT/MILE/DAY) :

          657.0    657.0    1170.0    1170.0    1732.0    1732.0


SECTION  1 RMILE= 523.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  859.850           0.0            0.0          600.000
                                  889.850       18000.000         30.000        600.000

          REACH  1 D50=  0.251 CDF,PDF:   0.0   0.040 0.710 0.970 0.990 0.996 0.998 0.999 1.000
                                            0.040 0.670 0.260 0.020 0.006 0.002 0.001 0.001

SECTION  2 RMILE= 533.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  869.850           0.0            0.0          600.000
                                  899.850       18000.000         30.000        600.000

          REACH  2 D50=  0.251 CDF,PDF:   0.0   0.040 0.710 0.970 0.990 0.996 0.998 0.999 1.000
                                            0.040 0.670 0.260 0.020 0.006 0.002 0.001 0.001

SECTION  3 RMILE= 543.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  879.850           0.0            0.0          600.000
                                  909.850       18000.000         30.000        600.000

          REACH  3 D50=  0.251 CDF,PDF:   0.0   0.040 0.710 0.970 0.990 0.996 0.998 0.999 1.000
                                            0.040 0.670 0.260 0.020 0.006 0.002 0.001 0.001




SECTION  4 RMILE= 553.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  889.850           0.0            0.0          600.000
                                  919.850       18000.000         30.000        600.000

          REACH  4 D50=  0.251 CDF,PDF:   0.0   0.040 0.710 0.970 0.990 0.996 0.998 0.999 1.000
                                            0.040 0.670 0.260 0.020 0.006 0.002 0.001 0.001

SECTION  5 RMILE= 561.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  900.820           0.0            0.0          675.000
                                  930.820       20250.000         30.000        675.000

          REACH  5 D50=  0.228 CDF,PDF:   0.0   0.100 0.850 0.973 0.991 0.996 0.998 0.999 1.000
                                            0.100 0.750 0.123 0.018 0.005 0.002 0.001 0.001

SECTION  6 RMILE= 571.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  910.250           0.0            0.0          575.000
                                  940.250       17250.000         30.000        575.000

          REACH  6 D50=  0.535 CDF,PDF:   0.0   0.016 0.200 0.570 0.802 0.944 0.986 0.996 1.000
                                            0.016 0.184 0.370 0.232 0.142 0.042 0.010 0.004

SECTION  7 RMILE= 581.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  919.930           0.0            0.0          575.000
                                  949.930       17250.000         30.000        575.000

          REACH  7 D50=  0.470 CDF,PDF:   0.0   0.018 0.200 0.708 0.920 0.982 0.995 0.998 1.000
                                            0.018 0.182 0.508 0.212 0.062 0.013 0.003 0.002

SECTION  8 RMILE= 591.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  930.120           0.0            0.0          550.000
                                  960.120       16500.000         30.000        550.000

          REACH  8 D50=  0.235 CDF,PDF:   0.0   0.086 0.800 0.976 0.991 0.996 0.998 0.999 1.000
                                            0.086 0.714 0.177 0.015 0.005 0.002 0.000 0.001

SECTION  9 RMILE= 600.00 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  938.390           0.0            0.0          575.000
                                  968.390       17250.000         30.000        575.000

          REACH  9 D50=  0.256 CDF,PDF:   0.0   0.030 0.680 0.970 0.989 0.995 0.997 0.998 1.000
                                            0.030 0.650 0.290 0.019 0.006 0.002 0.001 0.002

SECTION 10 RMILE= 610.50 MA=  2   STAGE          AREA           HYD. RAD.     SURF. WIDTH
--------------------------------------------------------------------------------------------
                                  946.800           0.0            0.0          600.000
                                  976.800       18000.000         30.000        600.000

          REACH 10 D50=  0.237 CDF,PDF:   0.0   0.070 0.790 0.970 0.990 0.995 0.997 0.999 1.000
                                            0.070 0.720 0.180 0.020 0.006 0.002 0.001 0.001
```

```
SECTION 11 RMILE= 620.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                  950.110            0.0             0.0          600.000
                                  980.110        18000.000          30.000        600.000

               REACH 11 D50=  0.241 CDF,PDF:   0.0    0.070 0.760 0.968 0.990 0.995 0.996 0.998 1.000
                                                 0.070 0.690 0.208 0.022 0.006 0.002 0.001 0.002

SECTION 12 RMILE= 630.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                  965.130            0.0             0.0          600.000
                                  995.130        18000.000          30.000        600.000

               REACH 12 D50=  0.357 CDF,PDF:   0.0    0.032 0.380 0.966 0.988 0.995 0.997 0.998 1.000
                                                 0.032 0.348 0.586 0.022 0.007 0.002 0.001 0.002

SECTION 13 RMILE= 640.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                  973.780            0.0             0.0          600.000
                                 1003.780        18000.000          30.000        600.000

               REACH 13 D50=  0.354 CDF,PDF:   0.0    0.022 0.390 0.960 0.987 0.995 0.997 0.998 1.000
                                                 0.022 0.368 0.570 0.027 0.008 0.002 0.001 0.002

SECTION 14 RMILE= 648.20 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                  981.060            0.0             0.0          600.000
                                 1011.060        18000.000          30.000        600.000

               REACH 14 D50=  0.404 CDF,PDF:   0.0    0.018 0.300 0.850 0.968 0.990 0.996 0.998 1.000
                                                 0.018 0.282 0.550 0.118 0.022 0.006 0.002 0.002

SECTION 15 RMILE= 658.50 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                  988.990            0.0             0.0          650.000
                                 1018.990        19500.000          30.000        650.000

               REACH 15 D50=  0.332 CDF,PDF:   0.0    0.040 0.440 0.940 0.984 0.994 0.997 0.998 1.000
                                                 0.040 0.400 0.500 0.044 0.010 0.003 0.001 0.002

SECTION 16 RMILE= 669.50 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1000.210            0.0             0.0          600.000
                                 1030.210        18000.000          30.000        600.000

               REACH 16 D50=  0.355 CDF,PDF:   0.0    0.040 0.400 0.905 0.978 0.992 0.997 0.998 1.000
                                                 0.040 0.360 0.505 0.073 0.014 0.004 0.002 0.002

SECTION 17 RMILE= 680.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1010.690            0.0             0.0          600.000
                                 1040.690        18000.000          30.000        600.000



               REACH 17 D50=  0.421 CDF,PDF:   0.0    0.020 0.230 0.870 0.963 0.983 0.992 0.996 1.000
                                                 0.020 0.210 0.640 0.093 0.020 0.009 0.004 0.004

SECTION 18 RMILE= 690.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1019.180            0.0             0.0          600.000
                                 1049.180        18000.000          30.000        600.000

               REACH 18 D50=  0.391 CDF,PDF:   0.0    0.030 0.300 0.925 0.970 0.985 0.992 0.997 1.000
                                                 0.030 0.270 0.625 0.045 0.015 0.007 0.005 0.003

SECTION 19 RMILE= 700.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1028.930            0.0             0.0          600.000
                                 1058.930        18000.000          30.000        600.000

               REACH 19 D50=  0.428 CDF,PDF:   0.0    0.029 0.240 0.820 0.950 0.979 0.990 0.996 1.000
                                                 0.029 0.211 0.580 0.130 0.029 0.011 0.006 0.004

SECTION 20 RMILE= 710.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1039.470            0.0             0.0          600.000
                                 1069.470        18000.000          30.000        600.000

               REACH 20 D50=  0.353 CDF,PDF:   0.0    0.024 0.400 0.925 0.970 0.987 0.992 0.997 1.000
                                                 0.024 0.376 0.525 0.045 0.017 0.005 0.005 0.003

SECTION 21 RMILE= 720.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1050.460            0.0             0.0          600.000
                                 1080.460        18000.000          30.000        600.000

               REACH 21 D50=  0.403 CDF,PDF:   0.0    0.020 0.290 0.870 0.960 0.982 0.991 0.997 1.000
                                                 0.020 0.270 0.580 0.090 0.022 0.010 0.005 0.003

SECTION 22 RMILE= 731.20 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1061.030            0.0             0.0          600.000
                                 1091.030        18000.000          30.000        600.000

               REACH 22 D50=  0.446 CDF,PDF:   0.0    0.016 0.240 0.750 0.915 0.965 0.984 0.994 1.000
                                                 0.016 0.224 0.510 0.165 0.050 0.019 0.011 0.006

SECTION 23 RMILE= 740.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1070.020            0.0             0.0          700.000
                                 1100.020        21000.000          30.000        700.000

               REACH 23 D50=  0.343 CDF,PDF:   0.0    0.028 0.420 0.930 0.973 0.988 0.994 0.997 1.000
                                                 0.028 0.392 0.510 0.043 0.015 0.006 0.004 0.003

SECTION 24 RMILE= 750.00 NA=  2   STAGE            AREA            HYD. RAD.     SURF. WIDTH
-------------------------------------------------------------------------------------------------
                                 1081.660            0.0             0.0          700.000
```

```
                             1111.000       21000.000          30.000          700.000

          REACH 24 D50=  0.400 CDF,PDF:   0.0    0.032 0.350 0.777 0.908 0.953 0.980 1.000 1.000
                                                 0.032 0.318 0.427 0.130 0.046 0.027 0.020 0.0

 SECTION 25 RMILE= 760.90 MA= 15   STAGE          AREA            HYD. RAD.      SURF. WIDTH
 -----------------------------------------------------------------------------------------------
                             1088.600           0.0             0.0             0.0
                             1090.000          44.000           0.600          73.000
                             1092.000         245.000           2.200         111.000
                             1094.000         489.000           3.700         128.000
                             1096.000         757.000           5.220         145.000
                             1098.000        1064.000           6.550         162.000
                             1100.000        1756.000           3.220         545.000
                             1102.000        3325.000           3.320        1002.000
                             1104.000        5573.000           4.600        1203.000
                             1106.000        8256.000           5.410        1525.000
                             1108.000       11406.000           7.040        1621.000
                             1110.000       14749.000           8.550        1724.000
                             1112.000       18963.000           7.310        2555.000
                             1114.000       26227.000           5.720        4562.000
                             1116.000       35713.000           7.020        5084.000

          REACH 25 D50=  0.365 CDF,PDF:   0.0    0.041 0.379 0.782 0.905 0.956 0.976 1.000 1.000
                                                 0.041 0.338 0.403 0.124 0.051 0.020 0.024 0.000

 SECTION 26 RMILE= 772.90 MA= 15   STAGE          AREA            HYD. RAD.      SURF. WIDTH
 -----------------------------------------------------------------------------------------------
                             1107.300           0.0             0.0             0.0
                             1109.000         131.000           0.780         168.000
                             1111.000         595.000           2.170         274.000
                             1113.000        1249.000           3.020         414.000
                             1115.000        2463.000           2.600         687.000
                             1117.000        4611.000           3.540        1304.000
                             1119.000        7700.000           4.310        1790.000
                             1121.000       11530.000           5.620        2050.000
                             1123.000       16190.000           6.170        2622.000
                             1125.000       22921.000           5.520        4153.000
                             1127.000       31417.000           7.250        4335.000
                             1129.000       40359.000           8.640        4672.000
                             1131.000       50053.000          10.250        4832.000
                             1133.000       59820.000          12.250        4884.000
                             1135.000       69591.000          14.240        4867.000

          REACH 26 D50=  0.367 CDF,PDF:   0.0    0.050 0.410 0.787 0.904 0.960 0.981 0.999 1.000
                                                 0.050 0.360 0.376 0.118 0.056 0.020 0.019 0.001

 SECTION 27 RMILE= 782.10 MA= 16   STAGE          AREA            HYD. RAD.      SURF. WIDTH
 -----------------------------------------------------------------------------------------------
                             1110.900           0.0             0.0             0.0
                             1112.000          30.000           0.560          54.000
                             1114.000         216.000           1.630         134.000
                             1116.000         550.000           2.990         184.000
                             1118.000         942.000           4.510         209.000
                             1120.000        1396.000           5.410         253.000
                             1122.000        1968.000           6.570         299.000
                             1124.000        2566.000           8.110         319.000
                             1126.000        3242.000           9.590         338.000



                             1128.000        3991.000           8.480         471.000
                             1130.000        5277.000           5.850         902.000
                             1132.000        7974.000           3.410        2335.000
                             1134.000       15895.000           3.440        4619.000
                             1136.000       25240.000           5.350        4718.000
                             1138.000       34682.000           7.340        4723.000
                             1140.000       76023.000          11.510        6606.000

          REACH 27 D50=  0.351 CDF,PDF:   0.0    0.057 0.435 0.791 0.903 0.963 0.984 0.999 1.000
                                                 0.057 0.377 0.356 0.113 0.060 0.021 0.015 0.001

 SECTION 28 RMILE= 792.00 MA= 16   STAGE          AREA            HYD. RAD.      SURF. WIDTH
 -----------------------------------------------------------------------------------------------
                             1123.000           0.0             0.0             0.0
                             1125.000          63.000           1.000          63.000
                             1127.000         234.000           2.440          96.000
                             1129.000         440.000           4.030         109.000
                             1131.000         671.000           5.500         122.000
                             1133.000        1082.000           4.800         222.000
                             1135.000        1544.000           6.070         254.000
                             1137.000        2342.000           5.310         441.000
                             1139.000        3260.000           5.690         573.000
                             1141.000        4784.000           5.180         924.000
                             1143.000        7061.000           4.590        1542.000
                             1145.000       10577.000           5.010        2113.000
                             1147.000       14811.000           6.700        2211.000
                             1149.000       19463.000           7.890        2467.000
                             1151.000       24839.000           8.300        2993.000
                             1155.000       38262.000           9.830        3094.000

          REACH 28 D50=  0.331 CDF,PDF:   0.0    0.065 0.461 0.795 0.902 0.966 0.986 0.999 1.000
                                                 0.065 0.396 0.334 0.108 0.064 0.021 0.011 0.001

 SECTION 29 RMILE= 801.90 MA= 15   STAGE          AREA            HYD. RAD.      SURF. WIDTH
 -----------------------------------------------------------------------------------------------
                             1134.500           0.0             0.0             0.0
                             1136.000          43.000           0.790          55.000
                             1138.000         205.000           1.680         122.000
                             1140.000         552.000           2.600         212.000
                             1142.000        1026.000           3.930         261.000
                             1144.000        1645.000           4.250         367.000
                             1146.000        2489.000           5.310         468.000
                             1148.000        3525.000           5.410         652.000
                             1150.000        4982.000           5.900         837.000
                             1152.000        6824.000           6.130        1113.000
                             1154.000        9955.000           4.990        1995.000
                             1156.000       14753.000           5.770        2558.000
                             1158.000       20036.000           7.200        2784.000
                             1160.000       26475.000           7.340        3609.000
                             1170.000       62505.000          17.340        3609.000

          REACH 29 D50=  0.309 CDF,PDF:   0.0    0.073 0.487 0.799 0.901 0.969 0.991 0.999 1.000
                                                 0.073 0.414 0.312 0.103 0.068 0.022 0.007 0.001

 SECTION 30 RMILE= 811.00 MA= 14   STAGE          AREA            HYD. RAD.      SURF. WIDTH
 -----------------------------------------------------------------------------------------------
                             1137.200           0.0             0.0             0.0
                             1139.000           9.000           0.400          23.000
```

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                         WATER SURFACE AND BED PROFILE AFTER 1800  DAYS (  4.93 YEARS )
                         ------------------------------------------------------------

SEC.  RM   B(FT.)   STAGE  Q(CFS.) DEP(FT) V(FT/S) EN.SLOPE    DZ(FT)   DB(FT) BED EL(FT)  D50(MM)   ACF    ADEP(FT.)   CBAR(PPM)  FRI.
-----------------------------------------------------------------------------------------------------------------------------------
 30 811.0  1393.  1163.22  36000.  12.66   2.041  0.000105   0.412   -0.026   1136.29    0.744   0.098                  0.0      0.08
                                                                                                       0.5382E-02
 29 801.9  2708.  1156.62  36776.   6.72   2.020  0.000173   0.718   -0.023   1133.76    0.625   0.091                 23.17     0.07
                                                                                                       0.5972E-02
 28 792.0  2251.  1146.95  36776.   6.89   2.373  0.000195   0.367   -0.031   1122.63    0.500   0.064                 46.36     0.06
                                                                                                      -0.1607E-02
 27 782.1  4645.  1134.65  37016.   3.95   2.020  0.000278  -0.126   -0.220   1111.03    0.459   0.023                 64.12     0.06
                                                                                                       0.3110E-03
 26 772.9  2420.  1122.39  37016.   5.98   2.560  0.000231  -0.102    0.336   1107.40    0.451   0.060                 75.21     0.05
                                                                                                      -0.4097E-02
 25 760.9  1623.  1106.67  37016.   7.07   3.227  0.000267   1.371    0.987   1087.43    0.680   0.395                 58.01     0.04
                                                                                                       0.1218E-01 *
 24 750.0   700.  1092.51  37016.  12.42   4.258  0.000206   1.177    0.406   1080.46    0.608   0.336                106.78     0.03
                                                                                                       0.0
 23 740.0   700.  1082.55  37016.  12.53   4.221  0.000167  -0.006    0.311   1070.03    0.425   0.011                211.16     0.03
                                                                                                       0.3021E-02
 22 731.2   600.  1073.32  39032.  13.32   4.883  0.000205   1.030    1.063   1060.00    0.446   0.118                214.19     0.02
                                                                                                      -0.1226E-01
 21 720.0   600.  1061.89  39032.  13.66   4.763  0.000182   2.241    1.267   1048.22    0.436   0.222                202.17     0.02
                                                                                                       0.4309E-01 *
 20 710.0   600.  1051.69  39032.  13.58   4.789  0.000194   1.184    1.037   1038.29    0.444   0.117                247.29     0.02
                                                                                                      -0.6934E-02
 19 700.0   600.  1042.13  39032.  14.23   4.570  0.000180   1.044    0.665   1027.89    0.453   0.094                205.83     0.03
                                                                                                       0.2709E-01 *
 18 690.0   600.  1032.17  39032.  13.61   4.779  0.000197   0.633    1.099   1018.55    0.466   0.122                234.43     0.03
                                                                                                      -0.1132E-01
 17 680.0   600.  1022.40  39032.  14.26   4.554  0.000173   2.568    1.510   1008.12    0.450   0.132                166.85     0.03
                                                                                                      -0.2561E-02
 16 669.5   600.  1013.22  41024.  15.07   4.537  0.000157   2.032    0.323    998.16    0.412   0.102                153.27     0.02
                                                                                                      -0.5653E-01
 15 658.5   650.  1003.71  41272.  14.44   4.396  0.000172  -0.283    0.281    989.27    0.443   0.031                196.39     0.03
                                                                                                       0.3929E-01
 14 648.2   600.   993.64  41272.  14.23   4.834  0.000189   1.472    1.315    979.59    0.443   0.050                266.15     0.02
                                                                                                       0.0
 13 640.0   600.   985.74  41272.  14.26   4.825  0.000182   2.301    1.516    971.48    0.415   0.057                274.63     0.02
                                                                                                       0.0
 12 630.0   600.   976.71  41862.  13.48   5.177  0.000161   1.699    0.624    963.24    0.269   0.059                411.63     0.02
                                                                                                      -0.1727E-01
 11 620.0   600.   969.37  41862.  14.36   4.859  0.000116   1.091   -0.912    955.02    0.202   0.041                435.66     0.01
                                                                                                       0.0
 10 610.5   600.   963.17  41862.  14.19   4.915  0.000132  -2.211   -2.366    949.01    0.257   0.019                379.28     0.0
                                                                                                      -0.6562E-01
  9 600.0   575.   956.60  41862.  16.24   4.463  0.000101  -2.203   -3.369    940.59    0.259   0.011                219.66     0.0
                                                                                                      -0.1417E-03
  8 591.0   550.   943.87  52662.  18.52   5.169  0.000186  -1.287   -2.656    931.41    0.562   0.011                 82.72     0.0
                                                                                                      -0.1293E 00
  7 581.0   575.   937.08  52662.  15.29   5.991  0.000292  -1.925    0.489    921.85    0.708   0.127                363.11     0.0
                                                                                                       0.0
  6 571.0   575.   923.35  52662.  14.40   6.360  0.000226   1.305    1.467    906.94    0.404   0.151                623.37     0.0
                                                                                                       0.0
  5 561.0   675.   912.21  52662.  12.95   6.025  0.000199   1.555    0.344    899.26    0.296   0.032                609.77     0.0
                                                                                                      -0.2624E-04
  4 553.0   600.   904.06  52662.  14.32   6.127  0.000183   0.119   -0.202    889.73    0.302   0.008                766.64     0.0
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                         WATER SURFACE AND BED PROFILE AFTER 3600  DAYS (  9.86 YEARS )
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SEC.  RM   B(FT.)   STAGE  Q(CFS.) DEP(FT) V(FT/S) EN.SLOPE    DZ(FT)   DB(FT) BED EL(FT)  D50(MM)   ACF    ADEP(FT.)   CBAR(PPM)  FRI.FR.
-----------------------------------------------------------------------------------------------------------------------------------
 30 811.0  1393.  1162.86  36000.  12.79   2.021  0.000103   1.399    0.337   1135.60    0.963   0.151                  0.0     0.0668
                                                                                                       0.3704E-02
 29 801.9  2716.  1156.23  36776.   6.78   1.996  0.000172   1.183    0.361   1133.32    0.741   0.152                 17.56    0.0752
                                                                                                       0.4533E-02
 28 792.0  2248.  1146.72  36776.   6.87   2.380  0.000191   0.576    0.196   1122.42    0.506   0.099                 45.20    0.0597
                                                                                                      -0.1603E-02
 27 782.1  4653.  1134.79  37016.   4.11   1.936  0.000269  -0.090   -0.353   1110.99    0.490   0.023                 51.60    0.0759
                                                                                                       0.3261E-02
 26 772.9  2390.  1122.36  37016.   5.95   2.604  0.000246  -0.171    0.370   1107.47    0.474   0.060                 79.41    0.0557
                                                                                                      -0.4151E-02
 25 760.9  1600.  1105.79  37016.   6.68   3.462  0.000277   1.776    1.671   1087.02    0.655   0.537                 53.41    0.0597
                                                                                                       0.7057E-02 *
 24 750.0   700.  1091.91  37016.  11.95   4.425  0.000204   1.708    1.407   1079.95    0.597   0.476                 64.59    0.0321
                                                                                                       0.0
 23 740.0   700.  1081.50  37016.  12.76   4.144  0.000192   1.294    1.365   1066.73    0.537   0.242                116.11    0.0367
                                                                                                       0.2186E-01 *
 22 731.2   600.  1072.09  39032.  13.06   4.981  0.000208   2.606    2.292   1059.02    0.502   0.356                140.51    0.0282
                                                                                                      -0.1012E-01
 21 720.0   600.  1060.63  39032.  12.90   5.044  0.000173   2.523    2.352   1047.94    0.327   0.275                290.66    0.0226
                                                                                                      -0.2926E-06
 20 710.0   600.  1051.06  39032.  13.08   4.973  0.000195   1.462    1.862   1037.99    0.409   0.171                279.00    0.0266
                                                                                                      -0.1293E-01
 19 700.0   600.  1041.18  39032.  13.89   4.664  0.000162   1.641    1.616   1027.29    0.442   0.167                266.05    0.0296
                                                                                                       0.1264E-01 *
 18 690.0   600.  1031.32  39032.  13.56   4.796  0.000190   1.424    1.946   1017.76    0.445   0.194                216.76    0.0269
                                                                                                      -0.1009E-01
 17 680.0   600.  1021.88  39032.  14.43   4.507  0.000170   3.240    2.631   1007.45    0.451   0.156                174.25    0.0312
                                                                                                      -0.1168E-02
 16 669.5   600.  1012.78  41024.  15.06   4.533  0.000157   2.485    0.761    997.73    0.423   0.126                144.06    0.0297
                                                                                                      -0.5853E-01
 15 658.5   650.  1003.26  41272.  14.42   4.404  0.000171   0.150    0.730    988.84    0.446   0.061                167.72    0.0328
                                                                                                       0.5993E-01
 14 648.2   600.   993.27  41272.  14.01   4.910  0.000193   1.634    1.666    979.23    0.436   0.081                280.34    0.0269
                                                                                                       0.0
 13 640.0   600.   985.39  41272.  14.12   4.872  0.000175   2.514    1.867    971.27    0.368   0.071                266.86    0.0266
                                                                                                       0.0
 12 630.0   600.   976.71  41862.  13.57   5.141  0.000149   1.986    0.826    963.14    0.260   0.074                421.80    0.0198
                                                                                                      -0.1727E-01
 11 620.0   600.   969.49  41862.  14.09   4.951  0.000126   0.698   -1.039    955.41    0.177   0.044                636.67    0.0167
                                                                                                      -0.3886E-03
 10 610.5   600.   963.09  41862.  14.70   4.746  0.000131  -1.585   -2.301    946.38    0.293   0.022                286.80    0.0220
                                                                                                      -0.2961E-05
  9 600.0   575.   955.60  41862.  15.40   4.727  0.000139  -1.610   -2.167    940.20    0.337   0.011                261.17    0.0247
                                                                                                      -0.7627E-02
  8 591.0   550.   947.63  52662.  17.52   5.465  0.000189  -0.077   -0.464    930.20    0.502   0.011                166.77    0.0285
                                                                                                      -0.1570E 00
  7 581.0   575.   935.90  52662.  15.45   5.929  0.000254  -0.600    1.666    920.53    0.606   0.127                368.00    0.0208
                                                                                                       0.0
  6 571.0   575.   923.31  52662.  14.53   6.304  0.000219   1.469    1.503    906.76    0.369   0.155                620.67    0.0207
                                                                                                       0.0
  5 561.0   675.   912.24  52662.  12.86   6.065  0.000203   1.447    0.322    899.37    0.298   0.036                830.00    0.0183
                                                                                                      -0.2633E-03
  4 553.0   600.   904.03  52662.  14.43   6.081  0.000184   0.251   -0.180    889.60    0.313   0.010                720.62    0.0165
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                       WATER SURFACE AND BED PROFILE AFTER 5400  DAYS ( 14.79 YEARS )
                       ------------------------------------------------------------------
C.  RM    B(FT.)  STAGE   Q(CFS.) DEP(FT) V(FT/S) EN.SLOPE    DZ(FT)   DH(FT) BED EL(FT)  D50(MM)   ACP    ADEP(FT.)    CBAR(PPM)   FRI.FR.
------------------------------------------------------------------------------------------------------------------------------------------
30 811.0  1393.  1162.52  36000.  12.81   2.017  0.000108    1.764    0.676   1135.44     1.112   0.190                   0.0      0.0076
                                                                                                         0.2813E-02
29 801.9  2720.  1155.65  36776.   6.60   1.989  0.000170    1.586    0.743   1132.91     0.620   0.207                  14.57     0.0752
                                                                                                         0.4057E-02
28 792.0  2240.  1146.45  36776.   6.64   2.401  0.000191    0.762    0.466   1122.22     0.512   0.134                  43.59     0.0563
                                                                                                        -0.1606E-02
27 782.1  4660.  1134.74  37016.   4.23   1.877  0.000259    0.090   -0.308   1110.81     0.529   0.026                  43.29     0.0802
                                                                                                         0.5932E-02
26 772.9  2356.  1122.21  37016.   5.91   2.656  0.000260   -0.144    0.515   1107.44     0.463   0.062                  86.11     0.0561
                                                                                                        -0.4195E-02
25 760.9  1600.  1105.38  37016.   6.68   3.462  0.000273    2.185    2.276   1086.61     0.667   0.559                  48.62     0.0392
                                                                                                         0.1275E-01 *
24 750.0   700.  1090.81  37016.  11.43   4.625  0.000230    2.284    2.499   1079.38     0.637   0.500                  95.18     0.0316
                                                                                                         0.0
23 740.0   700.  1079.93  37016.  12.03   4.395  0.000165    2.126    2.935   1067.69     0.463   0.392                 115.62     0.0297
                                                                                                         0.6743E-02 *
22 731.2   600.  1071.22  39032.  12.63   5.069  0.000185    2.637    3.156   1058.39     0.400   0.499                 120.75     0.0230
                                                                                                        -0.1012E-01
21 720.0   600.  1060.93  39032.  13.00   5.005  0.000164    2.529    2.254   1047.93     0.308   0.294                 202.97     0.0219
                                                                                                         0.6644E-02
20 710.0   600.  1051.21  39032.  12.67   5.053  0.000205    1.132    1.715   1038.34     0.419   0.190                 209.56     0.0266
                                                                                                        -0.1251E-01
19 700.0   600.  1040.84  39032.  13.49   4.823  0.000188    1.572    1.953   1027.36     0.434   0.207                 220.62     0.0280
                                                                                                         0.5923E-02
18 690.0   600.  1030.60  39032.  13.30   4.889  0.000192    1.679    2.463   1017.50     0.431   0.234                 226.52     0.0275
                                                                                                        -0.7830E-02
17 680.0   600.  1021.31  39032.  14.07   4.623  0.000170    3.442    2.596   1007.25     0.424   0.170                 193.20     0.0286
                                                                                                        -0.2304E-02
16 669.5   600.  1012.30  41024.  14.93   4.560  0.000157    2.813    1.245    997.40     0.418   0.141                 146.55     0.0289
                                                                                                        -0.5519E-01
15 658.5   650.  1002.63  41272.  14.33   4.430  0.000175    0.661    1.362    986.31     0.455   0.087                 163.51     0.0329
                                                                                                         0.2768E-01
14 648.2   600.   993.00  41272.  14.31   4.605  0.000178    2.389    2.154    978.67     0.424   0.107                 243.74     0.0285
                                                                                                         0.0
13 640.0   600.   985.56  41272.  14.24   4.830  0.000163    2.439    1.671    971.34     0.357   0.072                 266.18     0.0256
                                                                                                        -0.1478E-02
12 630.0   600.   977.63  41862.  14.51   4.807  0.000140    2.007   -0.094    963.12     0.298   0.074                 279.26     0.0226
                                                                                                        -0.1727E-01
11 620.0   600.   970.60  41862.  14.11   4.944  0.000128   -0.392   -2.139    956.50     0.236   0.044                 406.26     0.0151
                                                                                                        -0.2097E-01
10 610.5   600.   964.19  41862.  15.40   4.532  0.000129   -2.004   -3.405    948.60     0.323   0.022                 227.11     0.0250
                                                                                                        -0.6750E-05
 9 600.0   575.   955.64  41862.  16.12   4.518  0.000169   -1.337   -2.410    939.73     0.487   0.011                 192.04     0.0345
                                                                                                        -0.7174E-02
 8 591.0   550.   946.78  52662.  17.39   5.505  0.000207    0.669    0.394    929.45     0.558   0.027                 105.30     0.0306
                                                                                                        -0.1320E 00
 7 581.0   575.   934.97  52662.  15.46   5.925  0.000237    0.354    2.599    919.58     0.544   0.143                 383.83     0.0269
                                                                                                         0.0

 6 571.0   575.   923.11  52662.  14.65   6.250  0.000212    1.769    1.698    906.46     0.390   0.161                 572.52     0.0265
                                                                                                         0.0
 5 561.0   675.   912.06  52662.  12.88   6.056  0.000206    1.640    0.496    899.18     0.307   0.042                 801.30     0.0100
                                                                                                        -0.6425E-03
 4 553.0   600.   903.74  52662.  14.35   6.117  0.000168    0.457    0.112    889.39     0.322   0.016                 716.67     0.0106


                       WATER SURFACE AND BED PROFILE AFTER 7200  DAYS ( 19.73 YEARS )
                       ------------------------------------------------------------------
EC.  RM   B(FT.)  STAGE   Q(CFS.) DEP(FT) V(FT/S) EN.SLOPE    DZ(FT)   DH(FT) BED EL(FT)  D50(MM)   ACP    ADEP(FT.)    CBAR(PPM)   FRI.FR.
------------------------------------------------------------------------------------------------------------------------------------------
30 811.0  1393.  1162.07  36000.  12.63   2.046  0.000114    2.020    1.123   1135.17     1.190   0.216                   0.0      0.0606
                                                                                                         0.1749E-02
29 801.9  2730.  1155.56  36776.   6.86   1.964  0.000161    1.571    1.040   1132.53     0.517   0.261                  11.00     0.0756
                                                                                                         0.6732E-02
28 792.0  2209.  1145.56  36776.   6.67   2.496  0.000205    1.008    0.959   1121.99     0.521   0.174                  48.00     0.0566
                                                                                                        -0.2740E-02
27 782.1  4653.  1134.37  37016.   4.09   1.944  0.000243    0.316    0.065   1110.56     0.550   0.091                  37.49     0.0677
                                                                                                         0.6991E-02
26 772.9  2297.  1121.93  37016.   5.86   2.751  0.000269   -0.062    0.801   1107.36     0.497   0.127                  85.92     0.0536
                                                                                                        -0.4258E-02
25 760.9  1602.  1104.96  37016.   6.72   3.440  0.000271    2.653    2.700   1086.15     0.675   0.559                  47.06     0.0396
                                                                                                         0.1374E-01 *
24 750.0   700.  1090.20  37016.  11.40   4.639  0.000235    2.867    3.115   1078.79     0.650   0.500                  94.05     0.0321
                                                                                                         0.0
23 740.0   700.  1079.29  37016.  11.69   4.446  0.000180    2.626    3.575   1067.39     0.456   0.491                  99.99     0.0279
                                                                                                         0.4312E-02 *
22 731.2   600.  1070.87  39032.  12.63   5.069  0.000179    2.989    3.509   1058.04     0.383   0.598                 104.34     0.0230
                                                                                                        -0.1012E-01
21 720.0   600.  1060.80  39032.  13.00   5.004  0.000162    2.655    2.377   1047.80     0.299   0.324                 278.05     0.0216
                                                                                                         0.4779E-02
20 710.0   600.  1051.19  39032.  12.79   5.085  0.000204    1.068    1.730   1038.40     0.417   0.219                 262.61     0.0261
                                                                                                        -0.7927E-02
19 700.0   600.  1040.76  39032.  13.28   4.897  0.000191    1.448    2.031   1027.48     0.431   0.229                 226.08     0.0273
                                                                                                         0.4875E-02
18 690.0   600.  1030.53  39032.  13.11   4.963  0.000195    1.758    2.739   1017.42     0.428   0.256                 232.94     0.0267
                                                                                                        -0.4332E-02
17 680.0   600.  1020.70  39032.  13.74   4.736  0.000177    3.721    3.208   1006.97     0.423   0.185                 210.60     0.0260
                                                                                                        -0.5186E-05
16 669.5   600.  1011.07  41024.  14.28   4.789  0.000170    3.383    2.468    996.83     0.409   0.155                 177.64     0.0273
                                                                                                        -0.5853E-01
15 658.5   650.  1001.33  41272.  12.61   5.034  0.000167    0.229    2.660    986.76     0.267   0.090                 404.50     0.0214
                                                                                                        -0.3246E-01
14 648.2   600.   992.71  41272.  13.57   5.070  0.000149    1.905    2.448    979.15     0.473   0.110                 308.20     0.0202
                                                                                                        -0.5205E-05
13 640.0   600.   985.90  41272.  14.16   4.858  0.000167    2.035    1.353    971.74     0.365   0.072                 291.54     0.0230
                                                                                                        -0.1199E-01
12 630.0   600.   977.69  41862.  14.77   4.725  0.000136    1.992   -0.356    963.14     0.307   0.074                 252.15     0.0233
                                                                                                        -0.1727E-01
11 620.0   600.   970.92  41862.  14.23   4.903  0.000126   -0.594   -2.469    956.70     0.245   0.044                 309.21     0.0161
                                                                                                        -0.4402E-06
10 610.5   600.   964.20  41862.  14.74   4.734  0.000142   -2.664   -3.417    949.46     0.321   0.022                 260.11     0.0240
                                                                                                        -0.2745E-04
 9 600.0   575.   955.66  41862.  15.98   4.557  0.000170   -1.234   -2.228    939.68     0.463   0.011                 137.24     0.0330
                                                                                                        -0.8659E-02
 8 591.0   550.   946.68  52662.  17.54   5.458  0.000202    0.902    0.492    929.22     0.563   0.039                  97.70     0.0306
                                                                                                        -0.1590E 00
 7 581.0   575.   935.08  52662.  15.57   5.881  0.000234    0.348    2.490    919.58     0.554   0.155                 357.11     0.0272
                                                                                                         0.0
 6 571.0   575.   923.15  52662.  14.63   6.261  0.000215    1.734    1.668    908.52     0.386   0.164                 593.67     0.0206
                                                                                                         0.0
 5 561.0   675.   912.04  52662.  12.95   6.023  0.000207    1.737    0.522    899.06     0.311   0.045                 779.03     0.0190
                                                                                                        -0.8172E-03
 4 553.0   600.   903.66  52662.  14.32   6.130  0.000169    0.506    0.193    889.34     0.323   0.018                 722.92     0.0166
```

APPENDIX E

STRUCTURE OF NRES OUTPUT FILE

Logical Record Number	Description
1	'IAL1'; an identifying keyword
2	TITLE (15); 60-character title of run (card 1)
3	N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,NT3651 NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
4	(RMILE(I), I=1,N); River miles
5[1]	IT,ITIME,IDAY,KYR,VOLUME,CUMVOL
6[2]	B,STAGE,Q,DEP,VAV,SE,Y,DH,STAGE1(I,1),DMM,ACF,CBAR,FFR
7[2]	(PT(I,K), K=1,N1); mixed layer probability distribution function
8	(QTR(L), L=1, NTRIB), (QSTR(L), L=1, NTRIB); tributary water and sediment discharges

Notes:

1. For each time step, the file contains logical records of type 5,6,7, and 8.
2. For each of N points, upstream to downstream, the file contains one type 6 and one type 7 logical record.