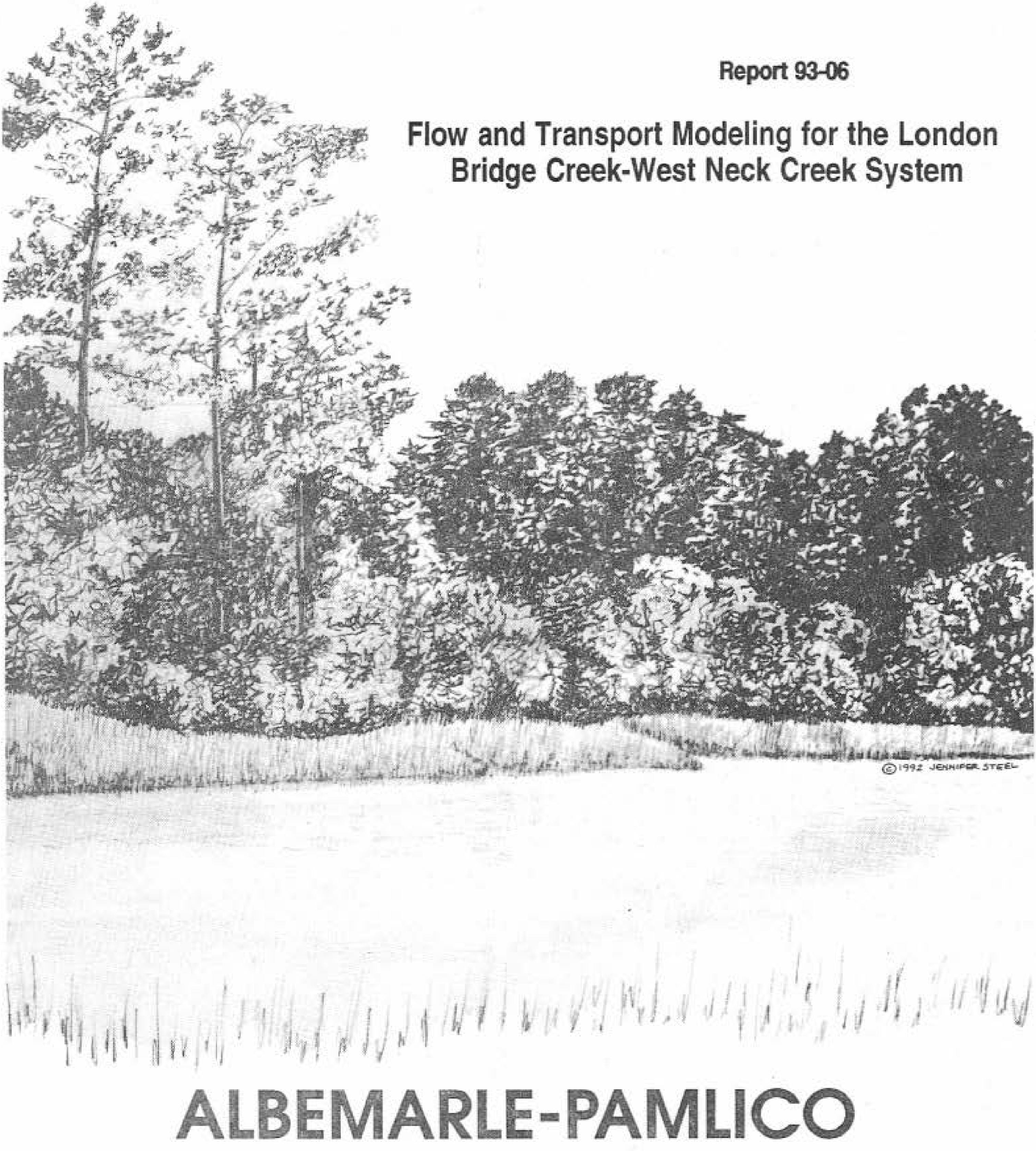
Report 93-06

Flow and Transport Modeling for the London Bridge Creek-West Neck Creek System



ALBEMARLE-PAMLICO ESTUARINE STUDY

NC Department of
Environment, Health,
and Natural Resources

Environmental
Protection Agency
National Estuary Program

Flow and Transport Modeling
for the
London Bridge Creek - West Neck Creek System

by

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Executive Summary

Currituck Sound, located in the northeast corner of North Carolina, consists of about 150 square miles of shallow estuary fed by hundreds of miles of channels, rivers and tributaries draining nearly 700 square miles of North Carolina and southeast Virginia. Currituck Sound connects to the south at the Wright Memorial Bridge with Albemarle Sound and to the west through Coinjock Canal to the North River. Currituck Sound is not directly connected to the Atlantic Ocean, although historically, inlets have occurred along Currituck Banks in several locations. Concern for the water quality in Currituck Sound has been expressed periodically over the past several decades in response to the perception that both natural phenomena and human activity have altered conditions in the Sound. Of current concern and focus is the potential for negative impact on the water quality of the system from the flows coming into the Sound from the highly developed Virginia Beach area. North Landing River branches westward to connect via the Albemarle and Chesapeake Canal to the Elizabeth River and eastward to West Neck Creek. Although the relatively high salinities and low water quality in the Elizabeth River could possibly be of concern, the lock system on the canal prevents continuous exchange of waters from the Elizabeth River to the North Landing River. However, in the eastern branch, the flows through West Neck Creek and London Bridge Creek connecting North Landing River to Lynnhaven Bay are unregulated. In addition, the recent completion of the Virginia Beach Canal Number Two increases the potential for exchange north and south.

The focus of this study is to investigate the potential for significant transport, using salinity as a conservative tracer, between Lynnhaven Bay and the North Landing River. The geographic scope is defined as the North Landing River area, extending from Lynnhaven Bay through London Bridge Creek and West Neck Creek to the mouth of the North Landing River. The objective of the project is to develop, calibrate and verify a computer model which can be used to determine under which conditions transport is achieved along the 23 miles from Lynnhaven Bay to Currituck Sound.

Model results have been presented for three different geometries. In the first of these, in which the model extended from Lynnhaven Bay to the mouth of the North Landing River, no field data exist to establish boundary conditions, and thus the results are uncalibrated. Nevertheless, the results suggest that normal tidal conditions do not cause significant transport through the system, while more extreme events potentially do. In one scenario investigated, 6.56 ft wind tide with a 5 day duration, was required to force the salinity at the mouth of the North Landing River to 20 ppt.

The second model geometry developed was that which described in more detail the reach between Princess Anne Bridge Station and the confluence of West Neck Creek and North Landing River. Using the USGS field data, a calibration exercise was undertaken to determine the flow field necessary in each of the three events to produce the salinity time histories documented at West Neck Bridge. The November 1990 event was characterized by a sustained, relatively large, unidirectional flow north to south for much of the 10 day record. In contrast, the May and June events returned to normal in 2.5 to 3 days, oscillating about zero. These results support the observation noted in the first study that significant transport to the south requires a sustained extreme event.

The third model geometry developed was that which described the reach between West Neck Bridge and the mouth of the North Landing River. The model was executed using the calibrated May and November flow fields in order to assess the potential transport downstream of West Neck Bridge. Again, the November event with sustained unidirectional flows forced the salinity to increase significantly 3.7 miles south of West Neck Bridge while the May flow field did not. Finally, three hypothetical scenarios were constructed to investigate conditions which could cause transport of salinity to the mouth of the North Landing River. Again, only the sustained unidirectional event caused transport to the mouth of North Landing River.

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Introduction

Currituck Sound, located in the northeast corner of North Carolina, consists of about 150 square miles of shallow estuary fed by hundreds of miles of channels, rivers and tributaries draining nearly 700 square miles of North Carolina and southeast Virginia. The sound is primarily fed from the north by the North Landing River, Figure 1. Currituck Sound connects to the south at the Wright Memorial Bridge with Albemarle Sound and to the west through Coinjock Canal to the North River. Currituck Sound is not directly connected to the Atlantic Ocean, although historically, inlets have occurred along Currituck Banks in several locations.

Concern for the water quality in Currituck Sound has been expressed periodically over the past several decades in response to the perception that both natural phenomena and human activity have altered conditions in the Sound. One such natural event was the Ash Wednesday Storm which occurred March 7, 1962 in which Currituck Banks was overwashed bringing ocean strength salinity into the relatively freshwater sound. This served to significantly increase the salinity in the sound and had a long lasting effect (~ 10 years) on the natural ecosystem in the sound.

Of current concern and focus is the potential for negative impact on the water quality of the system from the flows coming into the Sound from the highly developed Virginia Beach area. North Landing River branches westward to connect via the Albemarle and Chesapeake Canal to the Elizabeth River and eastward to West Neck Creek. Although the relatively high salinities and low water quality in the Elizabeth River could possibly be of concern, the lock system on the canal prevents continuous exchange of

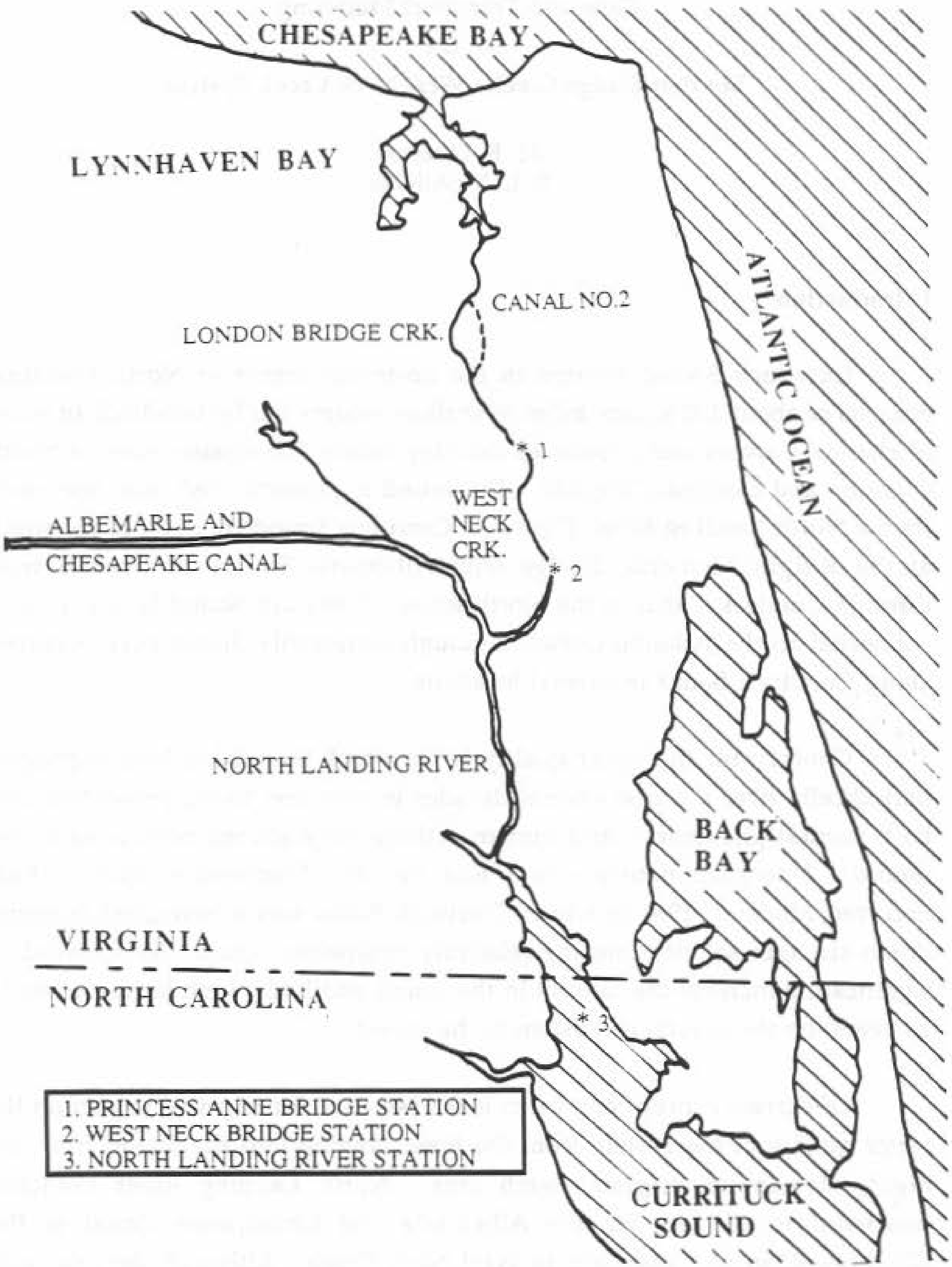

Figure 1. Map of the study area: Lynnhaven Bay to Currituck Sound.

waters from the Elizabeth River to the North Landing River. However, in the eastern branch, the flows through West Neck Creek and London Bridge Creek connecting North Landing River to Lynnhaven Bay are unregulated. In addition, the recent completion of the Virginia Beach Canal Number Two increases the potential for exchange north and south.

The focus of this study is to investigate the potential for significant transport, using salinity as a conservative tracer, between Lynnhaven Bay and the North Landing River. The geographic scope is defined as the North Landing River area, extending from Lynnhaven Bay through London Bridge Creek and West Neck Creek to the mouth of the North Landing River. The objective of the project is to develop, calibrate and verify a computer model which can be used to determine under which conditions transport is achieved along the 23 miles from Lynnhaven Bay to Currituck Sound.

Flow and Transport Model Description

The proposed methodology for this study specified that the WASP4 system, Water Quality Analysis Simulation Program, supported by US Environmental Protection Agency (EPA) would be used to model the system. The general accessibility to and support of the WASP4 model enables the transfer of the use of the system model presented herein to any other user of the WASP4 system. For more information on acquiring and using the WASP4 system, contact the Center for Exposure Assessment Modeling (CEAM), Environmental Research Laboratory, Office of Research and Development, US EPA, Athens, Georgia.

The WASP4 package consists of two independent programs - a hydrodynamics package and a water quality transport package. The hydrodynamic package, DYNHYD, is based on the one dimensional conservation of mass and momentum equations. The water quality package contains two sub-models, EUTRO, built to handle problems concerning dissolved oxygen, biological oxygen demand, nutrients and eutrophication, and TOXI, for organic chemicals, metals, and sediments. In each of the water quality sub-models, the one dimensional mass balance equation for dissolved constituents including advective and dispersive transport; physical, chemical, and biological transformation; and point and non-point source loading is solved. The water quality packages can be run independent of DYNHYD by including flow data in the input file or can be run to read from stage and flow data in the DYNHYD output.

The application of DYNHYD to a real system involves the subdivision (or discretization) of the system geometry into junctions and channels. The channels, a system of idealized three dimensional units with rectangular cross sections, serve to transport water between junctions. Junctions overlay the channels and act as reservoirs of water. The significance of the two is tied to the solution scheme. The equation of motion (conservation of momentum) is solved on the channels to determine water velocities and flows while the equation of continuity (conservation of mass) is solved on the junctions to determine water depths and volumes.

The application of the water quality model requires the subdivision of the system into three dimensional segments which are identified by volume, exchange area and exchange lengths. Segment geometry is identical for both the EUTRO and TOXI sub-models, allowing ease of use of the sub-models when modeling a wide range of constituents. Segments are analogous to DYNHYD junctions both in geometry and in solution methodology. Therefore, segments can be mapped to junctions if DYNHYD is used to determine the system hydrodynamics.

The subdivision of the system into channels junctions, and segments, (length of the channels in DYNHYD and the volumes of the segments in TOXI and EUTRO), influences the time step required for numerical stability and the minimization of numerical dispersion. In general, the controlling factor is the smallest geometric feature modeled, e.g. a short reach within the system that has a narrow cross section. The minimum channel section determines the maximum allowable time step in DYNHYD, while the minimum segment volume determines the time step which in turn influences the magnitude of the numerical dispersion. In addition, equal volume segments are recommended in order to minimize the contribution of numerical dispersion throughout the modeled system (Ambrose, 1988).

Therefore, modeling small geometric features increases the total number of channels, junctions and segments used and can increase both the disk storage space required and the computer run time significantly.

Once the geometry of the system has been determined, the WASP4 model is easily manipulated to simulate a wide range of conditions. DYNHYD is controlled through either flow or stage boundary conditions at the junctions. TOXI and EUTRO are driven by flows, concentration boundary conditions (loading rates), and kinetic reactions. For this study, the TOXI submodel was used to investigate the transport of salt, a conservative substance. However, the model is sufficiently developed to be used in an investigation of a wide variety of water quality parameters, using either TOXI or EUTRO, given the supporting field data required to calibrate and verify the model.

Data Review

In an independent study, sponsored jointly by the Division of Water Resources, NC Department of Environment, Health, and Natural Resources and US Geological Survey (USGS), two data collection stations, stage recorders and conductivity meters, were established in the study area in the fall 1990 (Figure 2). The objective was to define the flow regime of West Neck Creek. Stage gages and conductivity meters were established at the Princess Anne and West Neck Creek Bridges (fall 1990) and an acoustic velocity meter (AVM) was installed at the West Neck Bridge Station (spring 1991) to meet that objective. In addition, a station, consisting of conductivity, temperature and stage recorders, was established in the spring of 1991 in the North Landing River.

In a collaborative effort to support this project, USGS screened the available data for events which indicate transport from north to south. These events were defined by an increase in the salinity first at the Princess Anne Bridge Station followed by a subsequent increase in the salinity at the West Neck Bridge Station. USGS identified and made available three data sets as identified in the Table 1 below. The USGS data presented in this report are at the time of this report "provisional and subject to final approval by the Director of the Geological Survey".

LOCATION	Parameter	11/13 - 30/90	5/17 - 26/91	6/3 - 12/91
Princess Anne Bridge	Salinity	Y	Y	Y
	Stage	Y	NA	NA
West Neck Bridge	Salinity	Y	Y	Y
	Stage	Y	Y	Y
	Flow	NI	NA	NA
North Landing River	Salinity	NI	NA	NA
	Stage	NI	NA	NA

Table 1. USGS field data available for the project in digital format.
Y - data available
NI - station not installed at time of event
NA - data collected but not released by USGS at time of this report

In each event, salinity increased at Princess Anne Bridge by at least 5 ppt over background salinity values and remained high for 6 to 8 days, (Figures 2 - 4). After the initial rise, the tidal influence is apparent with periods of oscillating salinities as much as 2 ppt with an approximate half day cycle. Downstream, at the West Neck Bridge Station, the salinity also increased at least 3 ppt with sustained high salinities for about 4 to 6 days. The largest of the three events, with respect to rise in salinity, is the November 1990 event with an increase in salinity at Princess Anne Bridge of as much as 10 ppt and a corresponding rise at West Neck Creek of 8.5 to 9.0 ppt, Figure 2. Although there is clear evidence that salinity is transported north to south as far as West Neck Creek Bridge, there have been no documented events in which the salinity at the North Landing River station has risen in response to events which have been noted at the Princess Anne and West Neck Creek Stations (verbal communication, Dr. J. Bales, USGS,

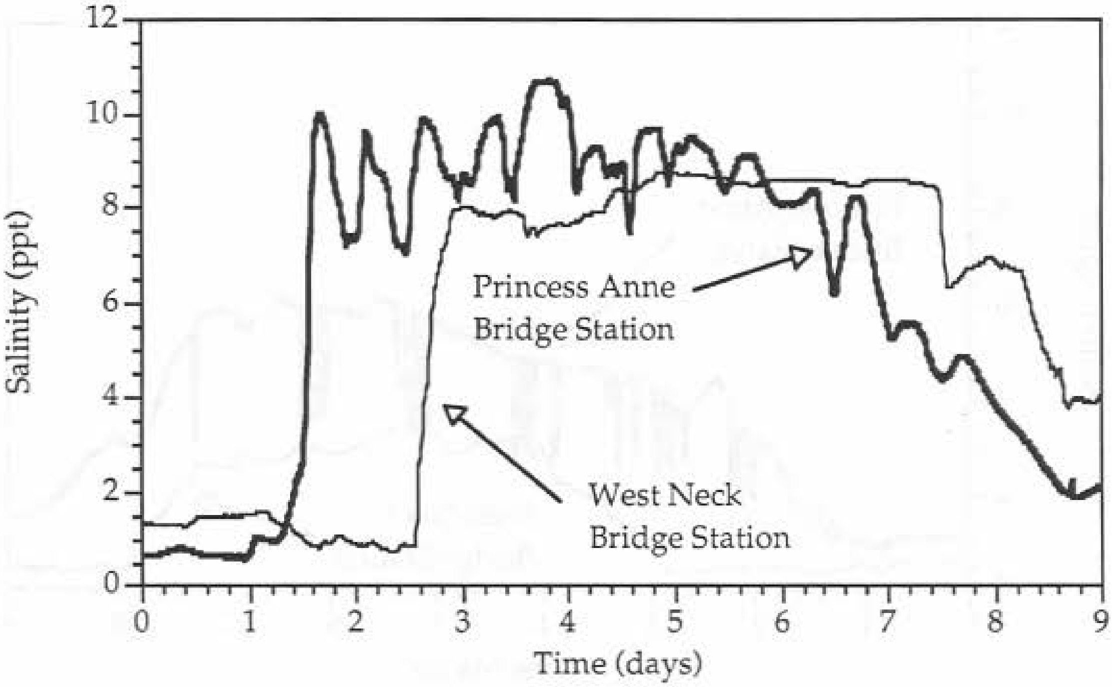

Figure 2. USGS data for November 17 - 25, 1990: salinity versus time.

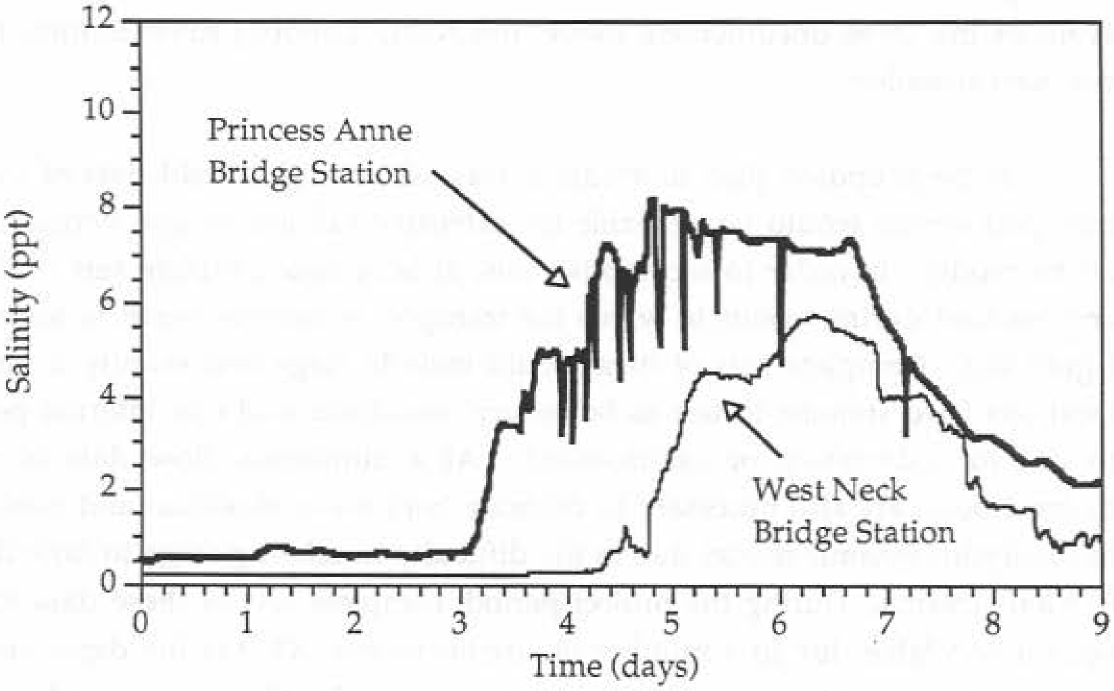

Figure 3. USGS data for May 16 -24, 1991: salinity versus time.

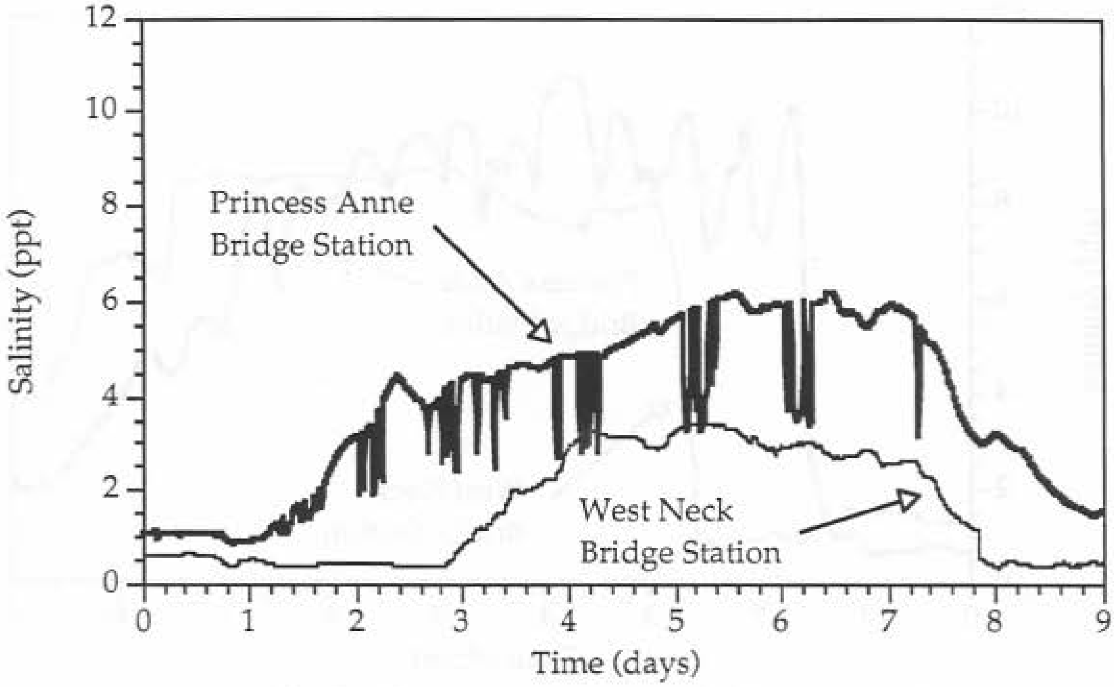

Figure 4. USGS data for June 4 - 12, 1991:
salinity versus time.

January 1992). However, at the time of the November 1990 event, the largest event of the three documented above, the North Landing River Station had not been installed.

In the proposed plan of study, it was assumed that field data of these transport events would be available for extensive calibration and verification of the model. In order to accomplish this, at least two complete sets of data are required during events in which the transport of salinity north to south is significant. Complete sets of data would include stage and salinity at three locations (two stations to use as boundary conditions and one internal point to use for calibration or verification). At a minimum, flow data at the internal point are also necessary to calibrate both water elevation and velocity in the hydrodynamic model due to the difficulty in relating stage to flow data in tidal streams. During the project period, complete sets of these data have been unavailable due to a number of circumstances. One is the dependence on nature to produce a significant transport event. The first and largest of the transport events occurred soon after the installation of the stage and conductivity stations in West Neck Creek but before the installation of the AVM at West Neck Creek and the North Landing River Station. Only two more significant events occurred in a time frame in which the data could be used for this project. There is an unavoidable delay between the time of collection of field data and the interpretation and release of that data. As an example, the stage data describing the May and June events between Princess Anne Bridge and West Neck Creek Bridge were unavailable at the time of this report (verbal communication, Dr. J. Bales, USGS, January 1992). In addition, the flow data were collected using a new device (the AVM) which led to delays in the calibration, interpretation and subsequent release of the data. Therefore, this study was constrained in the development, calibration, and verification of the model to the use of the available field data.

Model Development

In order to build the model, (define channels, junctions and segments) the channel cross sections were estimated from USGS topographic maps and physical surveys performed by the US Army Corps of Engineers (US Army Corps of Engineers, 1979). While these data cover most of the study area, the southernmost channel estimates were made based on the top width of the channel and the standard dredging depth for the channel based on the data of the northern channels. Most of the channel sections are unmaintained channels with irregular cross sections. DYNHYD accepts rectangular sections as approximations to the natural geometry. For each section, the depth is assumed to be that of the natural channel as specified in the Corps data but the width is selected such that the conveyance or carrying capacity of the rectangular section matches that of the natural section. This approximate description of the geometry should be recognized as a potential source of error in the model simulation results.

A general overview of the geometry is as follows. The first 3 miles of the system are wide, beginning with a width of about 165 ft at the mouth of the Eastern Branch of the Lynnhaven River narrowing through London Bridge Creek to about 65 ft. Depths average about 8 ft. At the 3 mile mark the system splits at the new Virginia Beach Canal Number Two which parallels the original channel. Both branches are about 2.5 miles in length but the eastern branch (Canal Number Two) has been widened to about 80 ft. West Neck Creek, south of the confluence of the two canals, is relatively narrow, 25 ft, but broadens to 70 ft 3.5 miles downstream. Depths in this reach are about 6 ft. This section is just upstream of the Princess Anne Bridge Station. Between Princess Anne and the West Neck Creek Station, about 5 miles apart, the depths average 6.5 ft and the width varies from about 65 ft to about 200 ft. Approximately 1.7 miles downstream of the West Neck Bridge, West Neck Creek flows into North Landing River. The model extends about 7 miles south along North Landing River until it widens significantly and feeds into Currituck Sound.

The geometry of the system from Lynnhaven Bay to Currituck Sound has been subdivided into several schemes to use as input to the WASP4 model. The first of these was a fairly course grid, with 27 channels, junctions and segments, (see Appendix A for details of the geometry), (Willis, 1990). This work was conducted prior to the installation of the USGS field stations. The focus was to explore the use of WASP4 in a modeling effort to determine the magnitude and duration of an individual storm event required to cause transport of salt north to south from Lynnhaven Bay to the mouth of the North Landing River. In each of these simulations, DYNHYD was used to determine the flow field and elevations and was coupled to TOXI to drive the transport. Four hypothetical scenarios, outlined in Table 2, were investigated. The scenarios were developed to provide a range of conditions from 'normal tidal' flows to 'storm events'. For each scenario, the range and period of the tidal head in Lynnhaven Bay was varied while the salinity was asssumed to be a constant 20 ppt. Results from these simulations are summarized in Table 3. Details of the study can be found in Willis, 1990.

The normal tide condition, 1.7 ft range and 12.5 hour period, failed to increase the salinity more than 2 ppt from Princess Anne Bridge south. These results are consistent with the field data. Background conditions at the Princess Anne Station vary between 0 and 2 ppt before and after the events documented in Figures 2, 3 and 4.

CASE	DESCRIPTION
1	Normal tide conditions with a range of 1.7 ft and period of 12.5 hrs.
2	Simulated extreme storm event with a 6.56 ft elevation difference between the boundary at Lynnhaven Bay and Currituck Sound, rising and falling in 5 days.
3	Simulated storm event with 3.28 ft elevation difference between the two boundaries and a 5 day duration.
4	Simulated storm event with 3.28 ft elevation difference between the two boundaries and a 2.5 day duration.

Table 2. Hypothetical scenarios used to investigate possible transport from Lynnhaven Bay to Currituck Sound.

Both Case 2 and Case 3, simulated storm events with a 5 day duration and 6.56 ft and 3.28 elevation range respectively, indicate that transport of salt water with a strength of 20 ppt will occur as far south as both Princess Anne Bridge and West Neck Bridge. However, in Case 3, the weaker of the two events, salinity drops off sharply downstream of West Neck Bridge, approaching the confluence of West Neck Creek with North Landing River.

CASE	PRINCESS ANNE BRIDGE	WEST NECK BRIDGE	NORTH LANDING RIVER
1	<2	<1	0
2	20	19	17
3	19.5	19	2.5
4	14	7	0

Table 3. Maximum salinity in parts per thousand at three locations based on the four hypothetical scenarios modeled by Willis, 1990.

Case 4, a 2.5 day simulated storm event with a 3.28 ft range forced saline waters of 14 ppt as far downstream as Princess Anne Bridge; however, salinities never exceed 7 ppt at the West Neck Bridge Station. Downstream of this point, the salinities decrease to 0 at the North Landing River.

These results are shown as examples of the type of scenarios DYNHYD and TOXI can model. These model results are uncalibrated and could have significant errors in the magnitude of the values obtained.

Model Calibration

The three field stations were intended to provide data for model calibration. The data taken at Princess Anne Bridge and the North Landing River stations were to be used as boundary conditions to drive the model and the data from the West Neck Creek Bridge station would serve as interior check points. Therefore, a second model was generated which extends from Princess Anne Bridge to the confluence of the North Landing River (see Appendix A). In order to carefully model the geometry between the two stations, the grid generated by Willis in this region was subdivided into smaller sections utilizing all of the Corps section data. In addition certain sections of the original grid system were subdivided to create segments of constant volume in order to minimize numerical dispersion.

Due to the lack of a complete set of stage and discharge field data to first calibrate and verify the DYNHYD submodel, TOXI was used for these studies as a stand alone package. The use of TOXI in this mode requires that input the flow field is specified throughout the system as a function of time. Note that flow data was not available for any of the three events. Therefore, the time of travel of salt between the two field stations was determined from the field data and velocity was calculated as distance between the stations divided by travel time. This value served as a first estimate of the flow conditions which caused the transport shown in the field data. In this sense, the calibration of the model depended entirely on the specification of the flow boundary condition. Given the necessary flow field data, this is an unnecessary exercise. In the absence of these data, this exercise provides a first estimate at the type of event which caused the documented transport. The flow time histories required to best fit the field data are plotted in Figures 5 - 7. Flow from the north to the south is plotted as positive. Note, TOXI assumes a linear fit between specified data points. Because this was a calibration effort, the model results and field data compare very well, (Figures 8 - 10).

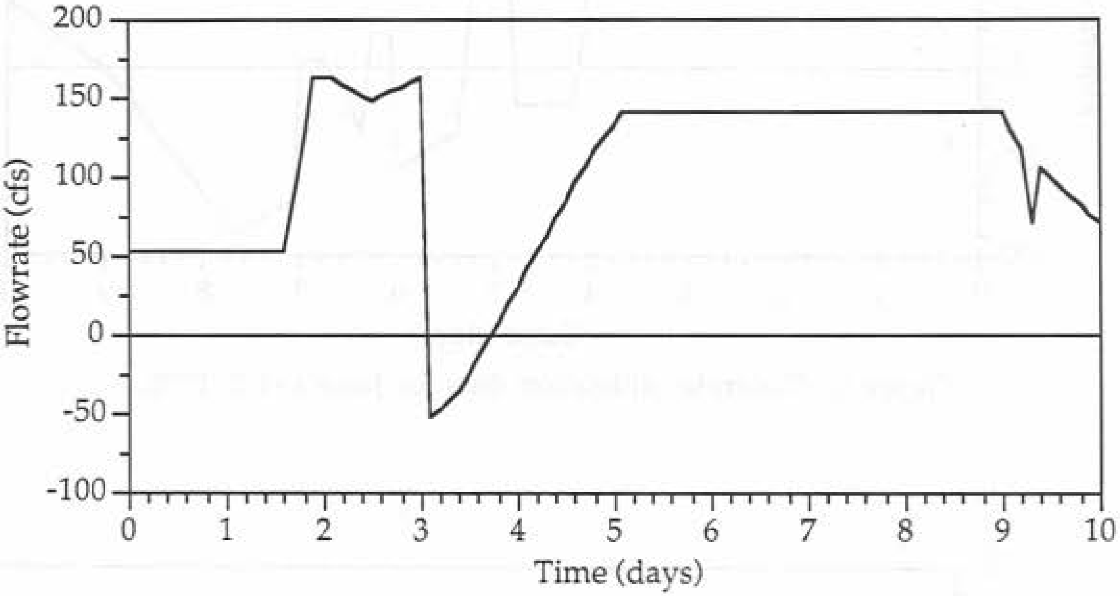

Figure 5. Flowrate calibration data for November 17 - 25, 1990.

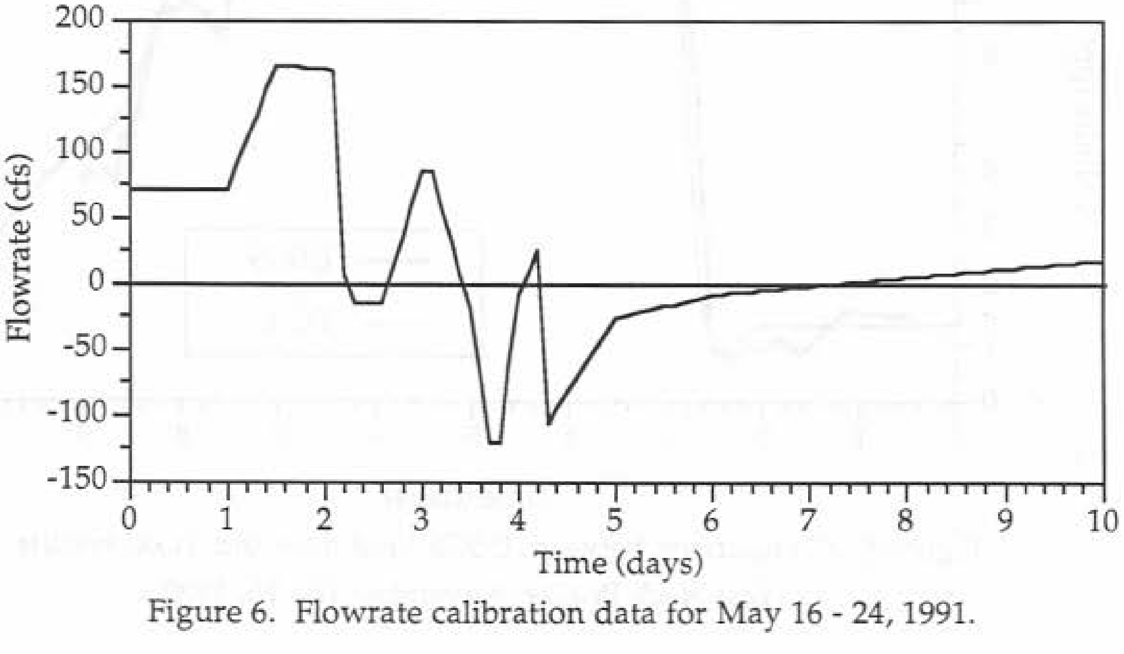

Figure 6. Flowrate calibration data for May 16 - 24, 1991.

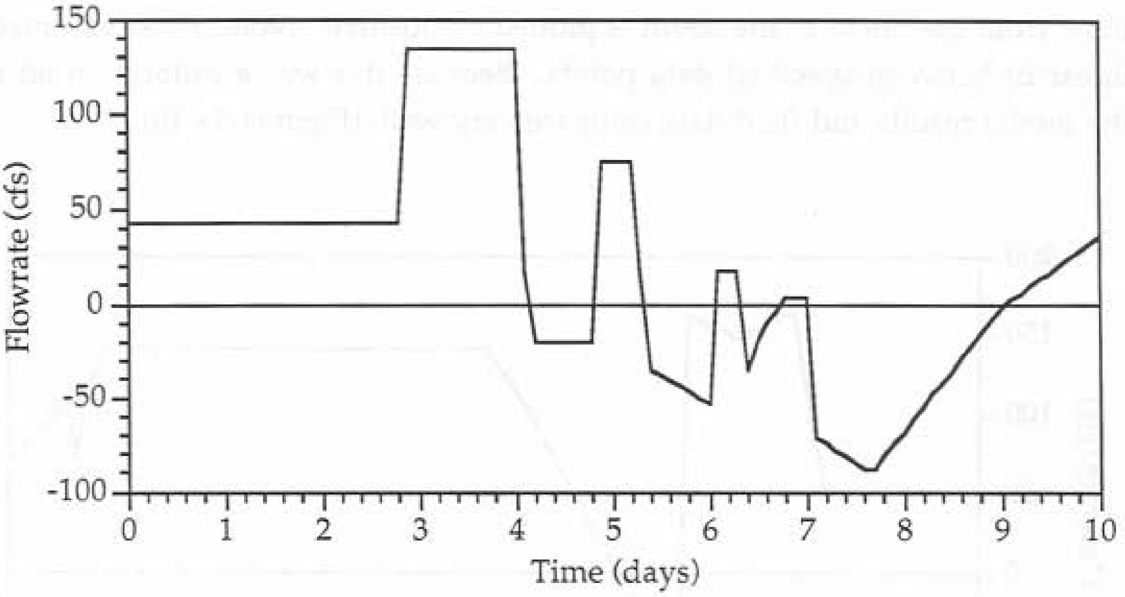

Figure 7. Flowrate calibration data for June 4 -1 2, 1991.

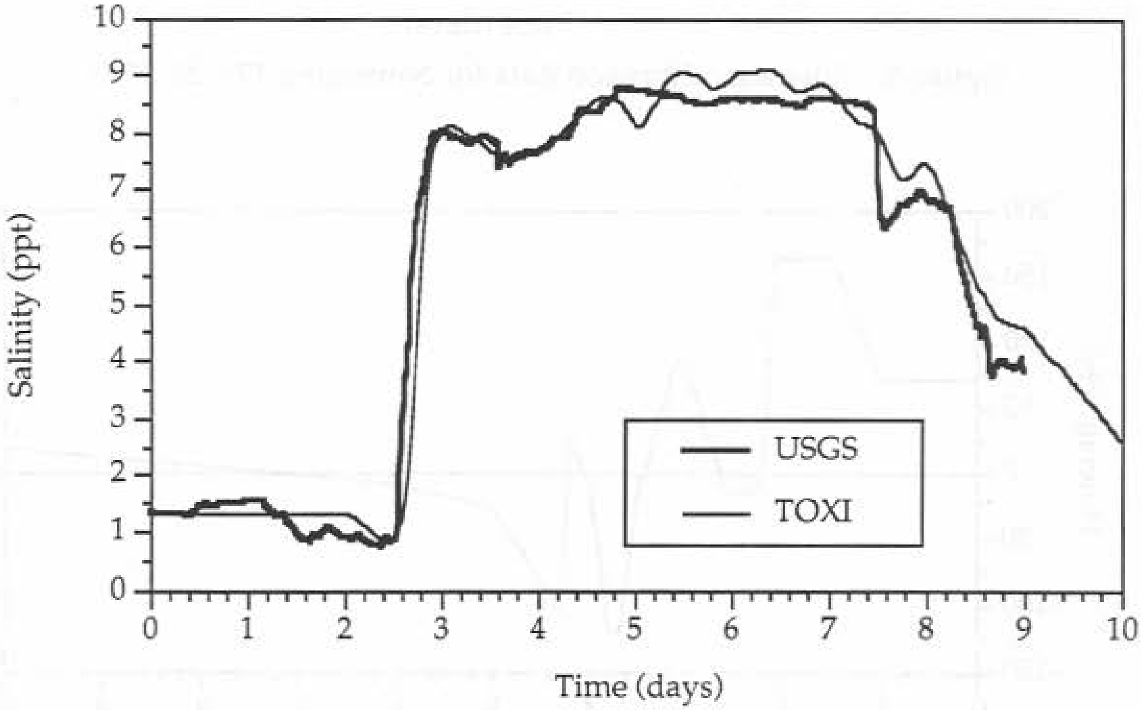

Figure 8. Comparison between USGS field data and TOXI results at West Neck Bridge: November 17 - 25, 1990.

Examining the calibrated flow data, the November event is distinct from the May and June events. The November event is characterized by high flow rates (~ 162 cfs north to south) which persist for a full day followed by a reversal of the flow with 25% of the strength of the north to south flow for about 0.5 days. This is followed by flow north to south with about 85% of the original flow rate and is sustained for about 4 days. The flowrate drops to 50% of the maximum but maintains a north to south orientation for the duration of the event. The strength of the November event and the suggestion that the event is essentially unidirectional can also be seen by comparing the field data at Princess Anne Bridge Station and West Neck Creek Station. By examining the area under the curve (salinity versus time, Figure 2), it is noted that nearly all of the salt that was transported past the Princess Anne Station was also transported downstream of the West Neck Creek Station. This is characteristic of a sustained unidirectional flow.

In contrast, the May and June events are characterized by initial north to south flows of large magnitude sustained for about half a day followed by a series of flow reversals with a half day period, Figures 6 and 7. Though the

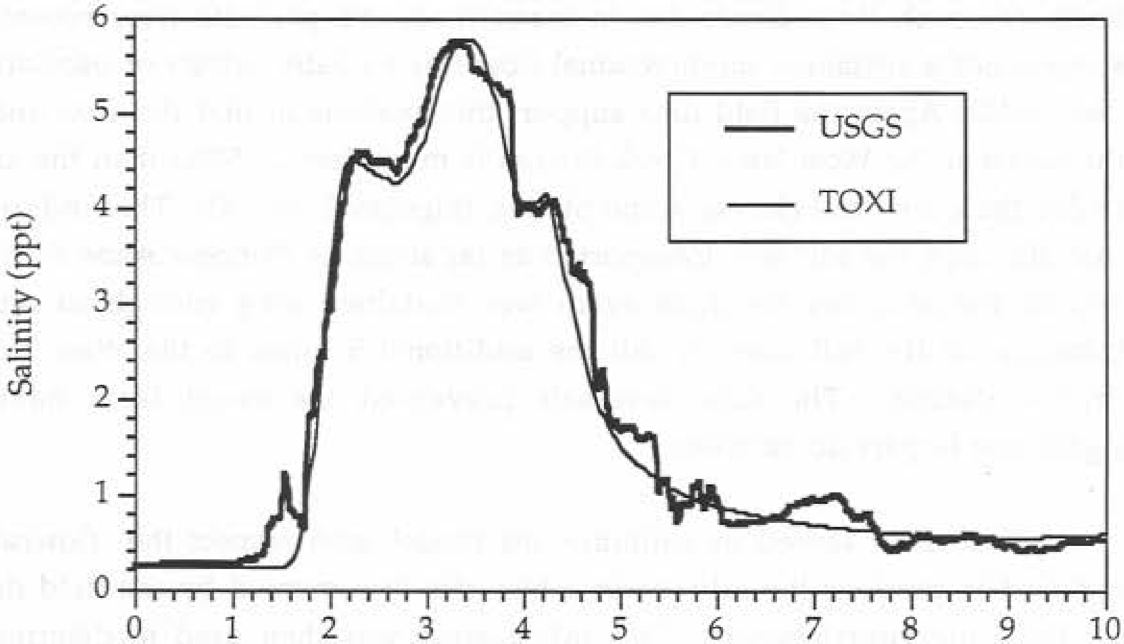

Figure 9. Comparison between USGS field data and TOXI results at West Neck Bridge: May 16 - 24, 1991.

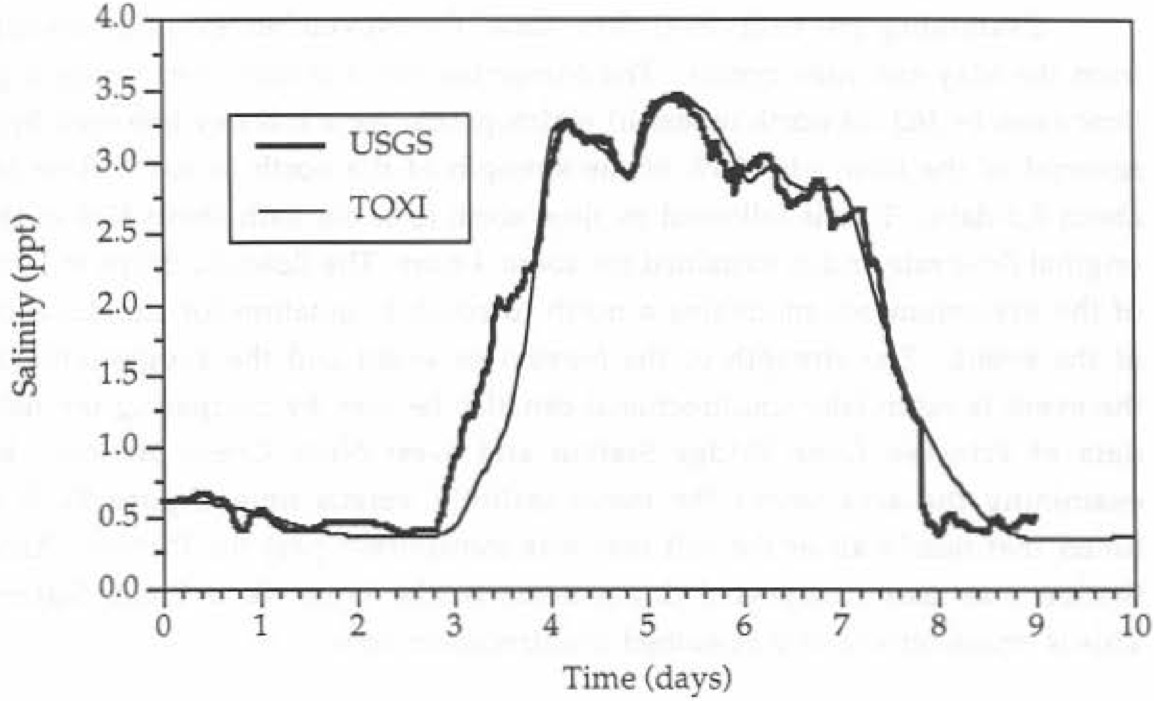

Figure 10. Comparison between USGS field data and TOXI results at West Neck Bridge: June 4 - 12, 1991.

north to south flow dominates in magnitude, the periodic flow reversals suggest not a sustained unidirectional flow but a tidally driven or oscillating flow field. Again the field data support this analysis in that the area under the curve at the West Neck Creek Station is much less (~ 50%) than the area under the curve at Princess Anne Station (Figures 3 and 4). This indicates that although the salt was transported as far south as Princess Anne Bridge, neither the May nor the June event was sustained long enough to cause transport of the full mass of salt the additional 5 miles to the West Neck Bridge Station. The flow reversals prevented the event from having significant impact downstream.

This effort served to 'calibrate' the model with respect the flowrates required to produce the salinity time histories documented by the field data for three individual events. This information was then used to determine the transport of salt downstream of the calibrated model domain. This approach is was necessitated by the limited amount of data available for model calibration and verification and is not generally recommended.

Model Application

While the model may be considered to be calibrated only between Princess Anne Bridge and West Neck Creek Bridge (for only a small range of events), the original scope of the project included using the model to determine transport as far south as North Landing River. Therefore, the following exercise was undertaken. The original coarse grid developed by Willis was subdivided into seventy segments to model the 8.7 mile reach between the West Neck Bridge Station and the mouth of the North Landing River at Currituck Sound, (Appendix A). Approximately 1.7 miles south of the West Neck Bridge Station, West Neck Creek flows into North Landing River. The May 1991 and November 1990 data were simulated as examples of two different type events - one, in which the flow is essentially unidirectional and two, in which the flow oscillates with a period approximately equal to the tidal period. In each case, the flow field calibrated from the simulations between the Princess Anne and West Neck Bridge stations along with the concentration provided by the field data at West Neck Bridge were used as boundary conditions. Initial salinities were taken to vary linearly from about 1.5 ppt at West Neck Bridge to 0 ppt at the mouth of the North Landing River. Simulation results were analyzed to determine the extent to which salinity was transported downstream of West Neck Bridge. These data were then compared with the observation (Bales, USGS) that salinities have not significantly increased at the North Landing River Station during the period of this project.

Salinity time histories from TOXI results at two locations, 0.95 and 1.15 miles downstream of West Neck Creek Bridge, in response to the May simulation are provided in Figure 11. The concentration boundary condition at West Neck Creek varies from less than 1 ppt to 4.5 ppt in 0.5 days with a peak of 5.5 ppt 1 day later (Figure 4). The concentration then falls to about 1 ppt in an additional 2 days. One mile downstream of this station the salinities do not rise above 1.2 ppt, though the concentration variation in time mimics the boundary condition. Further downstream the salinities are negligible. These models results are consistent with the observation that salinities did not increase at the North Landing River Station at any point during the study period.

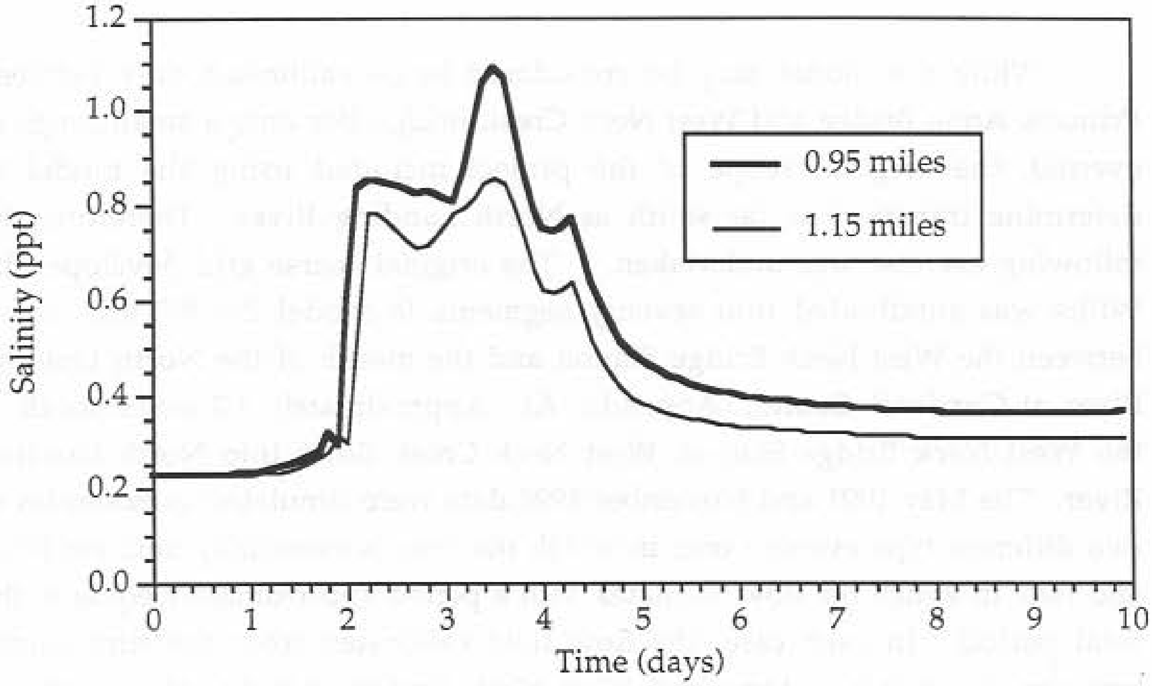

Figure 11. TOXI results downstream of West Neck Creek Bridge Station for the May 1991 event.

The November 1990 event was modeled in a similar manner. The flow field calibration data along with the salinity time history at West Neck Creek were used to drive the simulation. The results indicate that at a point midway between West Neck Creek Bridge and the mouth of the North Landing River, the salinity begins to increase on day 7, reaches a peak of about 8 ppt on day nine and does not begin to fall in the 10 day simulation. This result is shown in Figure 12. This observation led to the speculation about the impact on salinity downstream of this point for longer simulations. Therefore, the simulation was extending by first assuming that the unidirectional flow shown in Figure 5 between day 5 and day 9 continued for ten additional days before falling off. Model results indicate that salinity is driven through the system to the mouth of the North Landing River, Figure 12. This is not surprising considering the strength and duration of the forcing field.

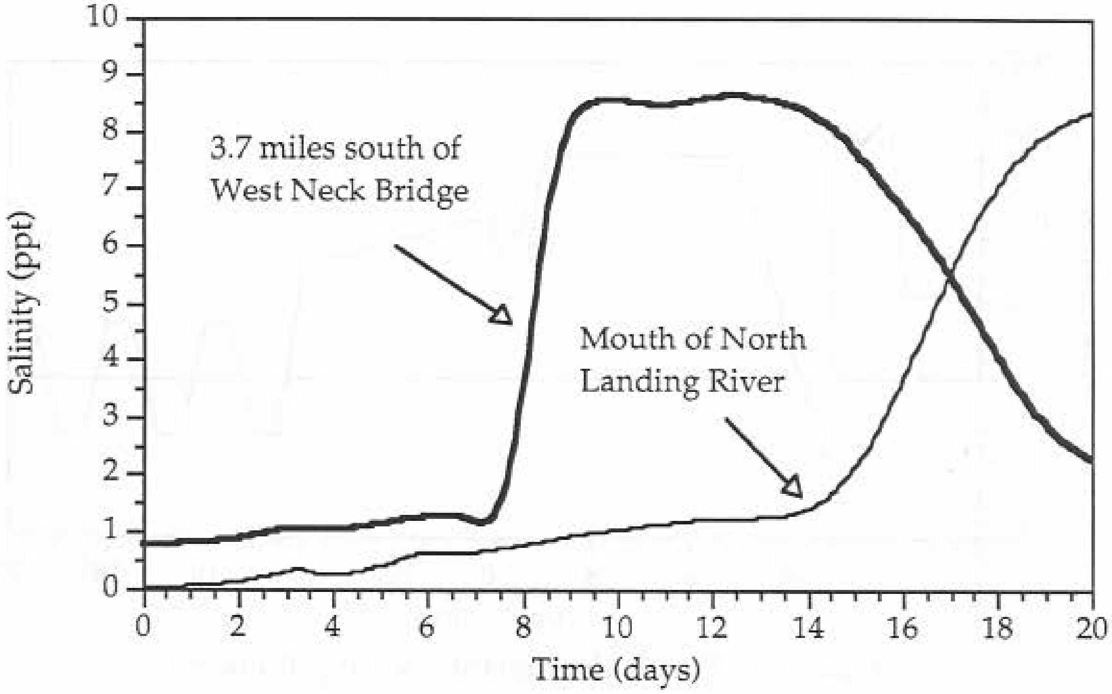

Figure 12. TOXI results at two locations downstream of West Neck Bridge Station for the November 1990 event.

Additional flow field scenarios were developed to determine the impact of milder flow conditions on the downstream salinity. The second flow field assumed flows remained at a moderate level north to south for 4 additional days following the 10 day documented event. This was followed by 6 days of oscillating flows (with a 24 hour period) with an equal balance between transport to the north and to the south, Figure 13.

Two miles downstream of West Neck Bridge the salinities rise and fall with the same signature of the upstream conditions, Figure 14. At 3.7 and 5.7 miles the salinity rises just over 8 ppt and only slightly falls off in the following 6 - 10 days. However, downstream an additional 1.1 miles the salinities increase to just 5 ppt and oscillate between 4 and 5 ppt for the remaining 5 days. Apparently the mass of salinity was transported downstream at least 2 miles and was impeded somewhere between mile 3.7 and mile 5.7. When the flows decreased, transport to the south decreased, and as flows began to oscillate with equal intensity north and south, the mass of salinity obtains negligible net transport in either direction. Further

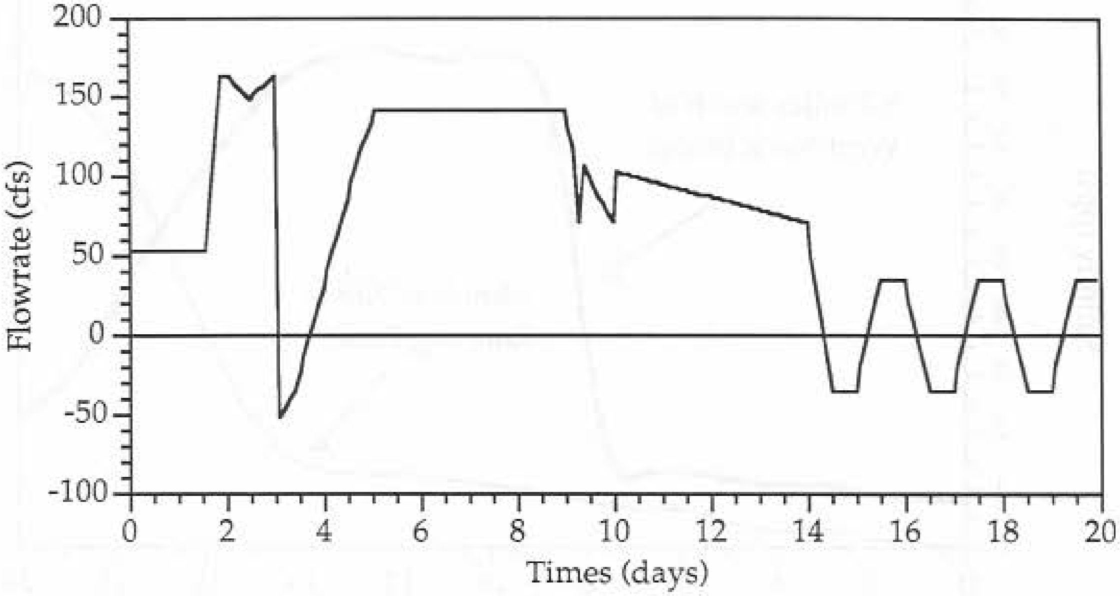

Figure 13. Flow field scenario two: equal intensity of flow north and south.

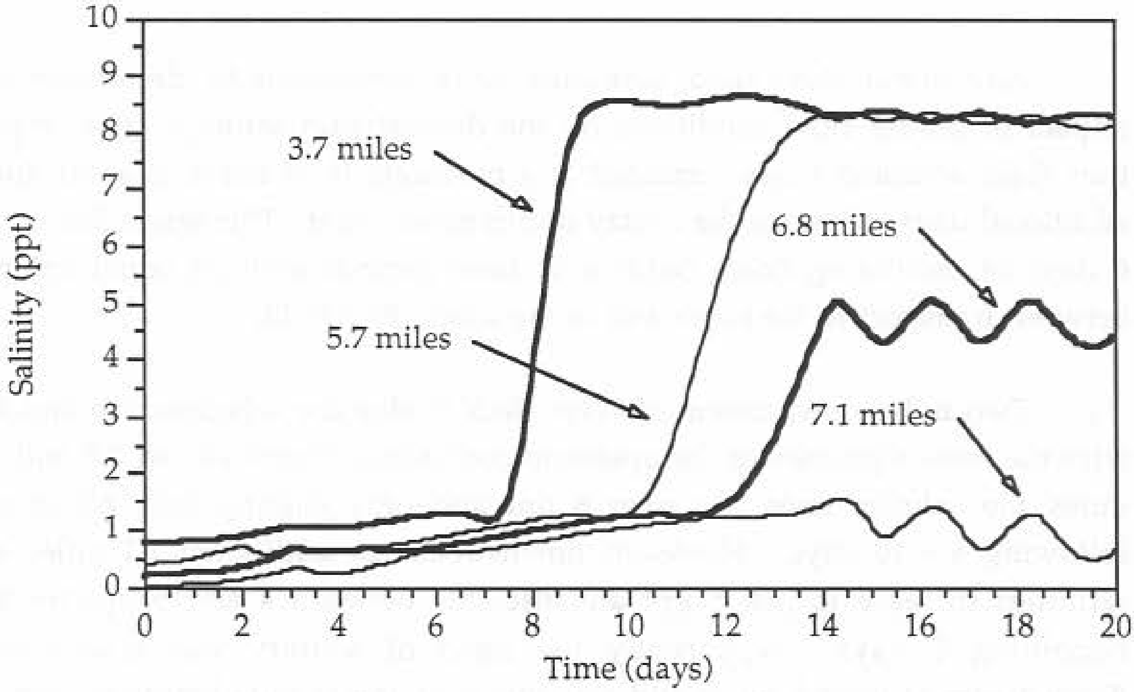

Figure 14. TOXI results for flow field scenario two at four downstream positions.

downstream, 7.1 miles from West Neck Bridge, salinities reach a maximum of approximately 1.5 ppt at about day 14.5 and then decrease as the flow reverses and brings fresher water from the southern boundary to the north.

A final hypothetical flow field was developed in which flows returned to 'normal' immediately following the 10 day event. Normal flows were defined to oscillate with a 0.5 day period (tidal driven) with the predominant flow south to north, Figure 15. Again, the flow field is strong enough to drive the high salinities (greater than 8 ppt) as far south as 5.7 miles but when flow conditions return to normal, the transport of the mass of salinity south is reversed (Figure 16). With normal flows biased to the north (35 cfs to the north versus 21 cfs to the south), the mass of salinity downstream of West Neck Bridge is slowly being pushed north by advective flows. Note that the salinity at miles 2.1 and 3.7 begins to increase again after day 14.5 as net transport is returned to the north.

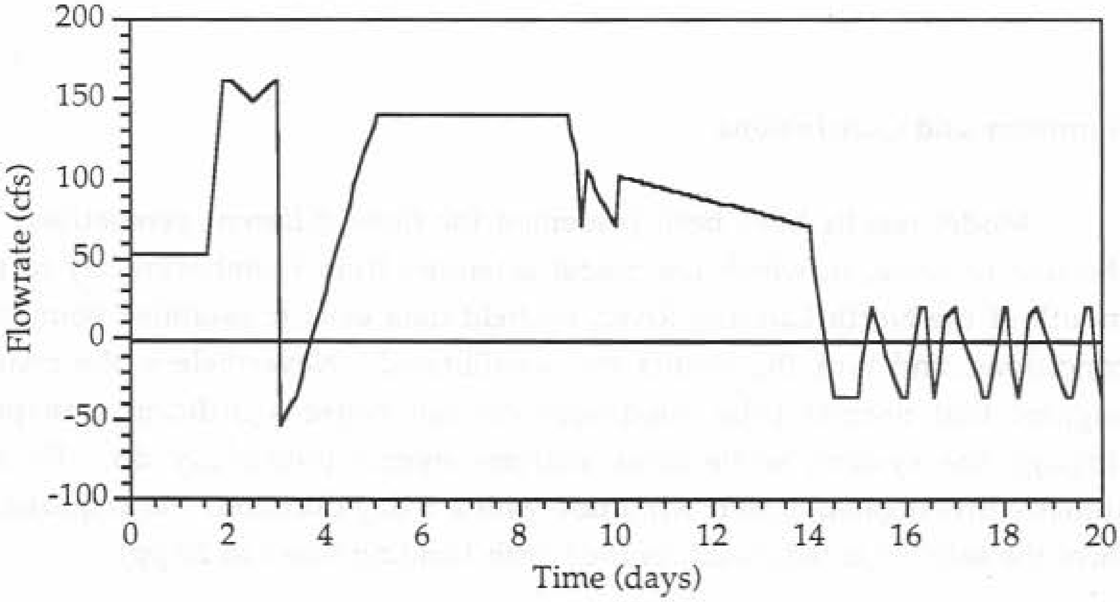

Figure 15. Flow field scenario three: predominant flow south to north.

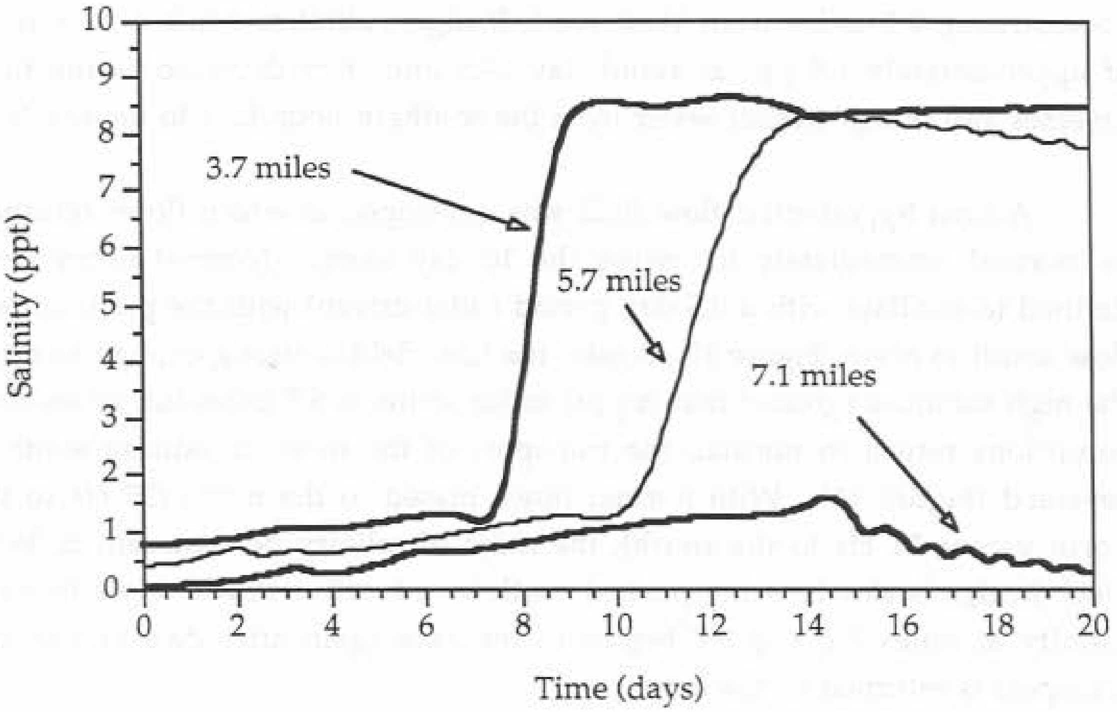

Figure 16. TOXI results for flow field scenario three at three downstream locations.

Summary and Conclusions

Model results have been presented for three different geometries. In the first of these, in which the model extended from Lynnhaven Bay to the mouth of the North Landing River, no field data exist to establish boundary conditions, and thus the results are uncalibrated. Nevertheless, the results suggest that normal tidal conditions do not cause significant transport through the system, while more extreme events potentially do. In one scenario investigated, 6.56 ft wind tide with a 5 day duration, was required to force the salinity at the mouth of the North Landing River to 20 ppt.

The second model geometry developed was that which described in more detail the reach between Princess Anne Bridge Station and the confluence of West Neck Creek and North Landing River. Using the USGS field data, a calibration exercise was undertaken to determine the flow field necessary in each of the three events to produce the salinity time histories documented at West Neck Bridge. The November 1990 event was characterized by a sustained, relatively large, unidirectional flow north to south for much of the 10 day record. In contrast, the May and June events returned to normal in 2.5 to 3 days, oscillating about zero. These results support the observation noted in the first study that significant transport to the south requires a sustained extreme event.

The third model geometry developed was that which described the reach between West Neck Bridge and the mouth of the North Landing River. The model was executed using the calibrated May and November flow fields in order to assess the potential transport downstream of West Neck Bridge. Again, the November event with sustained unidirectional flows forced the salinty to increase significantly 3.7 miles south of West Neck Bridge while the May flow field did not. Finally, three hypothetical scenarios were constructed to investigate conditions which could cause transport of salinity to the mouth of the North Landing River. Again, only the sustained unidirectional event caused transport to the mouth of North Landing River.

In conclusion, the WASP4 system was found to be a viable model for investigating potential transport in the West Neck Creek - North Landing River system. Unfortunately, the model could not be completely calibrated and verified at the time of this project due to the lack of a sufficient data set for that exercise.

REFERENCES

Ambrose, R. B., et. al., *WASP4, A Hydrodynamic and Water Quality Model - Model Theory, User's Manual, and Programmer's Guide,* US EPA Environmental Research Laboratory, Athens, Georgia, 1988.

US Army Corps of Engineers, Unpublished Data, 1979.

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APPENDIX A

MODEL GEOMETRY

Model Geometry

Model geometry is presented for the three sets of simulations discussed - a coarse grid for the system from Lynnhaven Bay to the mouth of the North Landing River and finer grids for a) the reach between Princess Anne Bridge and West Neck Bridge and b) the reach from West Neck Bridge to the mouth of the North Landing River. The units in these tables are metric because these are the original units of the DYNHYD and TOXI input files.

COURSE GRID GEOMETRY
EXTENDING FROM LYNNHAVEN BAY TO NORTH LANDING RIVER

CHANNEL NUMBER	LENGTH (m)	WIDTH (m)	DEPTH (m)	SEGMENT NUMBER	SEGMENT VOLUME (cms)
1	2000	50	2.5	1	125000
2	1000	43	2.5	2	178750
3	305	30	2.5	3	47437
4	640	45	2.5	4	45097
5	960	40	2.5	5	67200
6	500	15	2.5	6	45900
7	2185	25	2.0	7	64688
8	2000	25	2.0	8	160970
9	1710	18	1.5	9	180850
10	855	26	1.5	10	39623
11	1880	17	2.4	11	40650
12	1060	8	1.5	12	30330
13	670	6	1.5	13	6863
14	1885	11	1.5	14	18725
15	2030	21	1.5	15	64400
16	545	27	1.5	16	58400
17	2970	30	2.0	17	103800
18	1100	38	2.0	18	130900
19	1920	52	2.0	19	194755
20	1620	67	2.0	20	334320
21	2500	33	2.0	21	222775
22	1280	35	3.5	22	300300
23	3170	40	3.5	23	298900
24	1100	40	3.5	24	215600
25	1980	40	3.5	25	262500
26	1770	40	3.5	26	179550
27	795	40	3.5	27	556500

GEOMETRY FOR SUB - MODEL A
EXTENDING FROM PRINCESS ANNE BRIDGE STATION TO THE CONFLUENCE OF WEST NECK CREEK AND NORTH LANDING RIVER

CHANNEL NUMBER	LENGTH (m)	WIDTH (m)	DEPTH (m)	SEGMENT NUMBER	SEGMENT VOLUME (cms)
1	351	17	1.5	1	10121
2	305	17	1.8	2	10029
3	308	17	1.8	3	9379
4	305	17	1.8	4	9379
5	308	17	1.8	5	9379
6	308	17	1.8	6	9425
7	271	17	1.8	7	8859
8	299	17	1.8	8	8715
9	299	17	1.8	9	9137
10	299	17	1.8	10	9137
11	299	17	1.8	11	9137
12	299	17	1.8	12	9137
13	290	17	1.8	13	9006
14	358	17	1.8	14	9914
15	299	14	1.5	15	8474
16	360	17	1.8	16	8502
17	180	33	1.8	17	10846
18	180	33	1.8	18	10675
19	180	33	1.8	19	10675
20	180	33	1.8	20	10675
21	180	33	1.8	21	10675
22	180	33	1.8	22	10675
23	180	33	1.8	23	10675
24	92	63	1.8	24	10546
25	92	63	1.8	25	10417
26	92	63	1.8	26	10417
27	92	63	1.8	27	10417
28	92	63	1.8	28	10417
29	92	63	1.8	29	10417
30	92	63	1.8	30	10417
31	92	63	1.8	31	10417
32	92	63	1.8	32	10417
33	92	63	1.8	33	10417
35	92	63	1.8	34	10417
36	92	63	1.8	35	10417

GEOMETRY FOR SUB - MODEL A
EXTENDING FROM PRINCESS ANNE BRIDGE STATION TO THE CONFLUENCE OF WEST NECK CREEK AND NORTH LANDING RIVER
(CONTINUED)

CHANNEL NUMBER	LENGTH (m)	WIDTH (m)	DEPTH (m)	SEGMENT NUMBER	SEGMENT VOLUME (cms)
37	92	63	1.8	36	10417
38	92	63	1.8	37	10417
38	69	75	2.1	38	10417
39	69	75	2.1	39	10720
40	69	75	2.1	40	10938
41	69	75	2.1	41	10938
42	69	75	2.1	42	10938
43	69	75	2.1	43	10938
44	69	75	2.1	44	10938
45	69	75	2.1	45	10938
46	69	75	2.1	46	10938
47	69	75	2.1	47	10938
48	69	75	2.1	48	10938
49	69	75	2.1	49	10938
50	69	75	2.1	50	10938
51	69	75	2.1	51	10938
52	69	75	2.1	52	10938
53	69	75	2.1	53	10938
54	69	75	2.1	54	10938
55	69	75	2.1	55	10938
56	69	75	2.1	56	10938
57	69	75	2.1	57	10938
58	69	75	2.1	58	10938
59	69	75	2.1	59	10938
60	69	75	2.1	60	10938
61	69	75	2.1	61	10938
62	69	75	2.1	62	10938
63	69	75	2.1	63	10938
64	69	75	2.1	64	10938
65	69	75	2.1	65	10938
66	69	75	2.1	66	10938
67	69	75	2.1	67	10938
68	69	75	2.1	68	10938
69	69	75	2.1	69	10938

GEOMETRY FOR SUB - MODEL A
EXTENDING FROM PRINCESS ANNE BRIDGE STATION TO THE CONFLUENCE OF WEST NECK CREEK AND NORTH LANDING RIVER
(CONTINUED)

CHANNEL NUMBER	LENGTH (m)	WIDTH (m)	DEPTH (m)	SEGMENT NUMBER	SEGMENT VOLUME (cms)
70	69	75	2.1	70	10938
71	69	75	2.1	71	10938
72	69	75	2.1	72	10938
73	69	75	2.1	73	10938
74	34	85	3.4	74	9735
75	34	85	3.4	75	9735
76	34	85	3.4	76	9735
77	34	85	3.4	77	9735
78	34	85	3.4	78	9735
79	34	85	3.4	79	9735
80	34	85	3.4	80	9735
81	34	85	3.4	81	9735
82	34	85	3.4	82	9735
83	34	85	3.4	83	9735
84	34	85	3.4	84	9735

GEOMETRY FOR SUB - MODEL B
EXTENDING FROM THE WEST NECK BRIDGE STATION TO THE MOUTH OF THE NORTH LANDING RIVER

CHANNEL NUMBER	LENGTH (m)	WIDTH (m)	DEPTH (m)	SEGMENT NUMBER	SEGMENT VOLUME (cms)
1	307.6	75	2.1	1	48443
2	307.6	75	2.1	2	48443
3	307.6	75	2.1	3	48443
4	307.6	75	2.1	4	48443
5	307.6	75	2.1	5	48443
6	307.6	75	2.1	6	48443
7	307.6	75	2.1	7	48443
8	160	85	3.4	8	50418
9	160	85	3.4	9	46240
10	160	85	3.4	10	46240
11	160	85	3.4	11	46240
12	160	85	3.4	12	46240
13	160	85	3.4	13	46240
14	160	85	3.4	14	46240
15	160	85	3.4	15	46240
16	158.5	85	3.4	16	46023
17	158.5	85	3.4	17	45807
18	158.5	85	3.4	18	45807
19	158.5	85	3.4	19	45807
20	158.5	85	3.4	20	45807
21	158.5	85	3.4	21	45807
22	158.5	85	3.4	22	45807
23	158.5	85	3.4	23	45807
24	158.5	85	3.4	24	45807
25	158.5	85	3.4	25	45807
26	158.5	85	3.4	26	45807
27	158.5	85	3.4	27	45807
28	158.5	85	3.4	28	45807
29	158.5	85	3.4	29	45807
30	158.5	85	3.4	30	45807
31	158.5	85	3.4	31	45807
32	158.5	85	3.4	32	45807
33	158.5	85	3.4	33	45807
34	158.5	85	3.4	34	45807
35	158.5	85	3.4	35	45807

GEOMETRY FOR SUB - MODEL B EXTENDING FROM THE WEST NECK BRIDGE STATION TO THE MOUTH OF THE NORTH LANDING RIVER (CONTINUED)

CHANNEL NUMBER	LENGTH (m)	WIDTH (m)	DEPTH (m)	SEGMENT NUMBER	SEGMENT VOLUME (cms)
36	157.1	85	3.4	36	45610
37	157.1	85	3.4	37	45414
38	157.1	85	3.4	38	45414
39	157.1	85	3.4	39	45414
40	157.1	85	3.4	40	45414
41	157.1	85	3.4	41	45414
42	157.1	85	3.4	42	45414
43	165	85	3.4	43	46550
44	165	85	3.4	44	47685
45	165	85	3.4	45	47685
46	165	85	3.4	46	47685
47	165	85	3.4	47	47685
48	165	85	3.4	48	47685
49	165	85	3.4	49	47685
50	165	85	3.4	50	47685
51	165	85	3.4	51	47685
52	165	85	3.4	52	47685
53	165	85	3.4	53	47685
54	165	85	3.4	54	47685
55	160.9	85	3.4	55	47094
56	160.9	85	3.4	56	46503
57	160.9	85	3.4	57	46503
58	160.9	85	3.4	58	46503
59	160.9	85	3.4	59	46503
60	160.9	85	3.4	60	46503
61	160.9	85	3.4	61	46503
62	160.9	85	3.4	62	46503
63	160.9	85	3.4	63	46503
64	160.9	85	3.4	64	46503
65	160.9	85	3.4	65	46503
66	159	85	3.4	66	46227
67	159	85	3.4	67	45951
68	159	85	3.4	68	45951
69	159	85	3.4	69	45951
70	159	85	3.4	70	45951