

Pen Branch Delta and Savannah River Swamp Hydraulic Model

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Abstract

The proposed Savannah River Site (SRS) Wetlands Restoration Project area is located in Barnwell County, South Carolina on the southwestern boundary of the SRS Reservation. The swamp covers about 40.5 km² and is bounded to the west and south by the Savannah River and to the north and east by low bluffs at the edge of the Savannah River floodplain. Water levels within the swamp are determined by stage along the Savannah River, local drainage, groundwater seepage, and inflows from four tributaries, Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek. Historic discharges of heated process water into these tributaries scoured the streambed, created deltas in the adjacent wetland, and killed native vegetation in the vicinity of the delta deposits. Future releases from these tributaries will be substantially smaller and closer to ambient temperatures. One component of the proposed restoration project will be to reestablish indigenous wetland vegetation on the Pen Branch delta that covers about 1.0 km². Long-term predictions of water levels within the swamp are required to determine the characteristics of suitable plants. The objective of the study was to predict water levels at various locations within the proposed SRS Wetlands Restoration Project area for a range of Savannah River flows and regulated releases from Pen Branch. TABS-MD, a United States Army Corps of Engineer developed two-dimensional finite element open channel hydraulic computer code, was used to model the SRS swamp area for various flow conditions.

Key Words

Savannah River Site, Pen Branch Swamp, TABS-MD, Open Channel Hydraulic Modeling.

Introduction

Background

The proposed Savannah River Site (SRS) Wetlands Restoration Project area is located in Barnwell County, South Carolina on the southwestern boundary of the SRS Reservation (Figure 1). The swamp covers about 40.5 km² and is bounded to the west and south by the Savannah River and to the north and east by low bluffs at the edge of the Savannah River floodplain. Water levels within the swamp are determined by stage along the Savannah River, local drainage, groundwater seepage, and inflows from four tributaries, Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek. Historic discharges of heated process water into these tributaries scoured the streambed, created deltas in the adjacent wetland, and killed native vegetation in the vicinity of the delta deposits. Future releases from these tributaries will be substantially smaller and closer to ambient temperatures. One component of the proposed restoration project will be to reestablish indigenous wetland vegetation on the Pen Branch delta that covers about 1.0 km². Long-term predictions of water levels within the swamp are required to determine the characteristics of suitable plants.

Objective

The overall objective of the study was to predict water levels at various locations within the proposed SRS Wetlands Restoration Project area for a range of Savannah River flows and regulated releases from Pen Branch. The emphasis of this study was prediction of water levels in the vicinity of the Pen Branch delta. However, the modeling technique is extensible to water level prediction in the remainder of the swamp including the Fourmile Branch and Steel Creek deltas.

Approach

The model study was conducted using the TABS-MD modeling system (Thomas, et al, 1990). TABS-MD is a collection of computer programs and utility codes integrated into a numerical modeling system that provides multi-dimensional solutions to open-channel flow, transport and sedimentation problems in rivers, reservoirs, bays and estuaries. TABS-MD consists of three main modules: preprocessor, calculation and postprocessor. The calculation module has flow, transport and sedimentation models. The two-dimensional open channel flow model is RMA-2V. The sediment transport in unsteady two-dimensional flow model is STUDH and the two-dimensional pollutant transport model for water quality is RMA-4. RMA-2V, a two-dimensional, depth-averaged hydrodynamic numerical model was used to generate water levels and current patterns. RMA-2V employs finite element techniques to solve the Reynolds Form of the Navier-Stokes equations for turbulent flows. Input data requirements for RMA-2V include channel and floodplain

geometry in the form of a finite element mesh, Manning's roughness coefficients, turbulent exchange coefficients, and boundary conditions. RMA-2V has a "marsh porosity" feature which allows smooth wetting and drying of the mesh in response to gradual changes in water level, a critical requirement for modeling of flow in a wetland.

The Numerical Model

Model Development

A TABS-MD finite element mesh (Figure 2) consisting of 3270 elements and 9773 nodes was developed from the digitized topographic maps listed in Table 1. SRS Universal Transverse Mercator (UTM) coordinates scaled to feet were used for horizontal control, and ground elevations at the nodes were referenced to the National Geodetic Vertical Datum, 1929 (NGVD).

Key topographic features of the mesh are the Savannah River, excavated material disposal sites along the River, the swamp, islands within the swamp, tributary channels entering through the bluff line, and the Steel Creek outlet channel (Figure 3). The Savannah River is represented by a trapezoidal cross-section having a typical depth of 6.1 m and top-width of 36.6 m. This typical river cross-section and bottom slope was determined from cross-sections supplied by the Corps of Engineers Savannah District. This resolution of the river geometry is adequate only for computation of stages along the river. Personal communication with Mr. Bill Cook at US Army Corps of Engineers, Savannah District indicated that the high ground along the river was believed to be excavated material from construction and maintenance of the navigation project operated along this portion of the Savannah River until the mid- 1970's. The ridge of excavated material deposited along the river bank is represented by a trapezoidal cross-section of varying size.

Drainage openings in this ridge permit the exchange of water between the river and the swamp until flood waters overtop the ridge.

Some elevation relief within the swamp can be clearly identified. For example, islands of hardwood forest standing on relatively high ground within the predominantly cypress-tupelo swamp are clearly visible on aerial photography. However, these elevation differences are similar in magnitude to the contour interval of 1.524 m on the topographic maps. Bed elevations within the swamp were estimated from 23 transects through the swamp and the Pen Branch delta. In addition, previously developed gridded elevations covering approximately 8,100 m² of the Pen Branch delta were directly incorporated into the finite element model. The gridded elevation data was adjusted upwards 0.61 m to match the datum of the transects.

Mesh boundary specifications are shown in Figure 2. The effective upstream boundary of the study area was located at river kilometer 234.6 on the Savannah River about 2.1 km downstream of the Jackson, SC gauge (station no. 02197320). The drainage area at the Jackson gauge is about 20,202 km². The upstream boundary of the model was extended about 965 m upstream of that location and the model topography was transitioned to a uniform section with an invert of 24.4 m relative to NGVD. Using a uniform section at the upstream boundary permits specification of inflow without prior knowledge of the extent of overbank flooding. Inflows may also be specified at the upstream boundary of each of the tributaries.

The downstream boundary of the model was located at Savannah River kilometer 227.5 about 321.8 meters downstream of the Steel Creek gauge (station no. 02197357). The water surface

elevation at the downstream boundary was controlled to reproduce a selected stage at the Steel Creek gauge.

Model Adjustment

Roughness coefficients assigned by element type are shown in Table 2. Each element type represents a different roughness value as presented in Figure 4. The estimated channel n-value must account not only for roughness but also for discretization error in the geometric representation of the channel. Therefore, channel n-value was allowed to vary from 0.02 to 0.03 as necessary to reproduce the total head loss between the Jackson and Steel Creek gauges. Published n-values for hardwood forest floodplains range from 0.1 to 0.2 (Arcement, et al, 1989). An aggregate floodplain roughness value at the lower end of this range appears to provide the best reproduction of the total head loss between gauges. Ongoing research indicates that n-values for dense wetland vegetation may be 2 to 5 times greater than the values measured in hardwood floodplain (Hall, et al, 1994). Also, n-values can be expected to vary with seasonal and spatial changes in vegetative density and with changes in water depth, temperature, and current speed.

Simulation Input and Results

Boundary Conditions

Discharge in this portion of the Savannah River is regulated by three large multi-purpose reservoirs operated by the Corps of Engineers. The most downstream reservoir, J. Strom Thurmon near Clarks Hill, SC, was completed in 1951 and has a drainage area of 15,913 km². A relatively small impoundment formed by Stevens Creek Dam, downstream of J. Strom Thurmon, has little impact on flood discharges in the study area (Sanders, et al, 1990).

Discharge is not measured at the Jackson gauge for flows in excess of 623 m³/s because of the difficulty of obtaining reliable data in the floodplain. The published discharge is based on a rating curve, Figure 5, which is adjusted to periodic measurements as necessary to account for naturally occurring changes in the geometry and roughness of the alluvial channel. These shifts can be identified in specific gauge plots which display trends in the relationship between stage and a set of selected discharges. A shift of about 0.24 m during water year 1990 is shown in Figure 6. A normal shift of 0.0 m was used for these model simulations.

A comparison of the published stage at the Steel Creek (F) and Jackson (C) gauges is shown in Figure 7. Equation 1, developed by linear regression from 1516 observations, was used in

conjunction with the Jackson rating curve to estimate the stage at the Steel Creek gauge corresponding to a specified discharge at the upstream boundary.

$$C = 0.9797 * F + 11.25 \quad (1)$$

Equation 1 includes observations (estimated discharges) affected by rating curve shifts. Equation 2 was developed from 859 observations where the rating curve shift was less than ± 0.03 m.

$$C = 1.0190 * F + 8.311 \quad (2)$$

Despite the smaller number of observations, the correlation coefficient for Equation 2 was slightly better for Equation 2 ($r^2=0.976$) than for Equation 1 ($r^2=0.966$). However, for the range of flows (396 to 566 m^3/s) analyzed with this model, the change in predicted stage at the Steel Creek gauge from Equation 1 to Equation 2 was -0.06 to -0.12 m. Sensitivity tests performed on a preliminary grid indicated that a 0.3 m change in the downstream boundary stage generally produced a change of 0.03 m or less in the vicinity of the Pen Branch delta. Therefore, model boundary conditions were assigned by selecting a discharge then using the unshifted rating curve and Equation 1 to estimate the stage at the downstream boundary of the model. Model simulations were performed for a range of Savannah River inflows, described in Table 3, extending from minimal to complete flooding of the Pen Branch delta. All model simulations were conducted for steady-state flow conditions.

Simulation Results

Computed water surface elevations for each condition simulated are displayed in Figures 8 through 11. For these simulations an inflow of $2.83 \text{ m}^3/\text{s}$ was specified at the upstream boundary of Pen Branch. At an inflow of $396.48 \text{ m}^3/\text{s}$ (Figure 8), the high ground along the river produced a discontinuity between the water surface elevation in the swamp and the river in region just upstream of the Steel Creek outlet channel. The computed stage in the swamp is higher than in the river because the exchange of water between the swamp and the river was nearly zero in this region and flow through the swamp is restricted by relatively shallow depths and high roughness until it reaches the Steel Creek outlet channel. The exchange of flow between the river and swamp is controlled by the geometry of both the ridge of high ground along the river and the drainage openings through the ridge. At higher flows (Figures 9 to 11), the aerial extent of this discontinuity was reduced as the ridge of high ground was partially submerged by increasing water levels and the exchange of flow between the river and the swamp increased.

Computed water surface elevations in the Pen Branch delta, at the intersection of the U and T transacts, for varying Savannah River discharge are displayed in Figure 12 and compared to the water surface elevation at the Steel Creek gauge. The effect of reduced exchange of flow between the river and the swamp with decreasing discharge is demonstrated by the divergence in the predicted water levels.

The effect of Pen Branch inflows on water surface elevation in the Pen Branch delta for a Savannah River inflow of $453.12 \text{ m}^3/\text{s}$ is demonstrated in Figure 13. For the range of Savannah River inflows simulated with this model, the effect of low to moderate Pen Branch inflows is insignificant. Larger Pen Branch inflows associated with natural rainfall-runoff events may produce larger but relatively brief increases in stage. For lower Savannah River discharges, when the Pen Branch delta is not flooded by the Savannah River, variations in Pen Branch discharge may have a significant effect on water depth in the delta.

Conclusions and Recommendations

The precision of any estimate of water levels on the Pen Branch delta is limited by naturally occurring shifts in the stage-discharge relationship along the Savannah River such as the one demonstrated in Figure 6. The accuracy of water level estimates near the Pen Branch delta is determined primarily by the topographic description of the study area incorporated into the model and by adjustment of model coefficients. The minimal set of observed water surface elevation data in the floodplain was not sufficient to permit precise adjustment of model coefficients. Natural variations in water levels may be due to changes in physical properties such as roughness which are represented as model coefficients, therefore it was not feasible to prove that any particular combination of coefficient values which reproduced observed mean water levels was inherently more accurate or correct than any other reasonable combination. The water surface elevations estimated by this model appear reasonable; however, uncertainties including variations in hydraulic

roughness and possible errors in the vertical datum used for topographic definition should not be ignored when interpreting the model results.

In order to model the Fourmile Branch or Steel Creek deltas, it will be necessary to extend the model boundaries upstream and downstream to minimize the influence of possible errors in the boundary conditions on water level estimates in the vicinity of the deltas. Acquiring accurate topographic data by means of field surveys will be a prerequisite for extending the model boundary. Accurate adjustment of model coefficients will require development of a consistent and reliable set of observed water levels throughout the swamp. This can be accomplished by installation of water level recorders along the periphery of the swamp.

Acknowledgement

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Table 1. Topographic maps used for mesh generation.

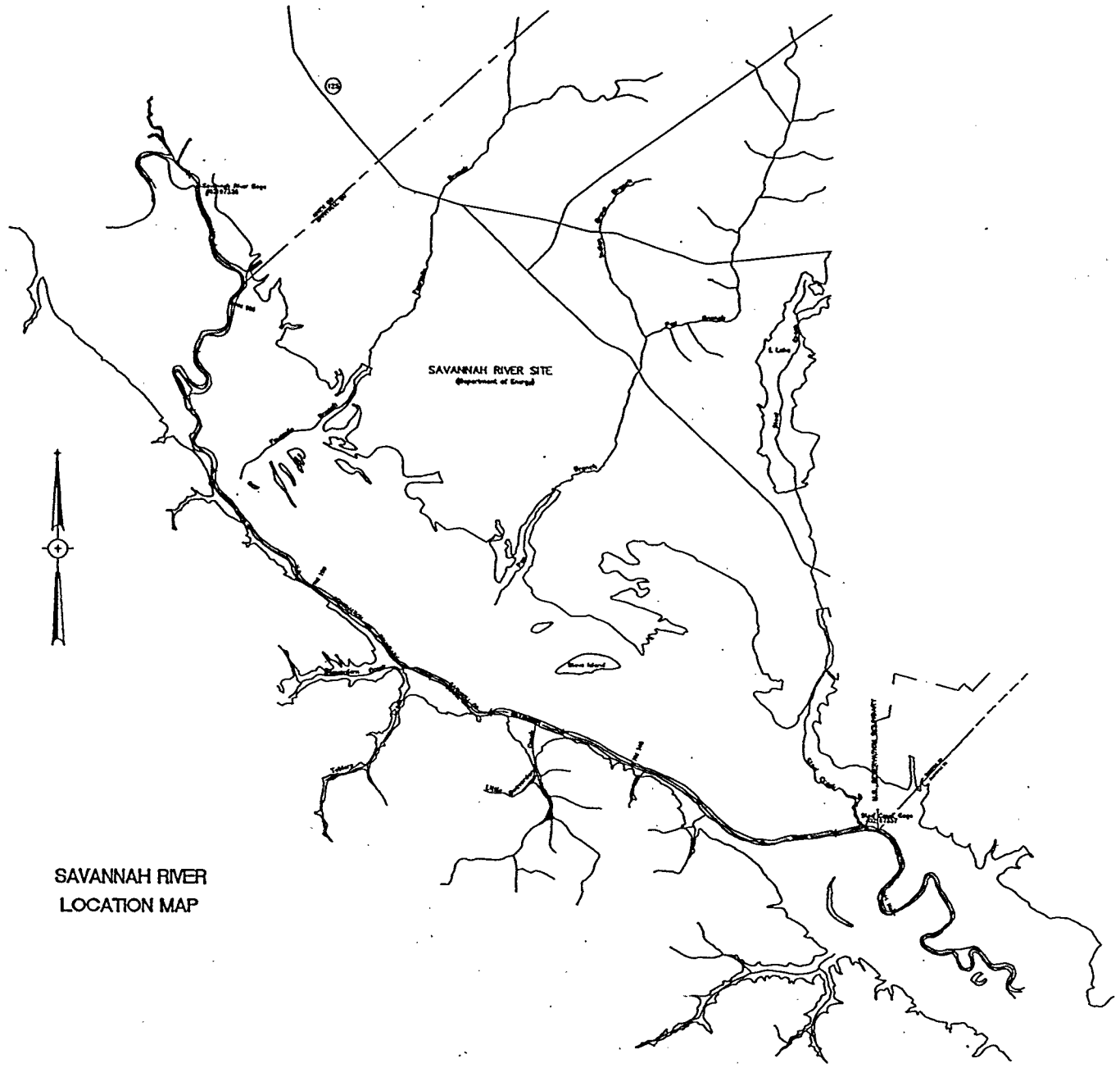
<u>Map Description</u>	<u>Publication Date</u>
Shell Bluff Landing Quadrangle	1965 (Photorevised 1989)
Girard NW Quadrangle	1964 (Photorevised 1989)
Girard Quadrangle	1964
Millet Quadrangle	1964

Table 2. Roughness Coef-Ficients.

<u>Element Type No.</u>	<u>Description</u>	<u>Manning's n-value</u>
1	Wetland	0.10
2	River channel	0.02-0.03
3	Hardwood islands	0.10
4	Hardwood ridge	0.10
5	Storage area	0.10
6	Tributary deltas	0.10

Table 3. Simulation Conditions

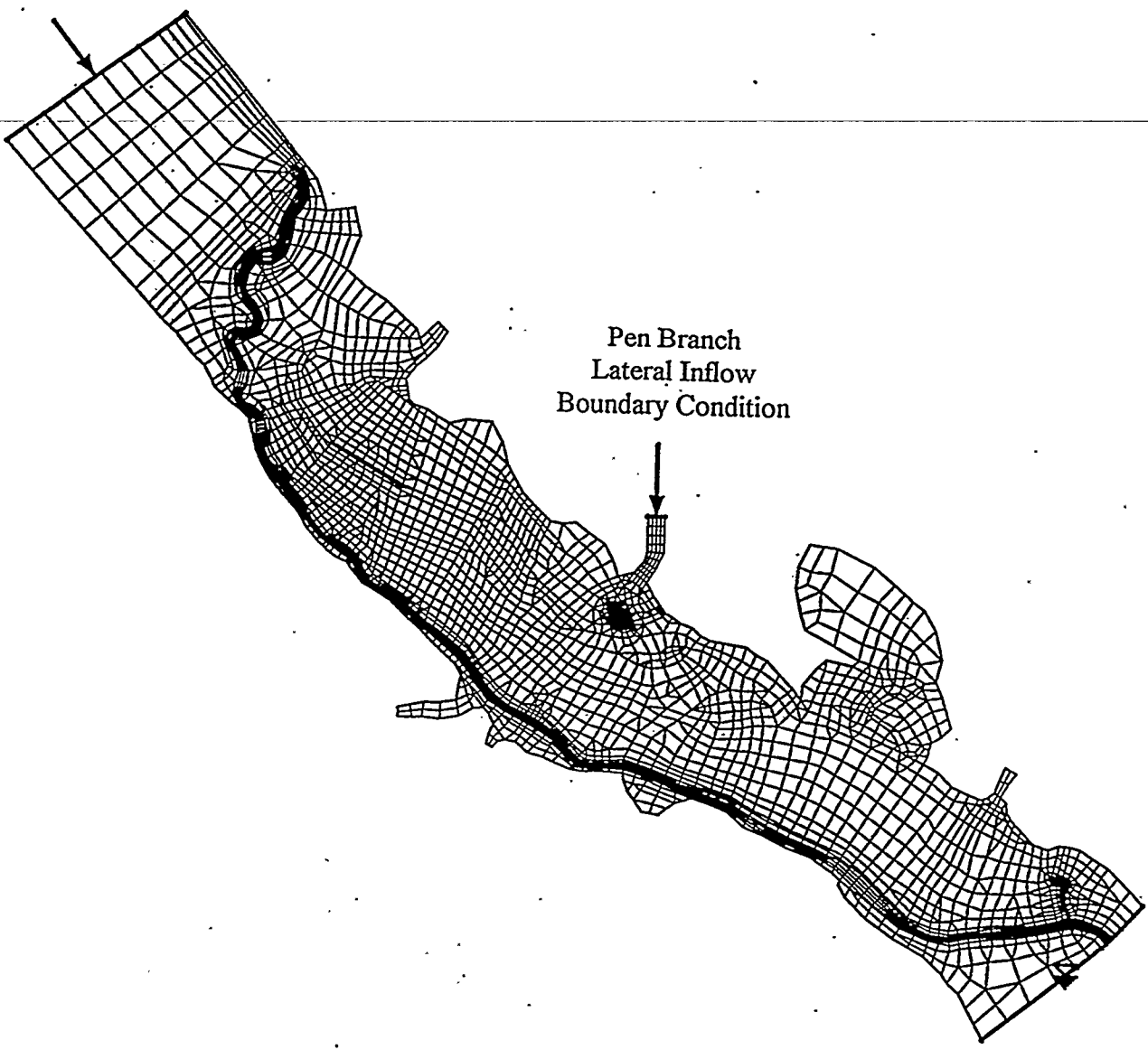
<u>Discharge at Jackson Gauge (m³/s)</u>	<u>Estimated Stage at Steel Creek Gauge (m)</u>
283.20	23.531
311.52	23.805
339.84	24.049
368.16	24.293
396.48	24.506
424.80	24.719
453.12	24.902
481.44	25.116
509.76	25.329
538.08	25.512
566.40	25.695
594.72	25.878
623.04	26.060



SAVANNAH RIVER
LOCATION MAP

Figure 1. Location map.

Savannah River
Upstream Inflow
Boundary Condition



Pen Branch
Lateral Inflow
Boundary Condition

Savannah River
Downstream Stage
Boundary Condition

Figure 2. Finite element mesh.

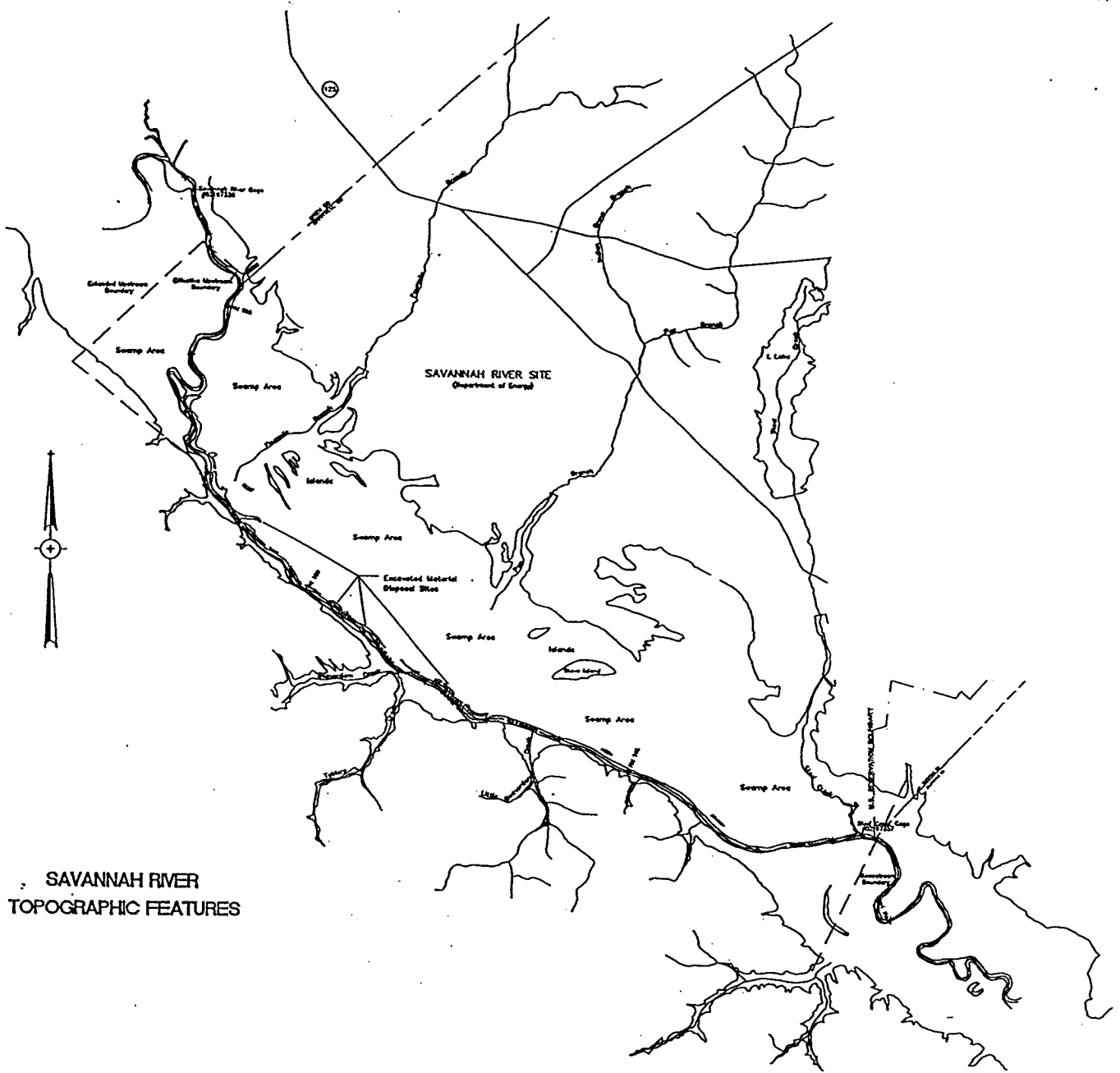


Figure 3. Key topographic features.

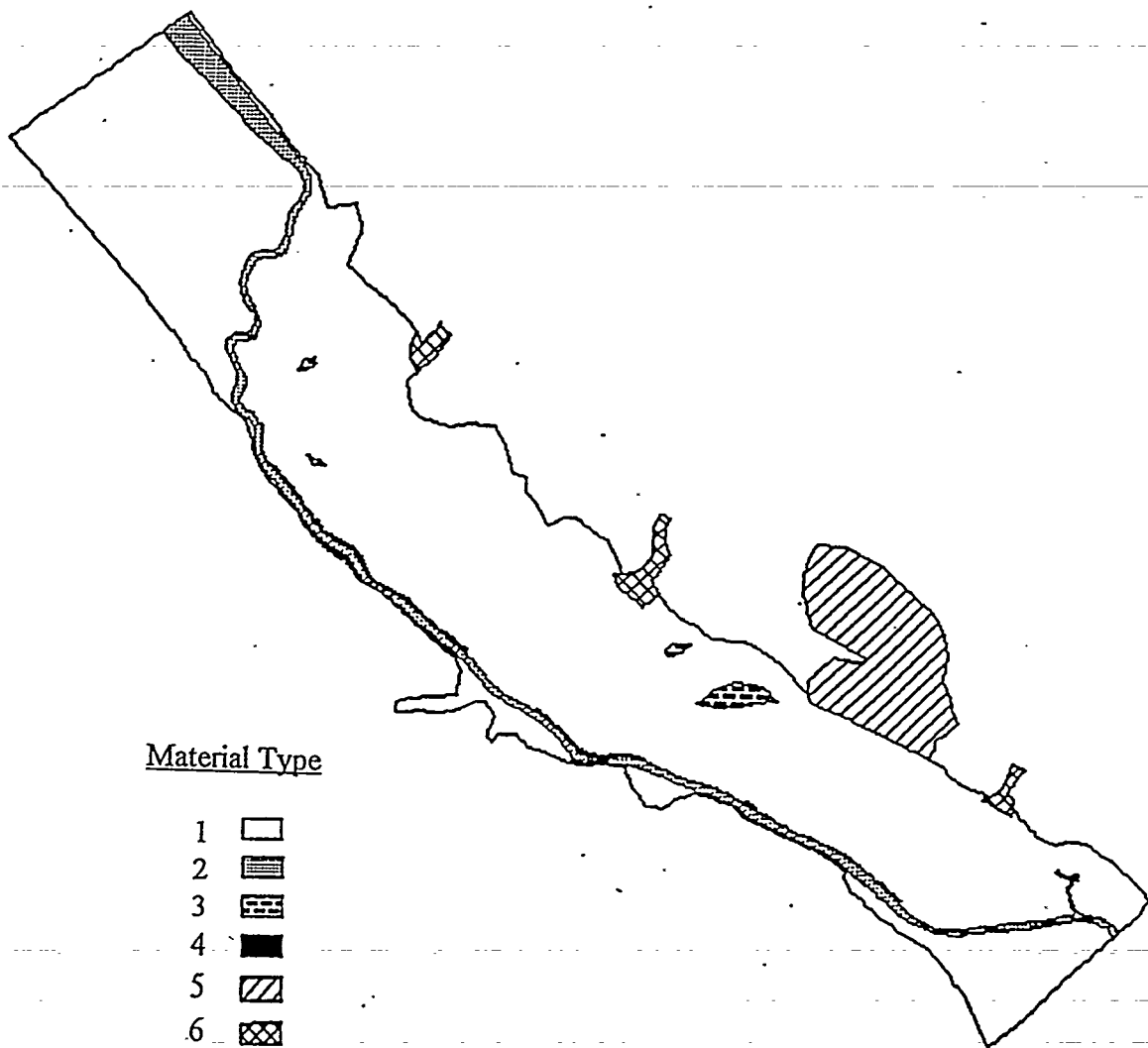


Figure 4. Element type key.

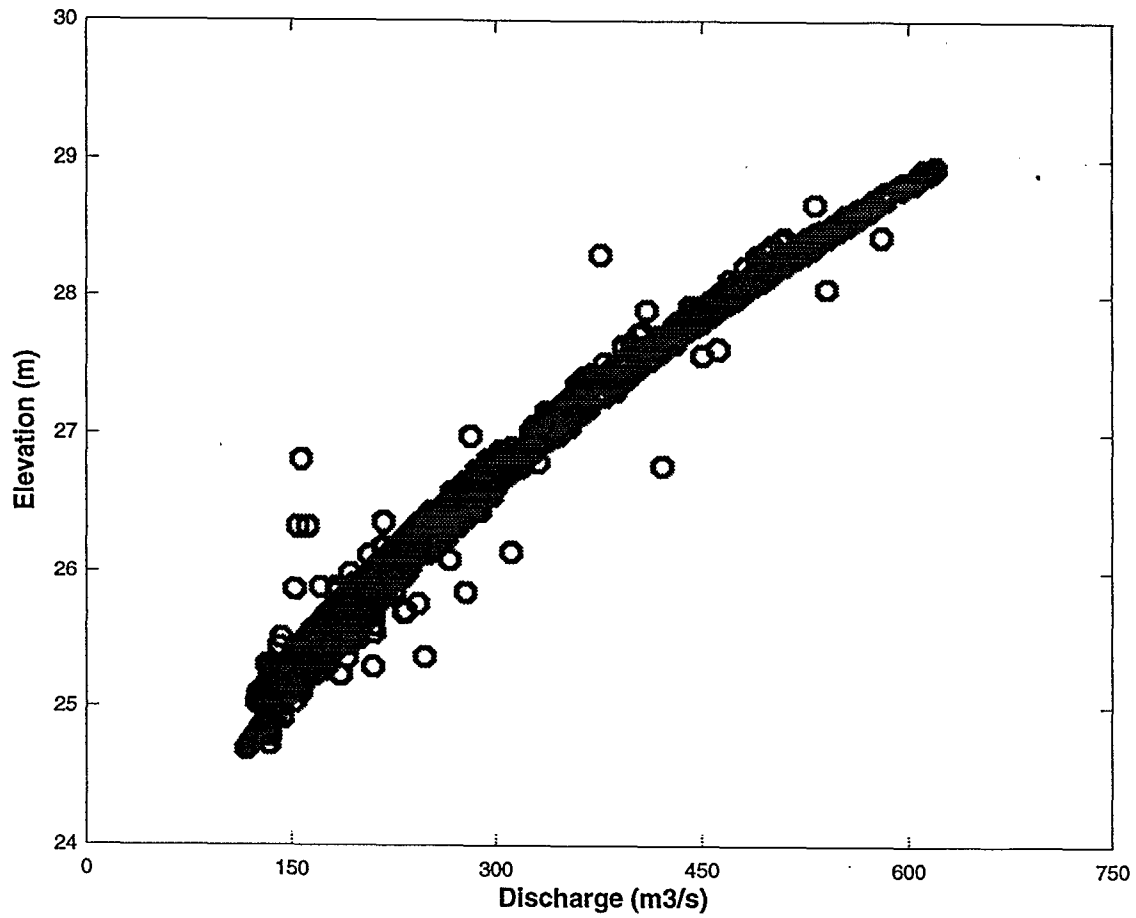


Figure05.gif

Figure 5. Rating Curve at Jackson, SC.

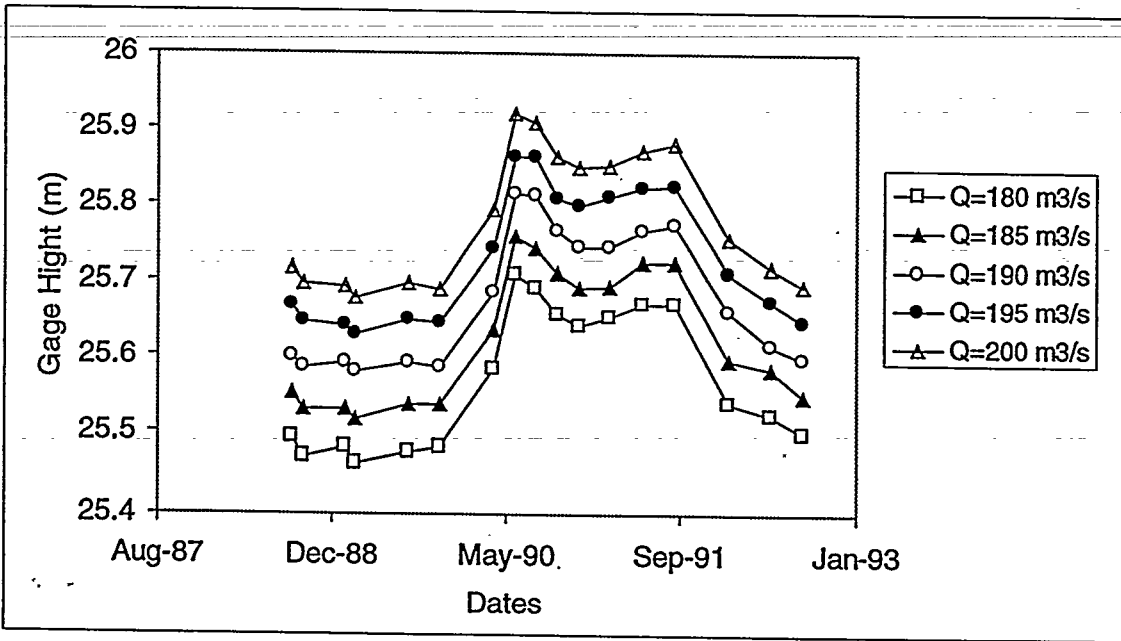


Figure 6. Specific-gauge plot at Jackson, SC.

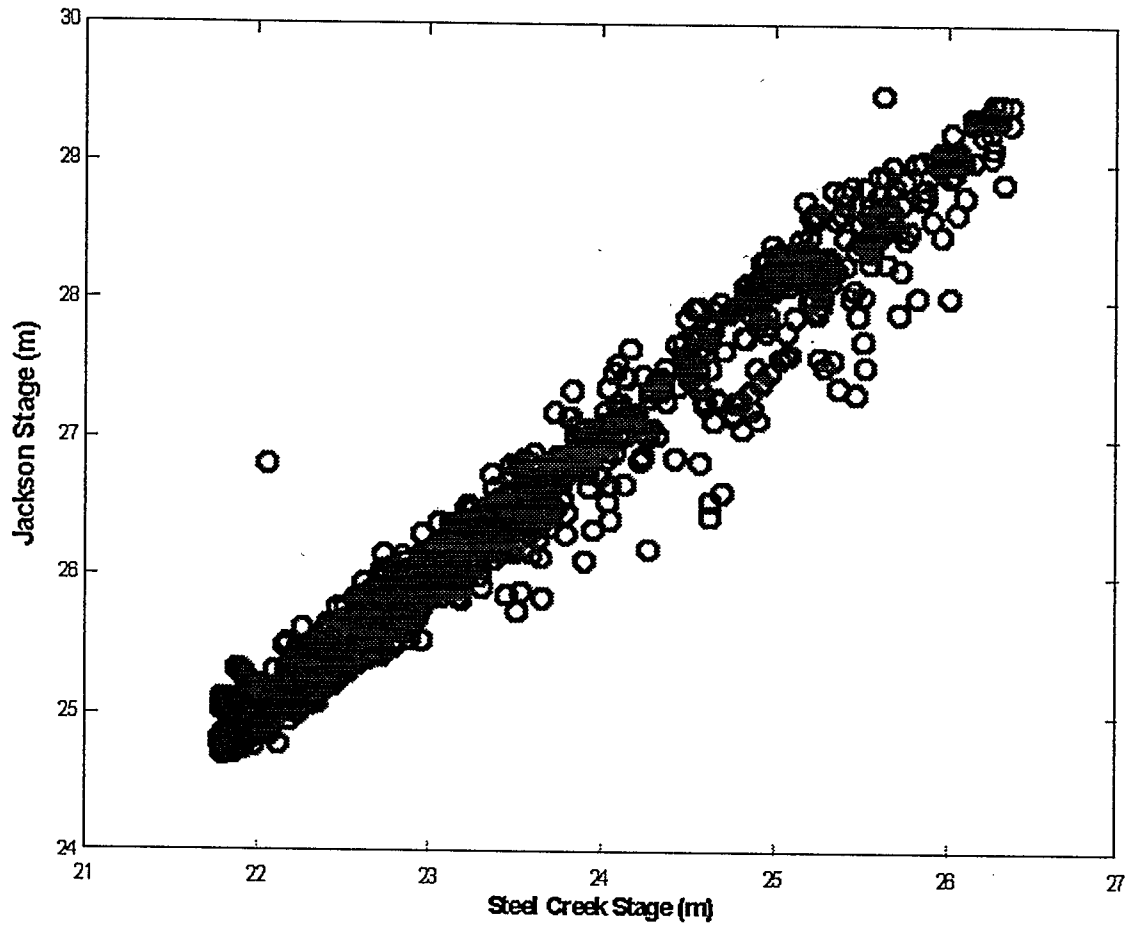


Figure07.gif

Figure 7. Observed stages at Jackson and Steel Creek gauges.

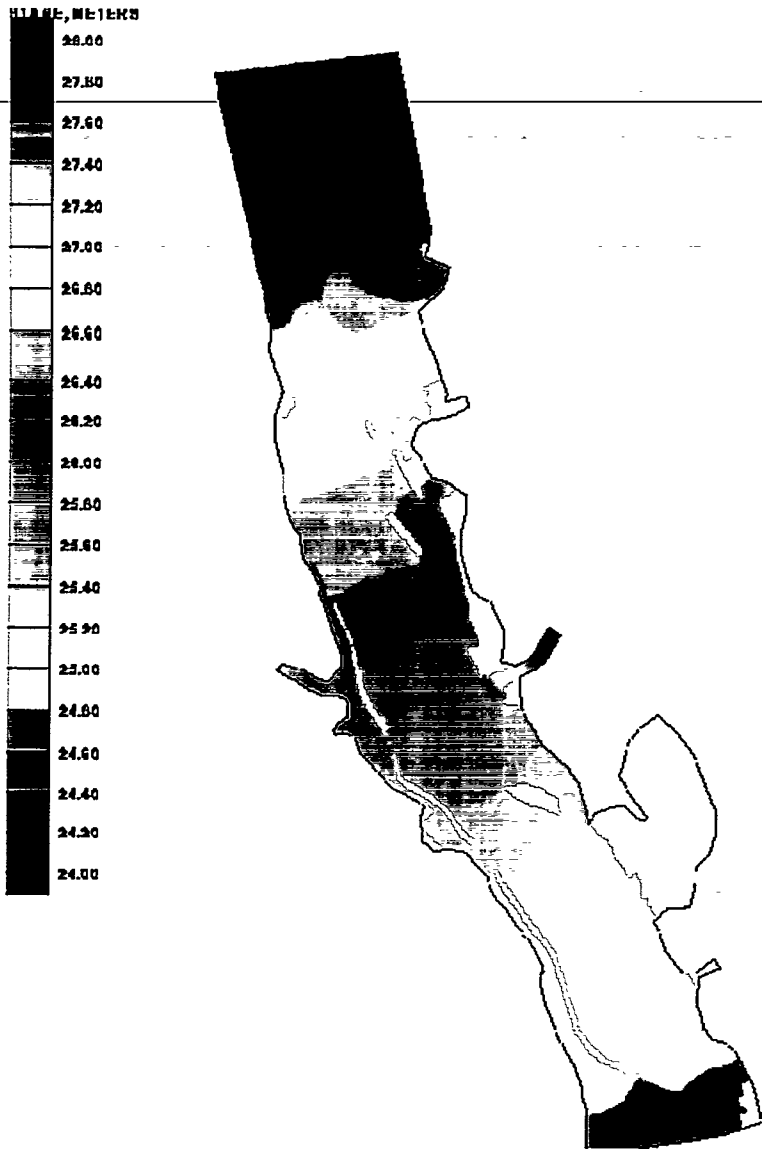


Figure 8. Computed water surface elevations for inflow of 396 m³/s.

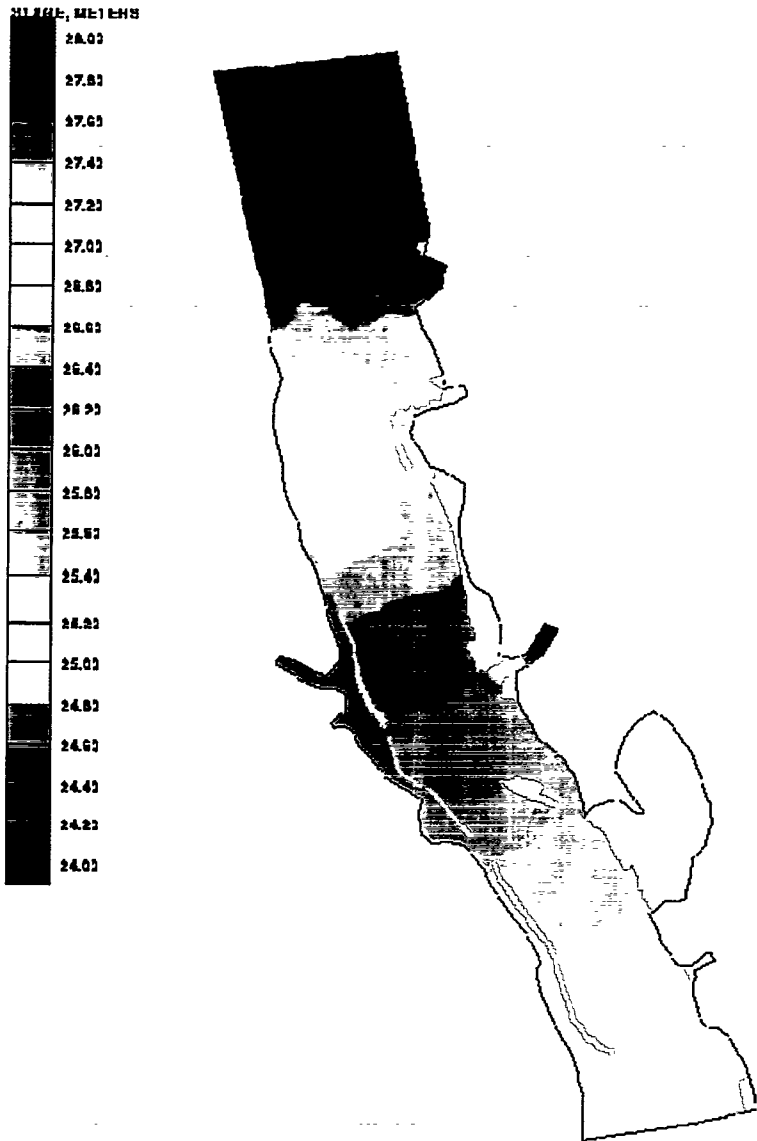


Figure 9. Computed water surface elevations for inflow of 453 m³/s.

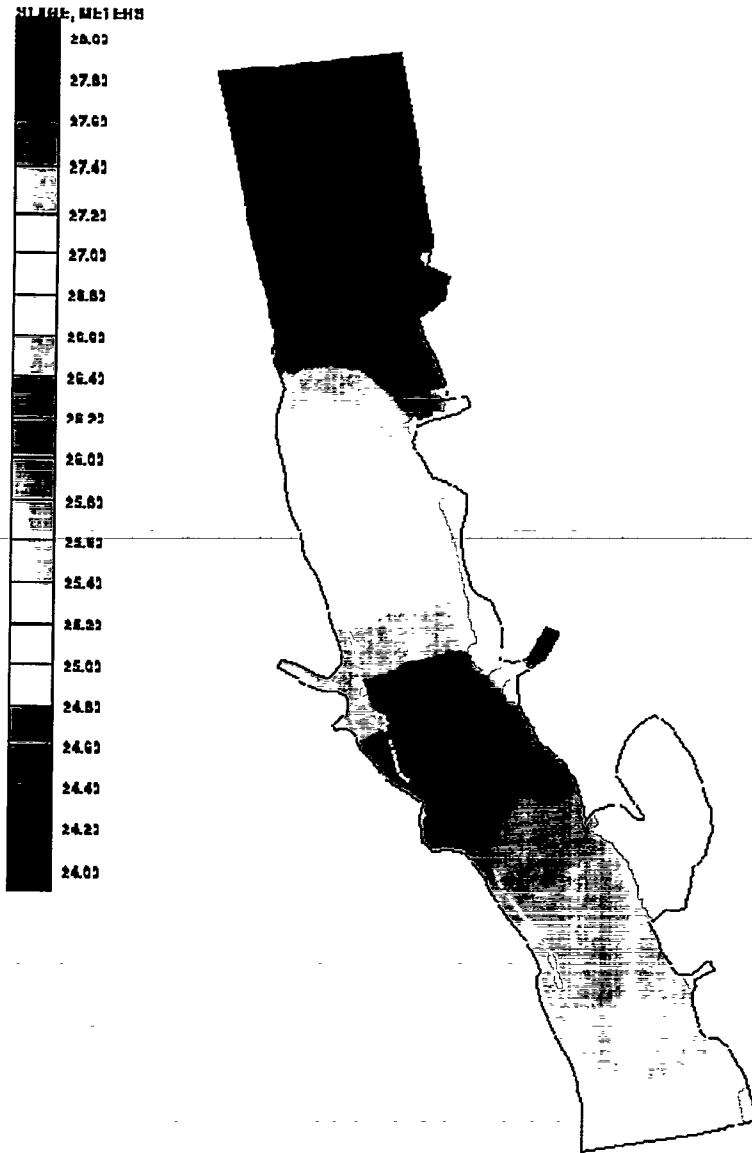


Figure 10. Computed water surface elevations for inflow of 510 m³/s.

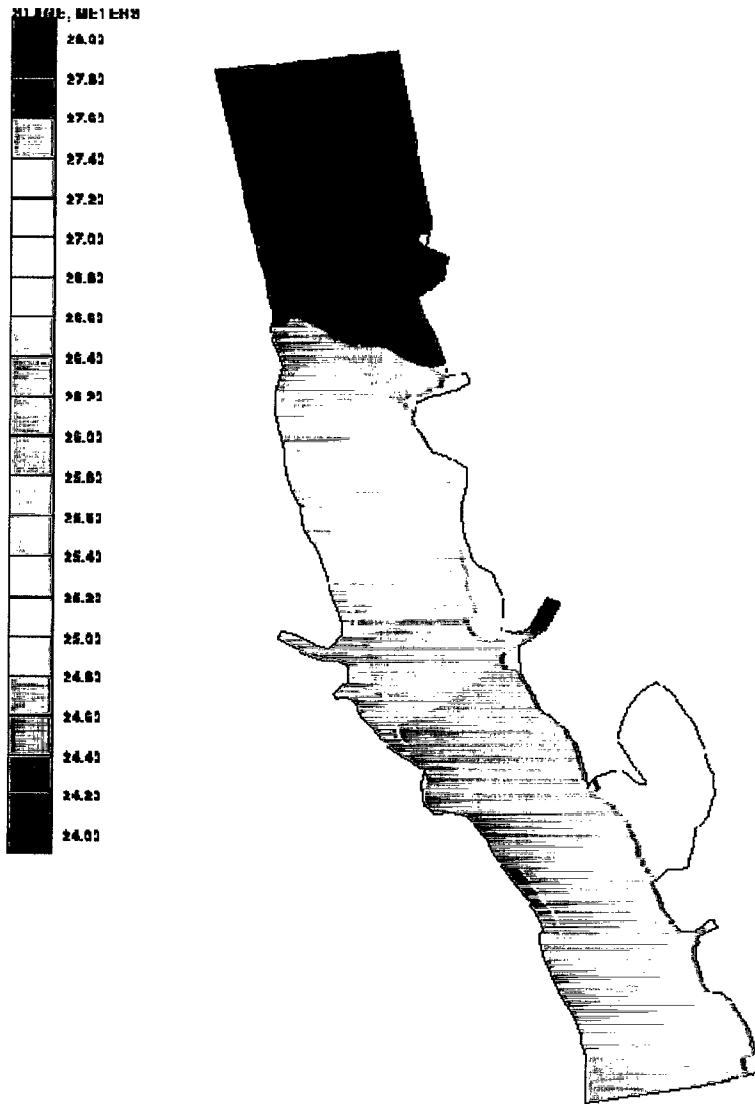


Figure 11. Computed water surface elevations for inflow of $566 \text{ m}^3/\text{s}$.

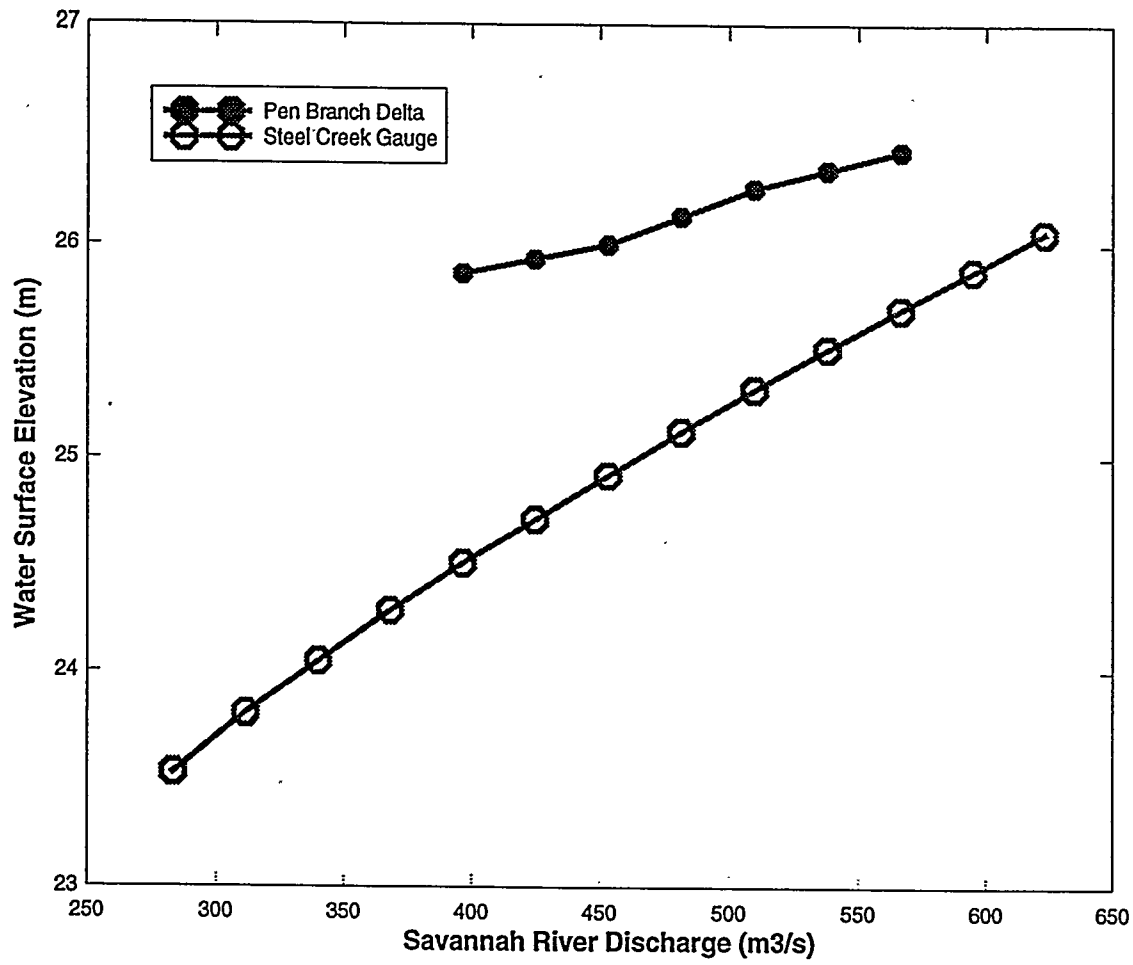


Figure12.gif

Figure 12. Variation of computed stage with Savannah River discharge.

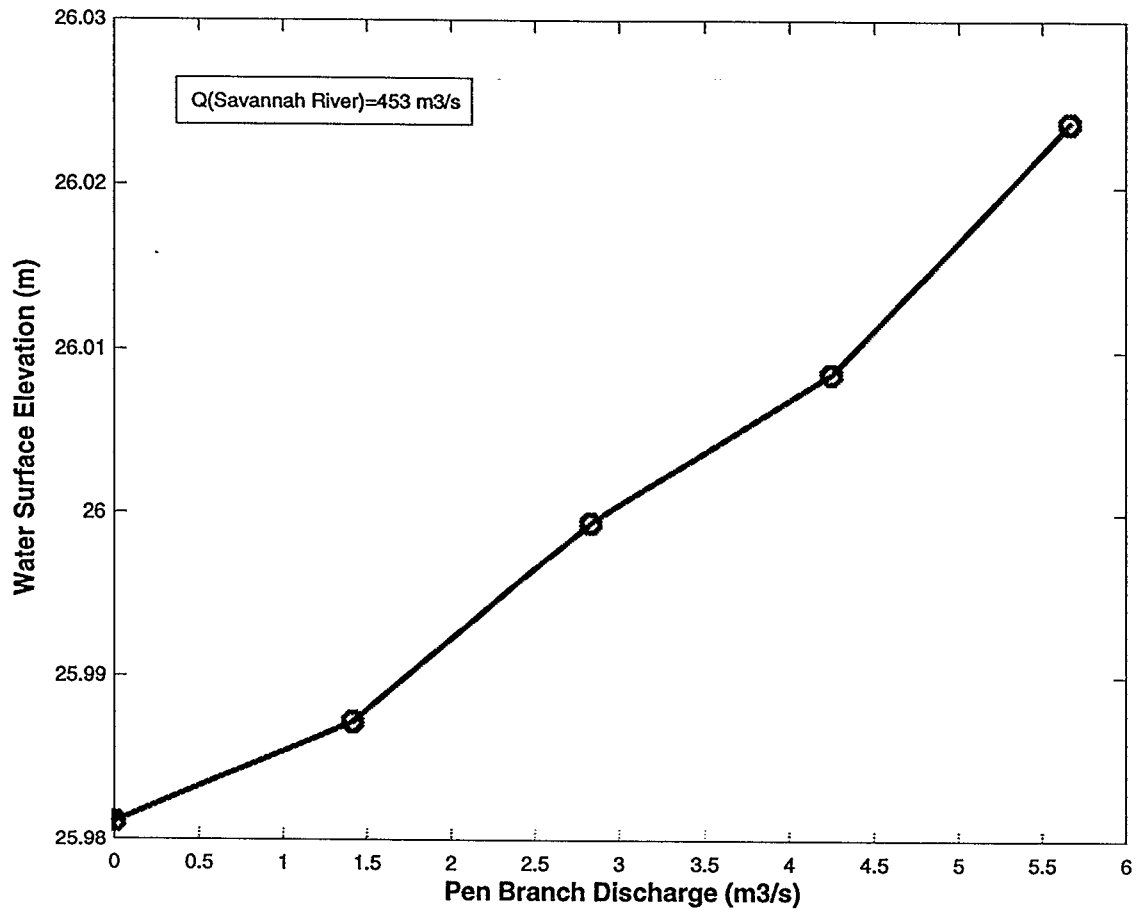


Figure13.gif

Figure 13. Variation of computed stage with Pen Branch discharge.