Miscellaneous Paper HL-94-3
July 1994

US Army Corps
of Engineers
Waterways Experiment
Station

James River Deep Trough Disposal Study

by Robert A. Evans, Jr.

WES

Prepared for U.S. Army Engineer District, Norfolk

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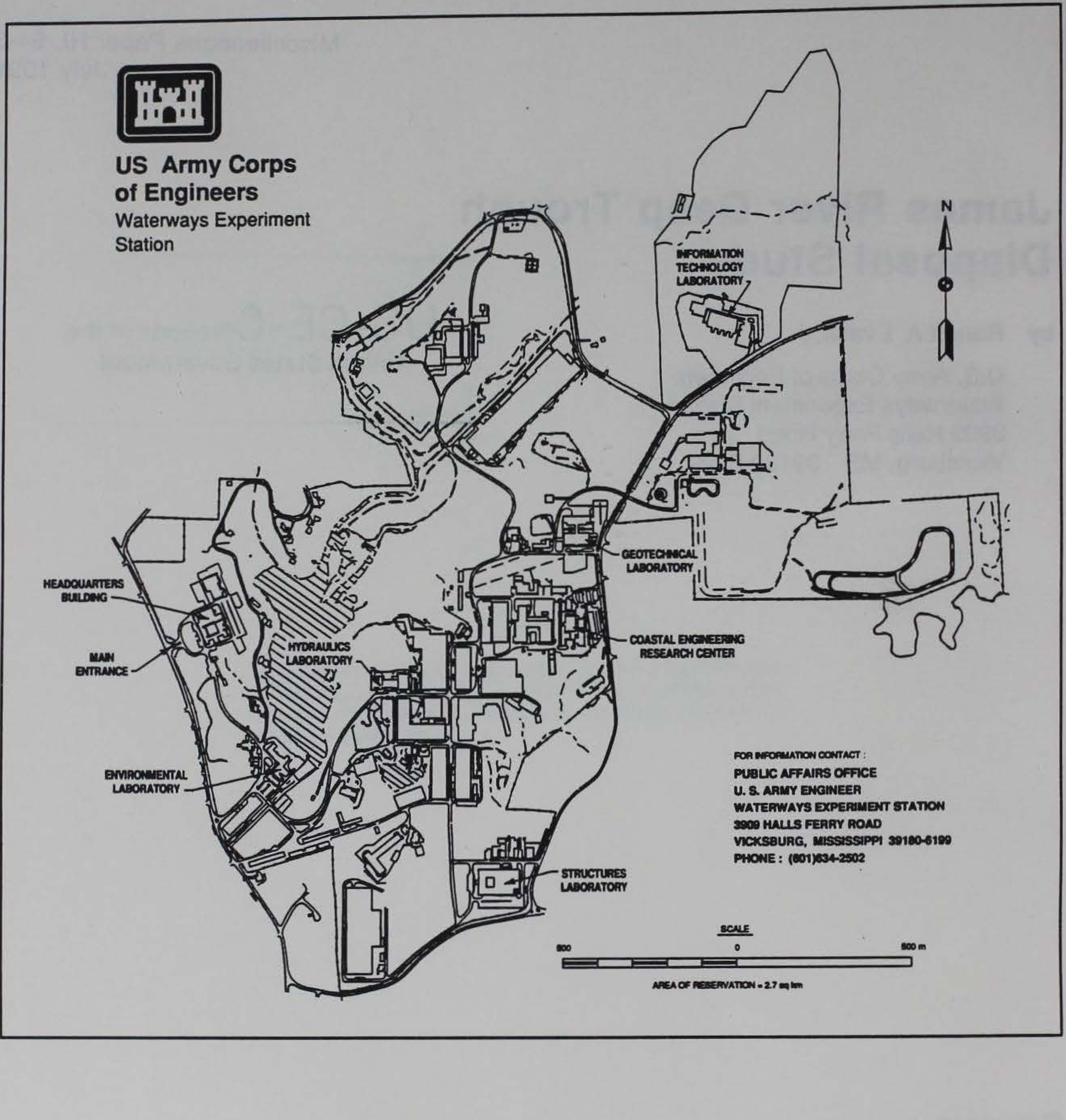
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Engineer District, Norfolk
Norfolk, VA 23510-1096



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Contents

Preface

The work herein was performed in the Hydraulics Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) as part of an investigation into sediment disposal in the James River for the U.S. Army Engineer District, Norfolk (NAO). This report presents the results of the three-dimensional numerical modeling work.

The work was conducted from November 1992 to April 1993 under the direction of the following personnel: Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief of the Hydraulics Laboratory; W. H. McAnally, Chief of the Estuaries Division, Hydraulics Laboratory; D. R. Richards, Chief of the Estuarine Simulation Branch, Estuaries Division; and Project Manager R. A. Evans, Jr., Estuarine Simulation Branch.

Mr. Evans prepared this report, and Messrs. Richards and McAnally, and Dr. R. C. Berger, Estuaries Division, assisted in the analysis of the results.

Mr. Mark Hudgins, NAO, served as the District's project coordinator.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic meters per second
feet	0.3048	meters
pounds (force)-second per square foot	47.88026	pascals-second
pounds (mass) per square foot	4.882428	kilograms per square meter

1 Introduction

Objective

Several dredged material disposal alternatives are being investigated by the Norfolk District (CENAO) for the Lower James River. They include, but are not limited to: (1) offshore disposal, (2) creation of wetland disposal islands, and (3) disposal into the deep trough at the entrance of the James River. CENAO has a thorough knowledge of offshore disposal issues and is currently conducting in-house investigations into the wetland island disposal alternatives. The third option, deep trough disposal, is much more difficult to evaluate due to the three-dimensional (3-D) nature of currents in the James River entrance. The objective of this study is to determine if disposal of dredged materials in the James River Deep Trough was feasible.

Approach

Due to the stratified nature of the lower James River estuary and the need to represent bed velocity and shear stress, a three-dimensional numerical model, RMA-10, was used to predict the hydrodynamics. Although the original scope of work required a limited resolution flume-like schematic model, a more detailed flume-like schematic model which incorporated more of the geographical features and a better representation of the tidal prism of the James River was used. While this model will give more accurate results than the limited resolution flume-like schematic model, it remains a flume-like schematic model and the results should be judged as such.

Several numerical model meshes were constructed to test different conditions. A Base geometry was made which consisted of prototype sizes and depths, with more detail in the area of the Deep Trough. Figure 1 shows the model boundary superimposed on the James River region. Note the location of the Deep Trough at the entrance. Natural bottom elevations in the Deep Trough exceed -85 feet MLLW. Three Plan geometries were constructed which consisted of changing the bottom elevations in the Deep Trough to simulate different levels of dredge material fill. The Plan geometry depths are shown in Table 1.

Table 1
Plan Geometry Depths

Plan	Deep Trough Depth (MLLW)
1	-60
2	-70
3	-80

2 Hydrodynamic Model Validation

Tidal stations, major tributaries and major freshwater inflows are shown in Figure 1. Note that the model has two tidal boundaries, one in the Chesapeake Bay, the other in the Atlantic Ocean. The elements of the model were divided into 15 material types based on depth, location, and whether the elements were two- or three-dimensional. Table 2 lists the hydraulic material types and associated hydraulic parameters. Note that material types 6, 11, and 12 are listed as boundary elements. Hydraulic constants for these types were adjusted to control the instability near the boundaries. Elements with no 3-D layers are 2-D. The number of layers corresponds to the number of elements in the vertical. Since the boundary conditions for these boundaries were not known and were difficult to define, large eddy viscosity values had to be used. These values are numerically rather than physically based but will not compromise results near the deep trough due to the large distance from the boundaries. It should be noted that the Manning's *n* values are generally higher than one would expect from previous 2-D modeling experience. This is a result of the 3-D hydrodynamic code using the near bed velocity to calculate shear stress, not a vertically averaged velocity.

Figure 2 shows the area of interest (the Deep Trough) with locations of velocity stations. The stations JG-xx-yy correspond approximately to velocity stations on the Chesapeake Bay Physical Model. The stations T1, T2, T3, TS, and TN are in locations in or near the Deep Trough.

The 3-D numerical model, RMA-10, was run for a total of 24.3 tidal cycles with a repetitive M_2 tide (period = 12.42 hours) for a total of 303 hours (12.74 days). Using the Base geometry, a single simulation of 253 hours was made as a spin-up to create hotstart conditions for the model. This hotstart was used with the Base and Plan geometries to generate 50 hours of simulation. Only the last 25 hours of these results were used in the validation and plan comparison in order to minimize the effects of the hotstart conditions. The tidal amplitude for the last 50 hours of the simulation was 4.2 feet. The salinity concentrations at the Chesapeake Bay and Atlantic Ocean boundaries were 22 and 25 ppt, respectively. Freshwater inflow at the upper end of the James River was set at 9,181 cfs. These boundary conditions are greatly

Table 2
Hydraulic Constants

Material Type	Deep Range ft	Eddy Viscosity lb-sec/ft^2	Manning's n	Number of 3-D Layers
1	0 - 6	750	0.030	1
2	6 - 18	650	0.030	1
3	18 - 30	500	0.025	1
4	30 - 45	450	0.025	1
5	> 45	250	0.025	2
6	Boundary	2200	0.050	1
7	0 - 6	500	0.025	0
8	6 - 18	450	0.025	0
9	18 - 30	300	0.020	0
10	30 - 45	300	0.018	0
11	Boundary	4000	0.060	1
12	Boundary	3000	0.055	1
13	6 - 18	2500	0.040	1
14	18 - 30	1800	0.035	1
15	> 30	1600	0.035	1

simplified representations of real conditions that were necessary to conduct this limited scope study.

Since this is primarily a flume-like schematic model, the numerical results in the vicinity of the Deep Trough were the only results considered in the validation of the model. Figure 3 shows the numerical model predicted tide for Old Pt. Comfort and Newport News, with the physical model tide ranges. A comparison of tide ranges between the numerical and physical models shows a difference of approximately 0.12 feet for Old Pt. Comfort and 0.30 feet for Newport News.

Figures 4 through 6 show the numerical model surface and bottom velocities for the three physical model stations nearest to the Deep Trough. The dashed lines indicate the maximum flood and ebb velocities measured in the physical model for the same locations. The numerical model results are in fair agreement with the physical model results, with the best agreement being in the Deep Trough at station JG-01-03. Figure 7 shows the tide ranges predicted by the numerical model and compared to the physical model for three stations in the upper part of the model. Overall, velocities in the numerical model are too small compared to the physical model. There are two reasons for this. First, due to the schematization of the James, large amounts of intertidal areas were not included, resulting in a smaller tidal prism and, therefore, smaller velocities. Second, vertical mixing appeared to be greater in the numerical model, reducing surface currents which would have been affected by a larger salinity gradient. These are somewhat related, but are not considered fatal flaws due to the limited expectations for a modeling effort of this level.

Figures 8 through 11 present the surface and bottom velocities for the Base and Plan geometries at three stations in the vicinity of Old Pt. Comfort. Figures 12 through 15 present the surface and bottom velocities for the Base and Plan geometries at three stations in the vicinity of Newport News.

Figures 16 through 23 show the surface and bottom velocities at locations in the trough (T1, T2, and T3) and both north and south of the trough (TN and TS, respectively). These also show very small changes in the velocities due to the various plans.

3 Shear Stress Analysis

Shear stress along the bottom was computed using the following formula:

$$\tau = 1/2\ \rho f_c u^2$$

with

τ = shear stress, lb/sq ft
ρ = water density, 1.935 slugs
f_c = current friction factor, 0.007
u = water velocity, ft/sec

Based on information provided by the Norfolk District, typical sediment size to be disposed in the trough will be approximately 0.2 mm (fine sand). The critical shear stress (τ_c) for quartz spheres of this size is approximately 0.005 lb/sq ft. This study examined scour patterns for two values of critical shear stress. Areas where the critical shear stress equalled or exceeded 0.008 lb/sq ft at any time during the last two tidal cycles were examined. This value is very conservative and erosion is most probable for such a high value. However, this value may only occur at maximum ebb and flood and may not be representative of a significant portion of the tidal cycle. In fact, this value was not exceeded for a significant portion of the tidal cycle. The second value of critical shear stress, 0.006 lb/sq ft, was used to develop scour patterns. But these patterns represent areas where the shear stress exceeded 0.006 lb/sq ft at least 33 percent of the time. While 0.006 lb/sq ft is a less conservative estimate of critical shear stress than 0.008 lb/sq ft, it still exceeds the value of 0.005 lb/sq ft given for quartz spheres.

Figures 24 through 27 show regions with shear stress greater than or equal to 0.008 lb/sq ft during some point in the last two tidal cycles of the simulations for the Base and Plan geometries. Note that all show regions of potential scour coincident with the Deep Trough. Figure 28 shows Plan 1 results superimposed on the Base results. Since Plan 1 is the most drastic change in geometry, it should show the most deviation from the Base. This figure shows very little change.

Figures 24 through 28 show only that, at some times in the tidal period, the shear stress will be large enough for scour to occur. However, they give no indication of the amount of time that critical shear stress will be equalled or exceeded. Figures 29 through 33 show the regions in which shear stress exceeds 0.006 lb/sq ft at least 33 percent of the time. It is believed that these give a better estimate of scour potential. However, as shown in Figures 24 through 28, there appears to be no significant change in the scour patterns.

4 Conclusion

The 3-dimensional hydrodynamic model RMA-10 and a schematized model mesh, with average boundary conditions, was used to simulate water velocities and elevations of the lower James River. It is concluded that dredge material disposed in the Deep Trough is not likely to remain without protective armoring. This determination was made by calculating the bottom shear stress using the near-bottom water velocities and comparing with a conservative critical shear stress value. For each plan tested, water velocities were sufficient to cause scouring during parts of the tidal cycle. However, if a mildly dispersive site was desired, these results indicate that it could be feasible to use the Deep Trough as a disposal area without protective armoring. More accurate results will require a more detailed 3-D model mesh and, perhaps, a 3-D sedimentation model.

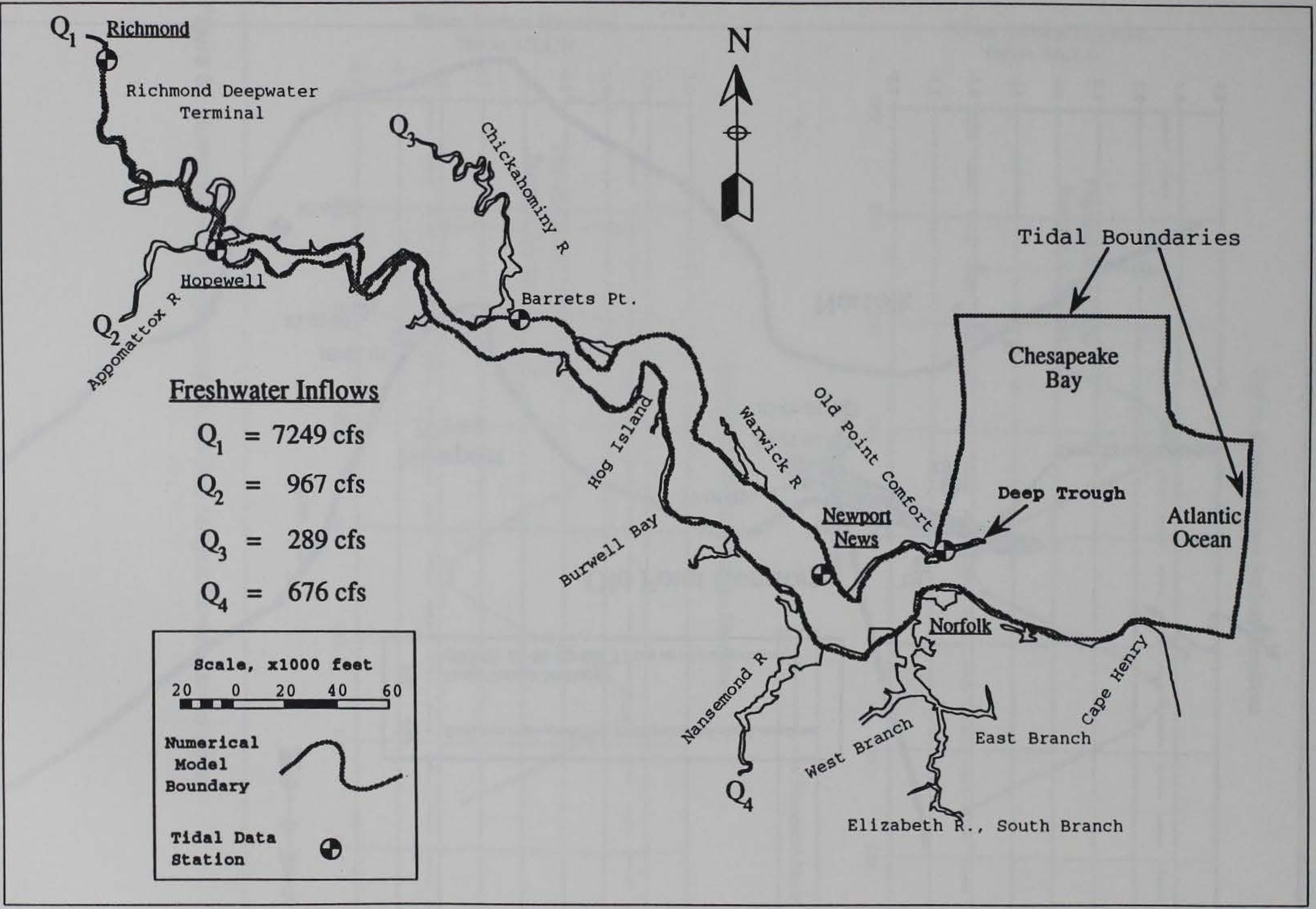


Figure 1. Location map showing numerical model limits, tide stations, and proposed Deep Trough disposal area

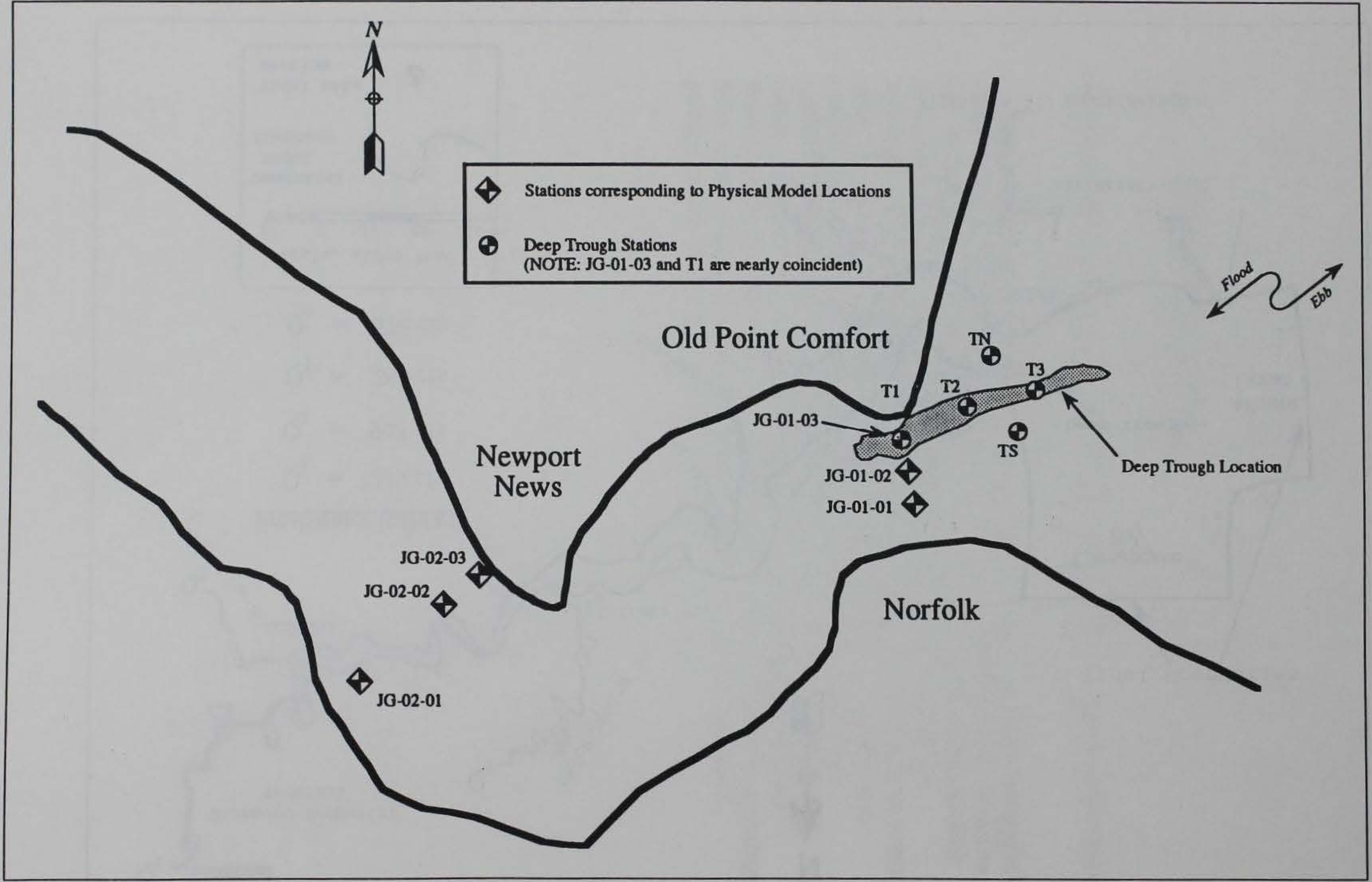


Figure 2. Locations of velocity stations in the vicinity of the Deep Trough

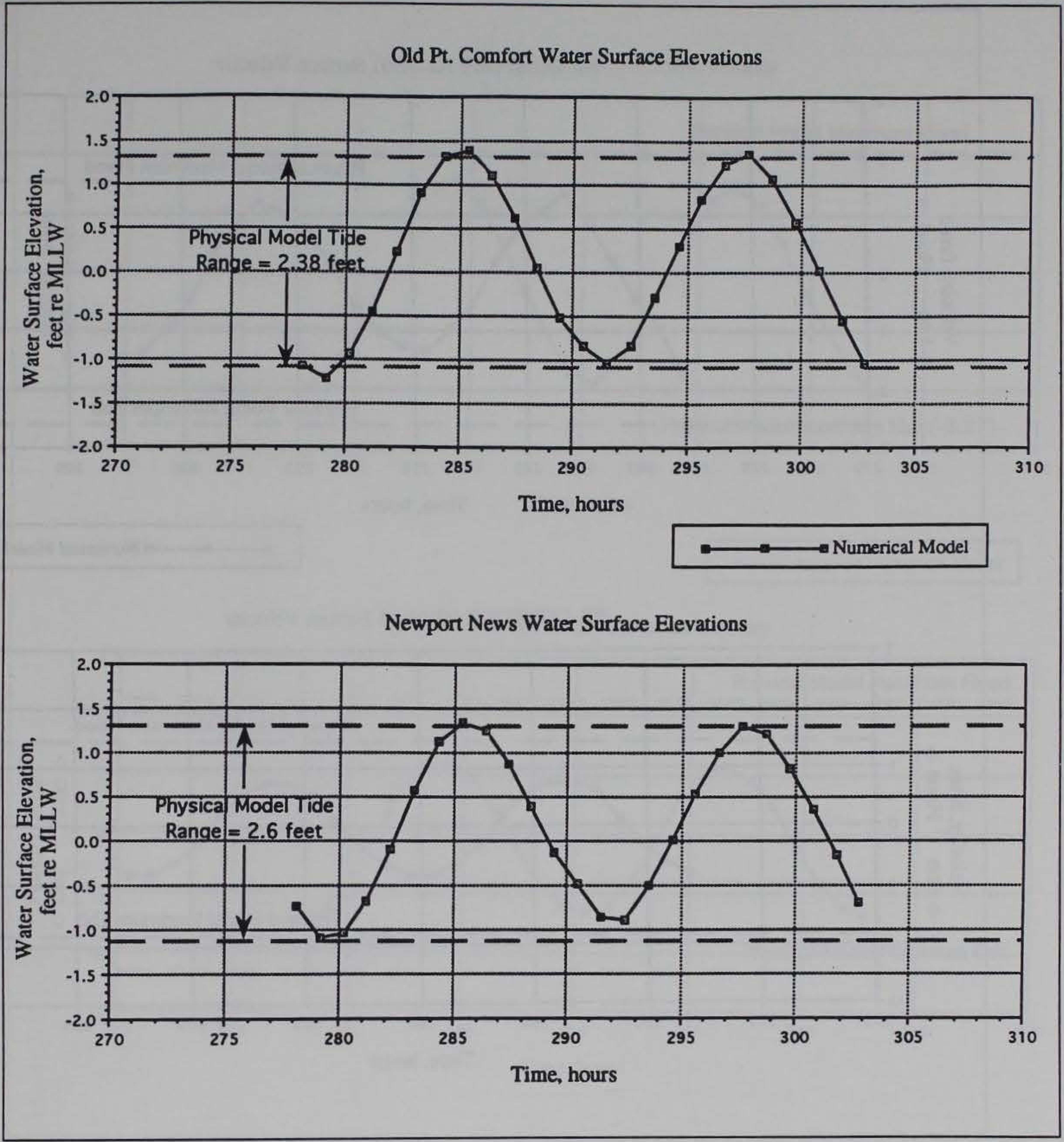


Figure 3. Numerical versus physical model tidal ranges, Lower James River

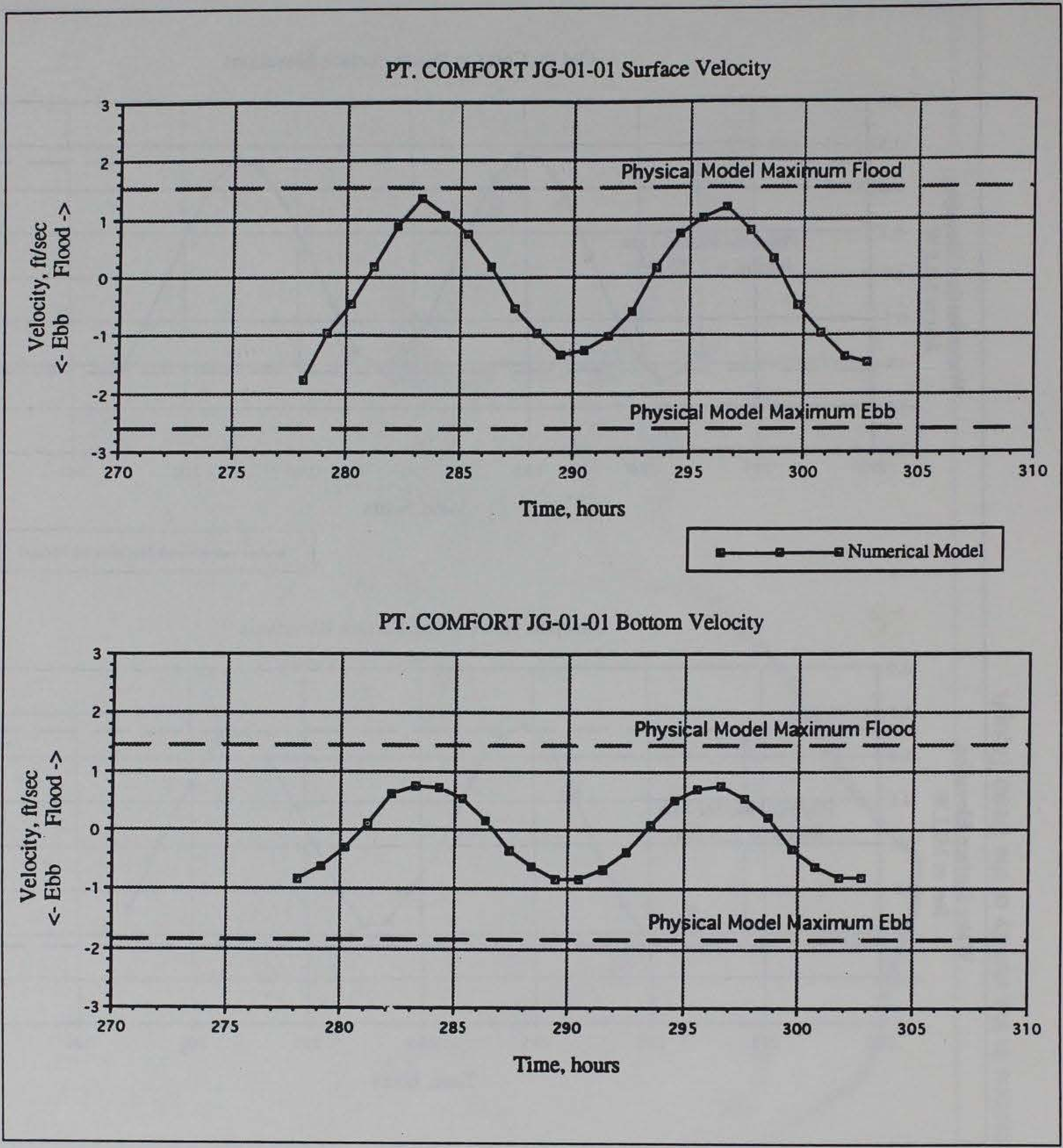


Figure 4. Numerical model surface and bottom velocities versus the physical model velocity ranges (M_2 tide), Station JG-01-01

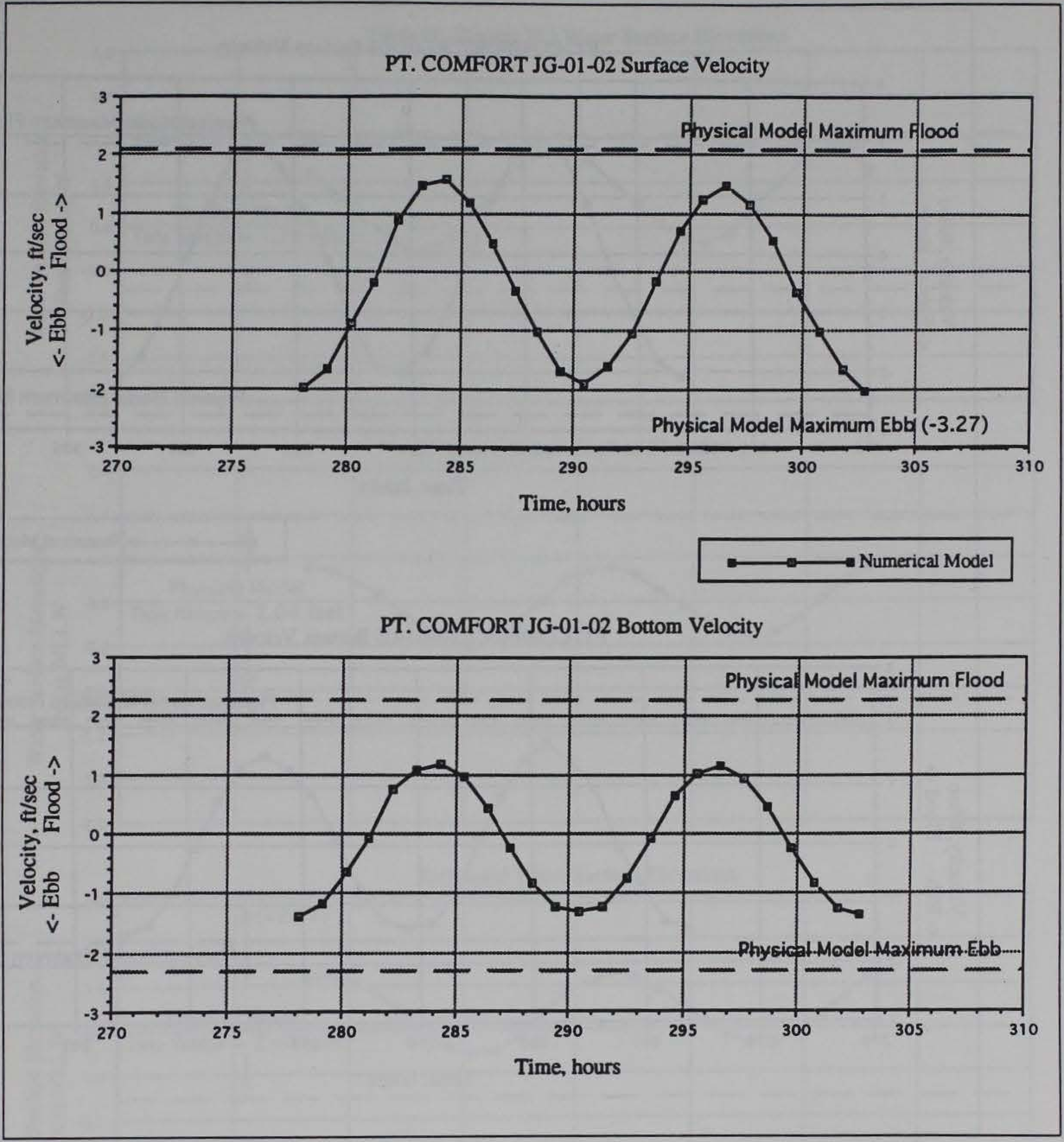


Figure 5. Numerical model surface and bottom velocities versus the physical model velocity ranges (M_2 tide), Station JG-01-02

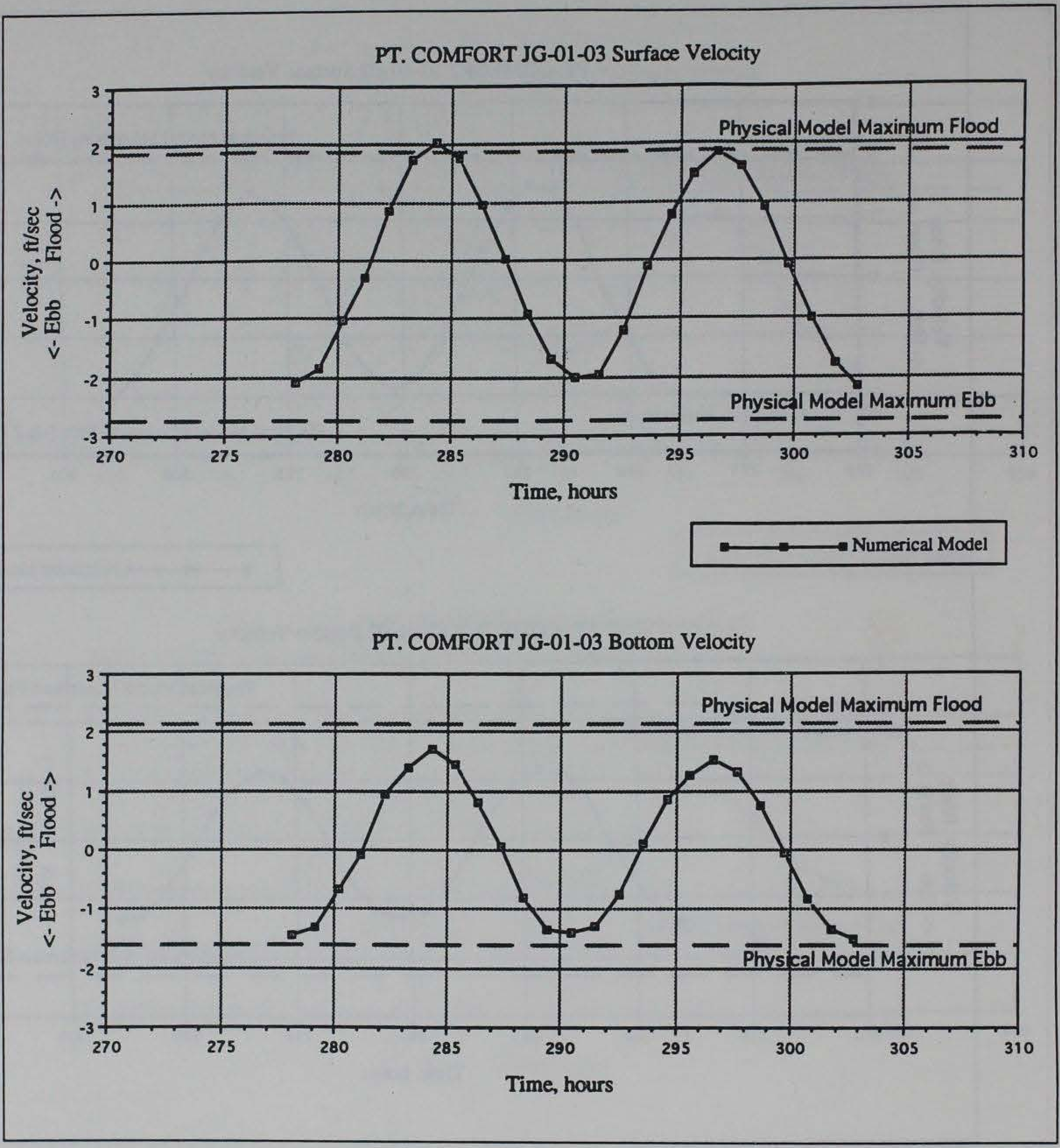


Figure 6. Numerical model surface and bottom velocities versus the physical model velocity ranges (M_2 tide), Station JG-01-03

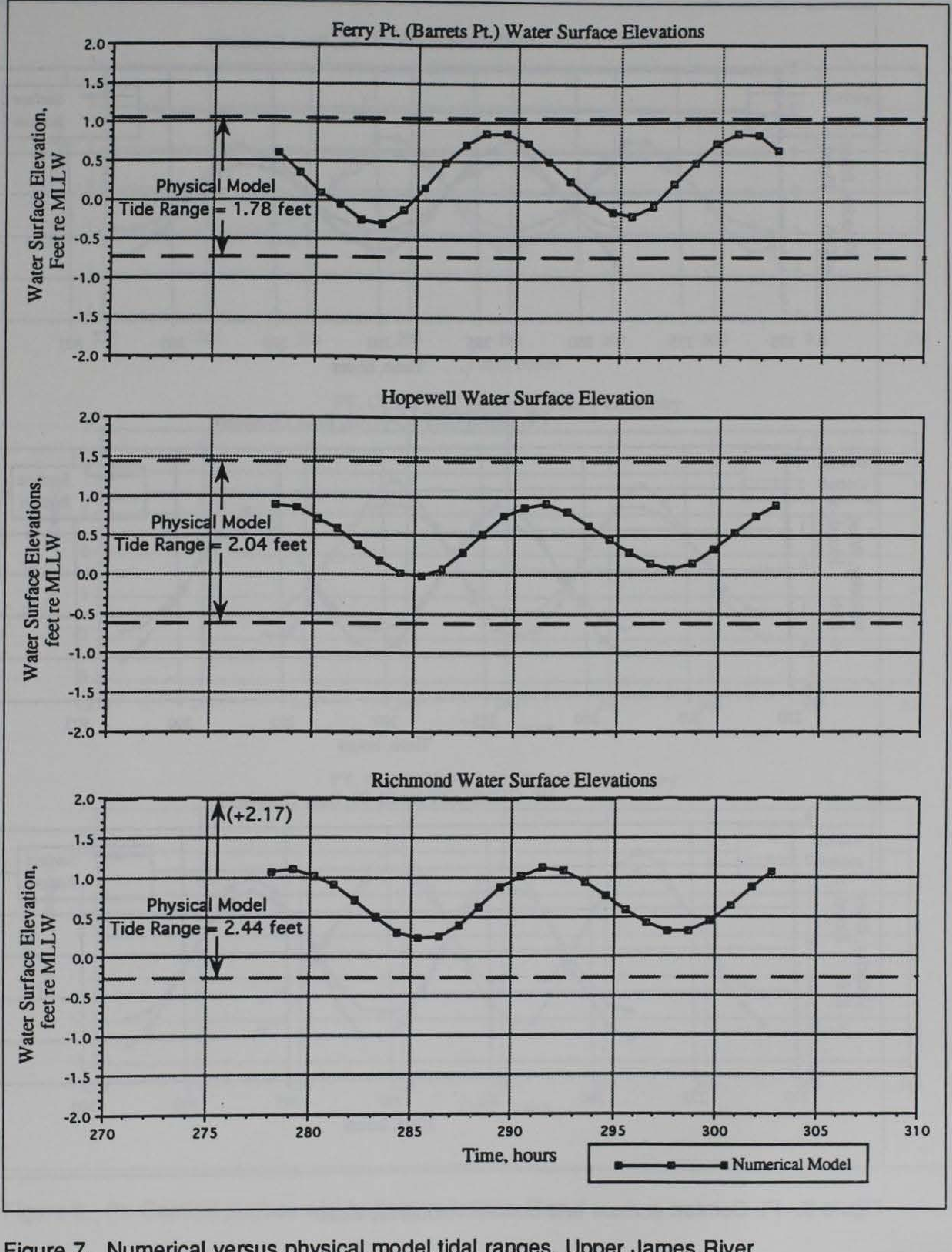


Figure 7. Numerical versus physical model tidal ranges, Upper James River

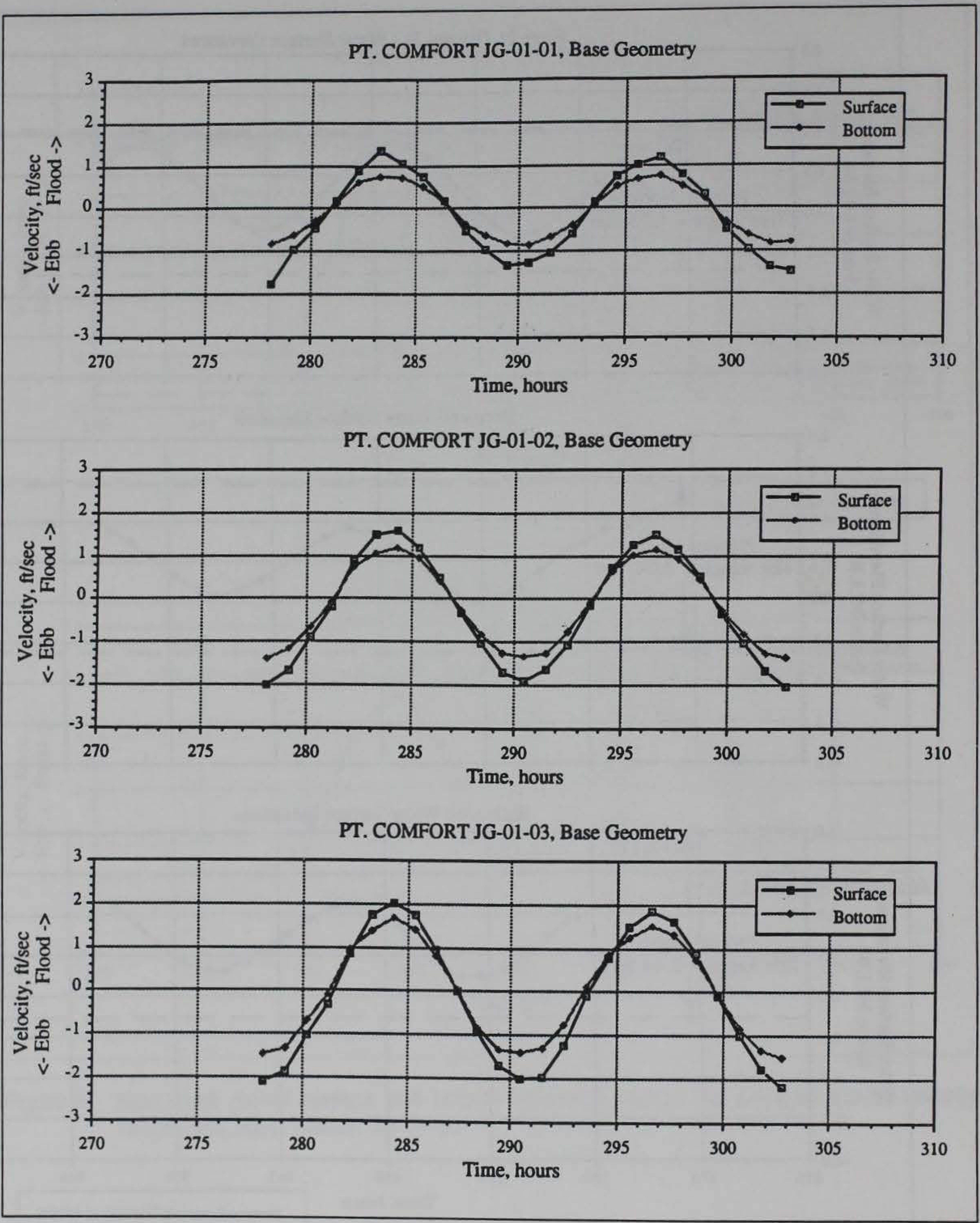


Figure 8. Pt. Comfort surface and bottom velocities, Base

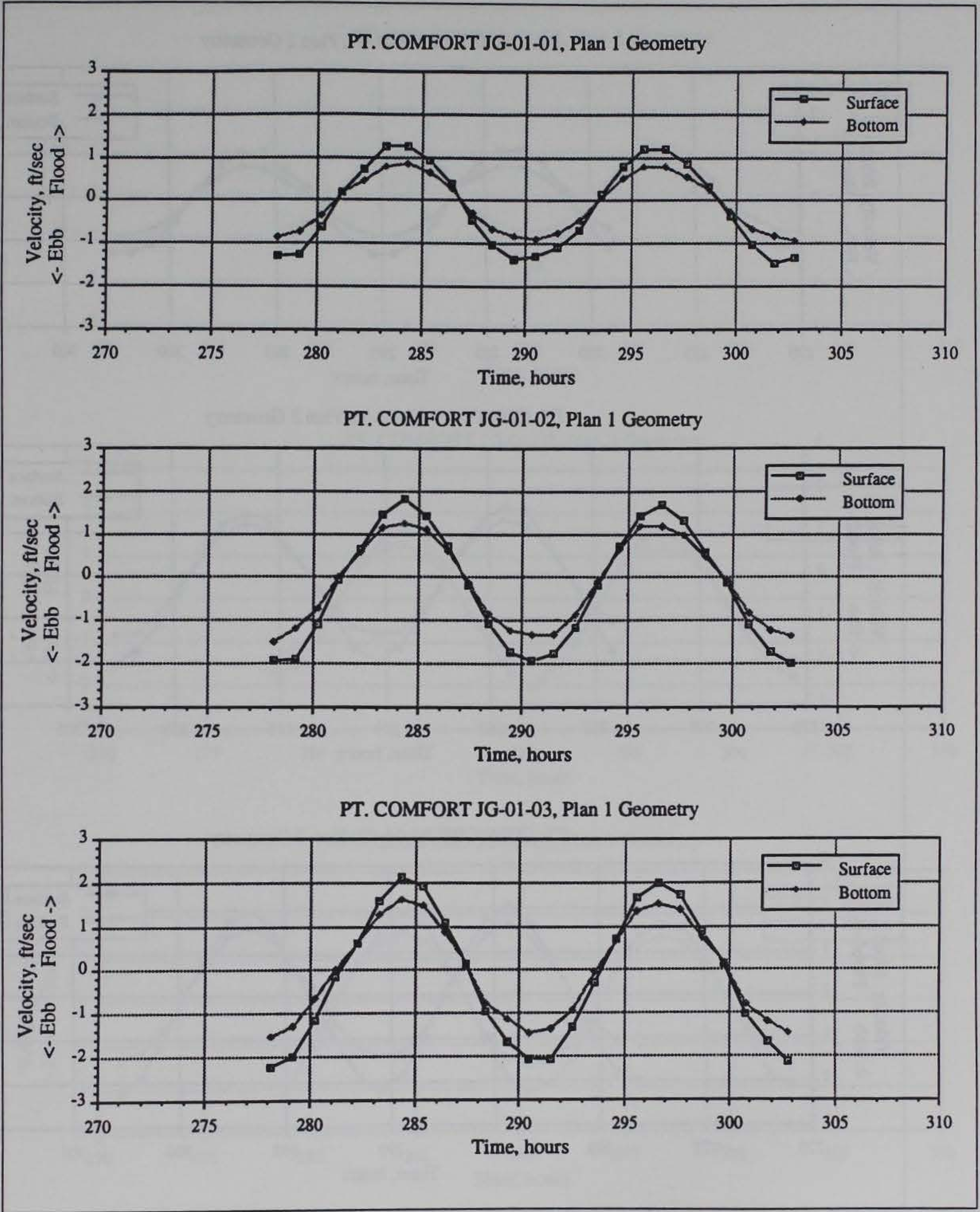


Figure 9. Pt. Comfort surface and bottom velocities, Plan 1

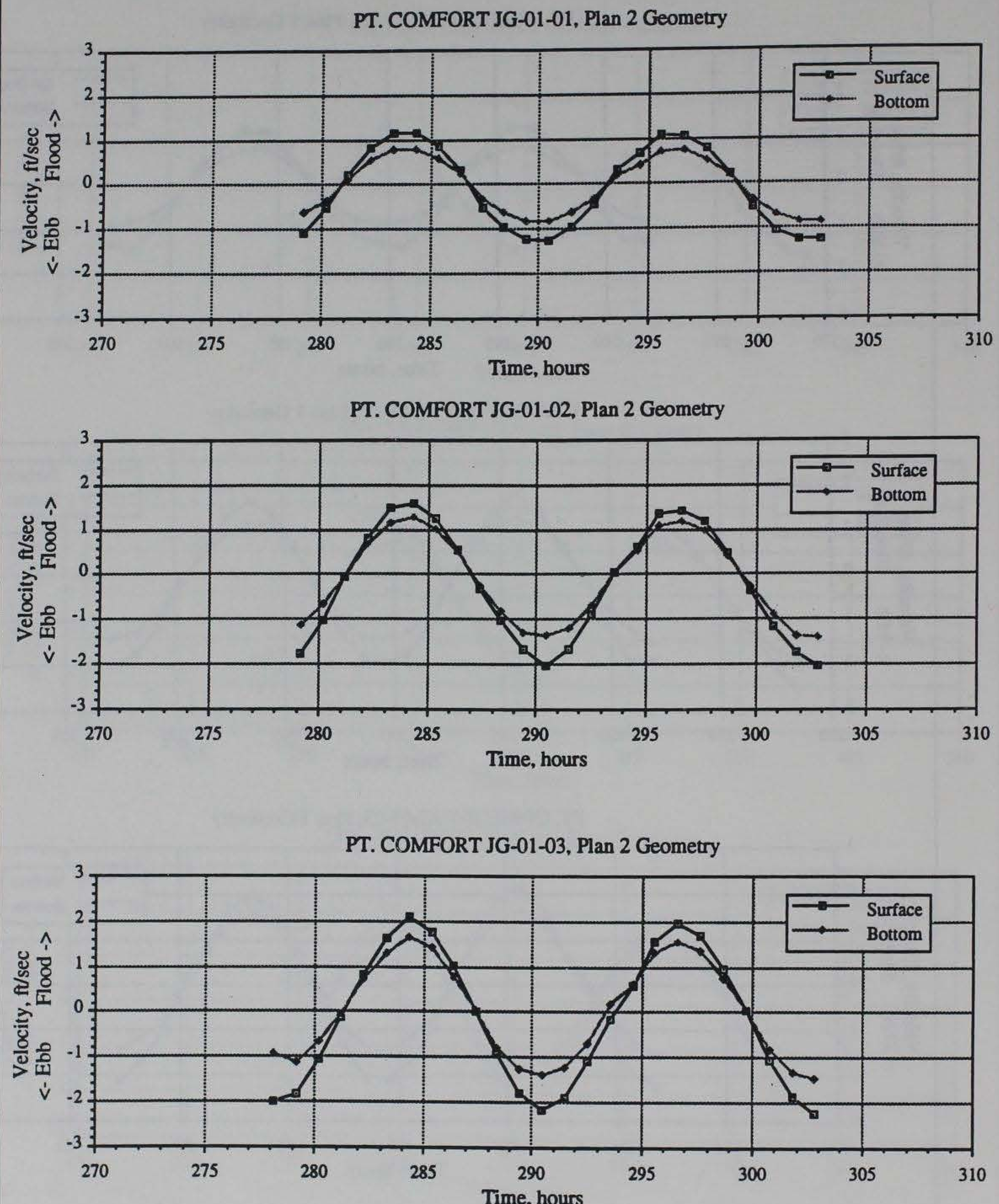
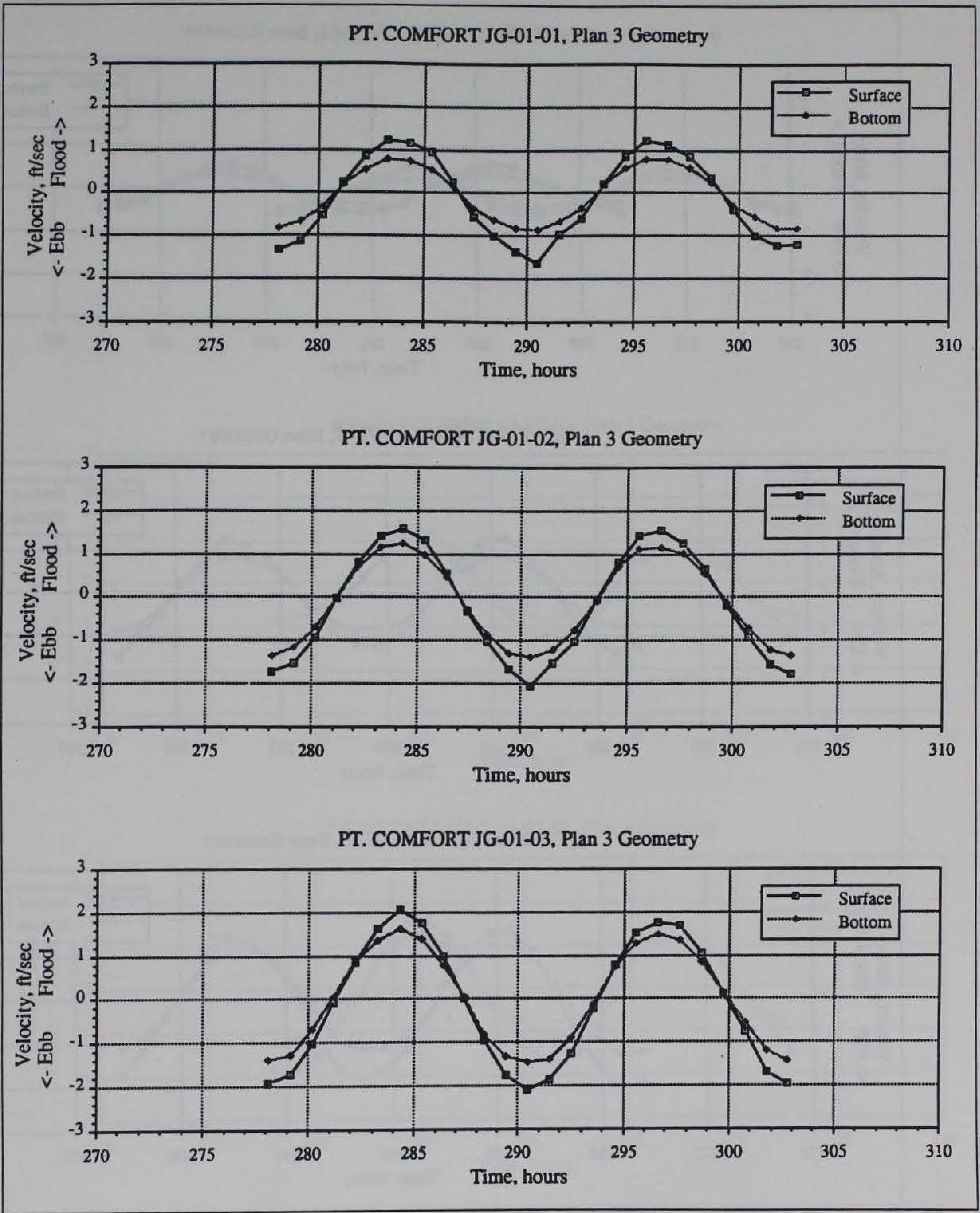


Figure 10. Pt. Comfort surface and bottom velocities, Plan 2

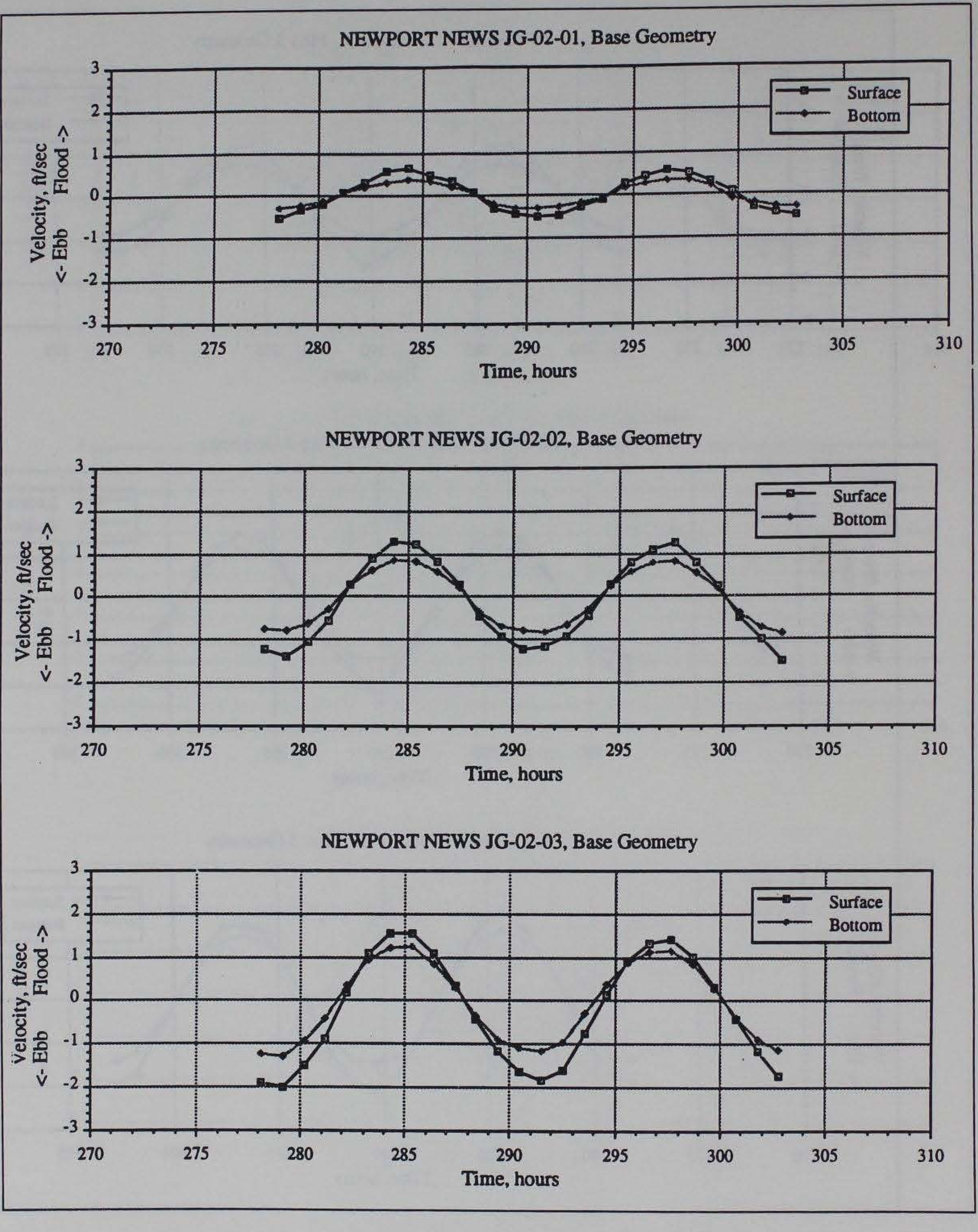


PT. COMFORT JG-01-01, Plan 3 Geometry

PT. COMFORT JG-01-02, Plan 3 Geometry

PT. COMFORT JG-01-03, Plan 3 Geometry

Figure 11. Pt. Comfort surface and bottom velocities, Plan 3



NEWPORT NEWS JG-02-01, Base Geometry

NEWPORT NEWS JG-02-02, Base Geometry

NEWPORT NEWS JG-02-03, Base Geometry

Figure 12. Newport News surface and bottom velocities, Base

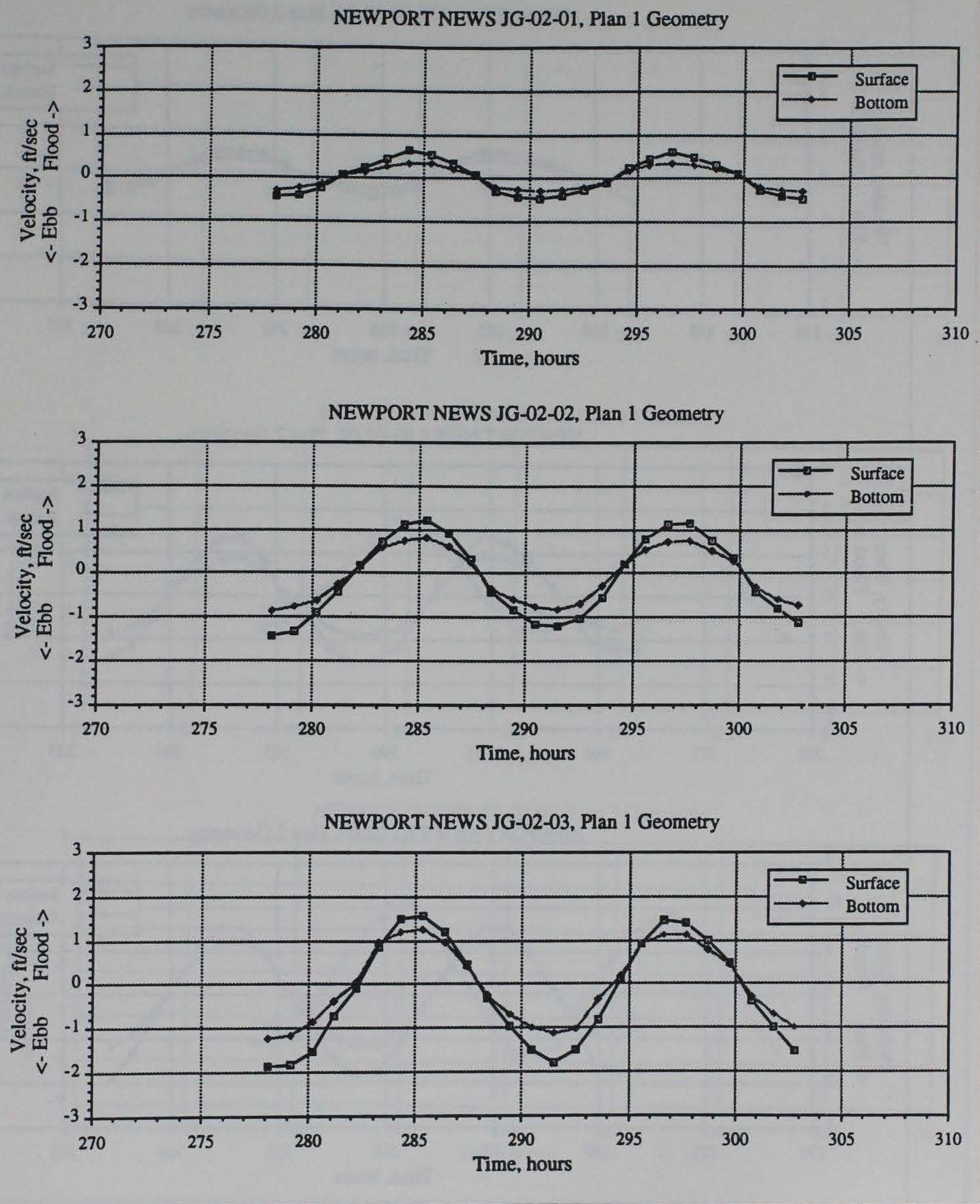


Figure 13. Newport News surface and bottom velocities, Plan 1

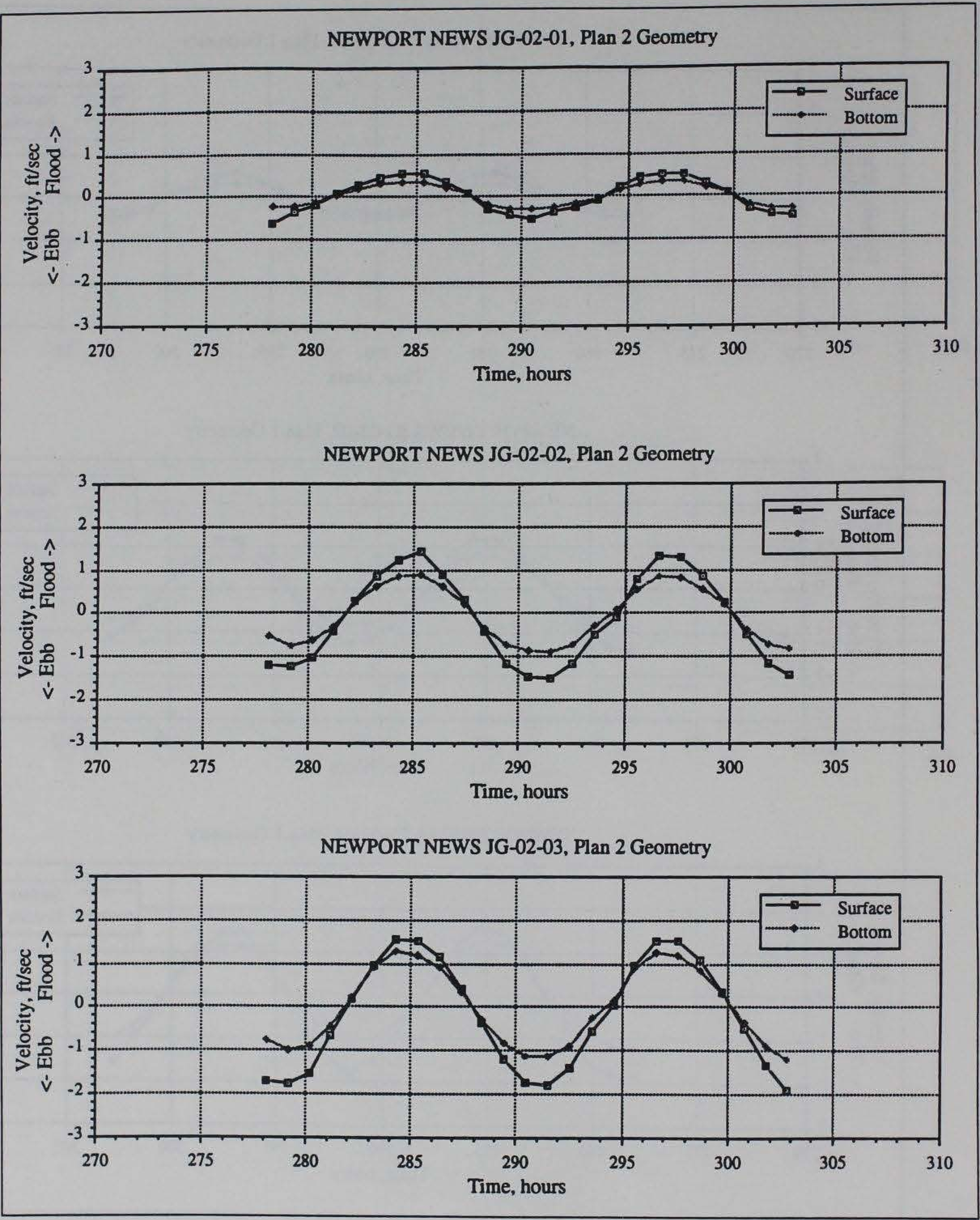


Figure 14. Newport News surface and bottom velocities, Plan 2

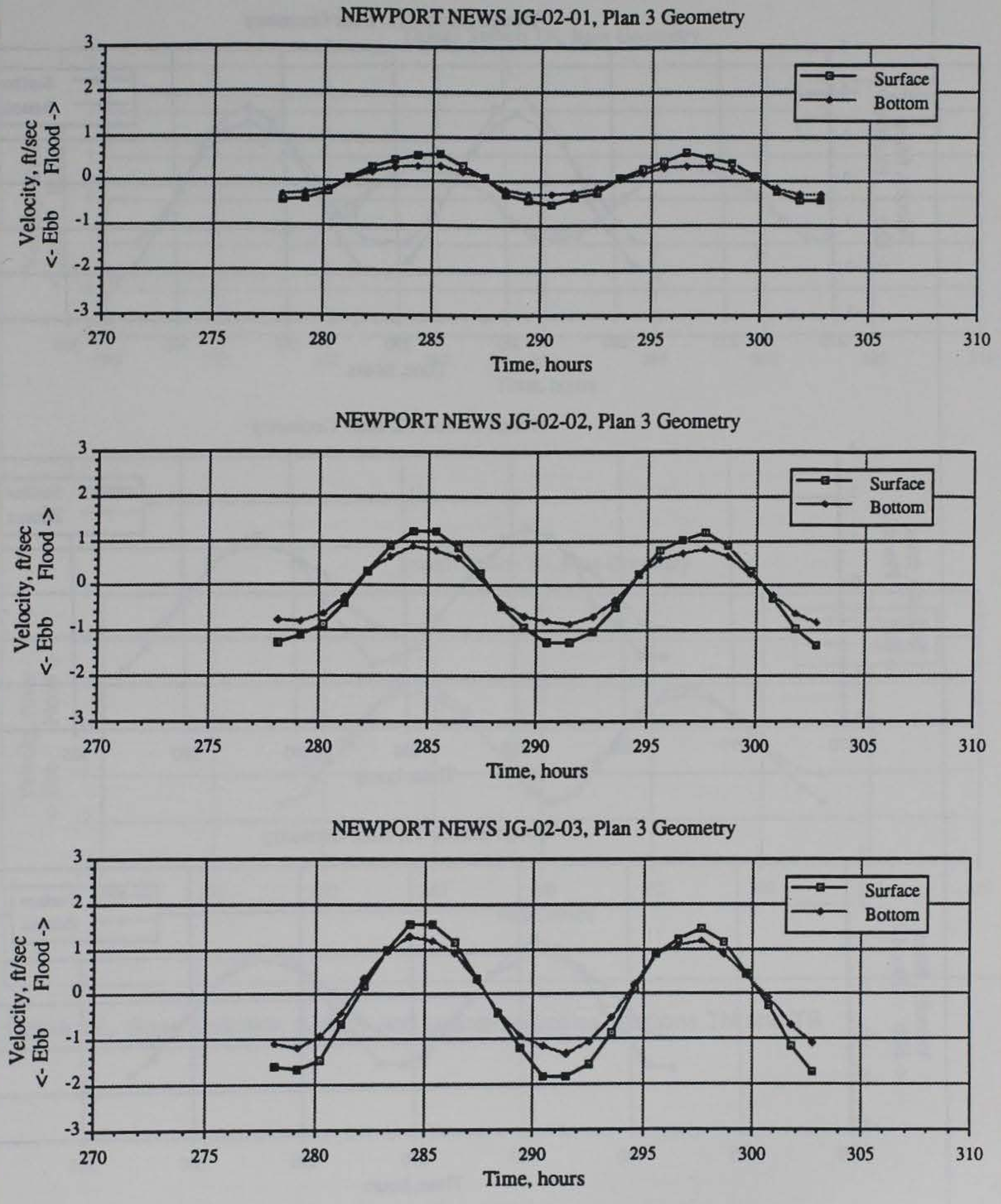


Figure 15. Newport News surface and bottom velocities, Plan 3

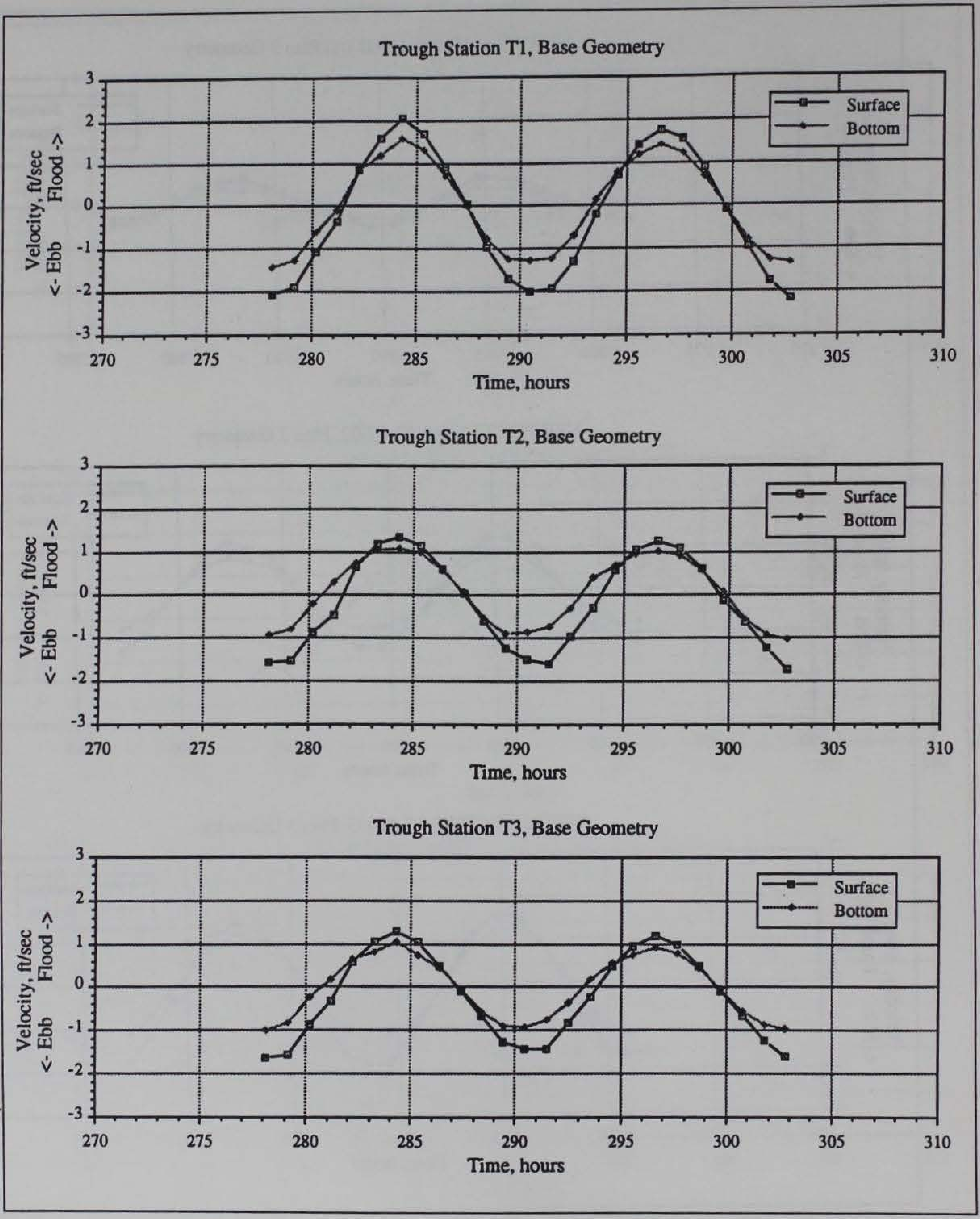


Figure 16. Base condition surface and bottom velocities, Stations T1-T3

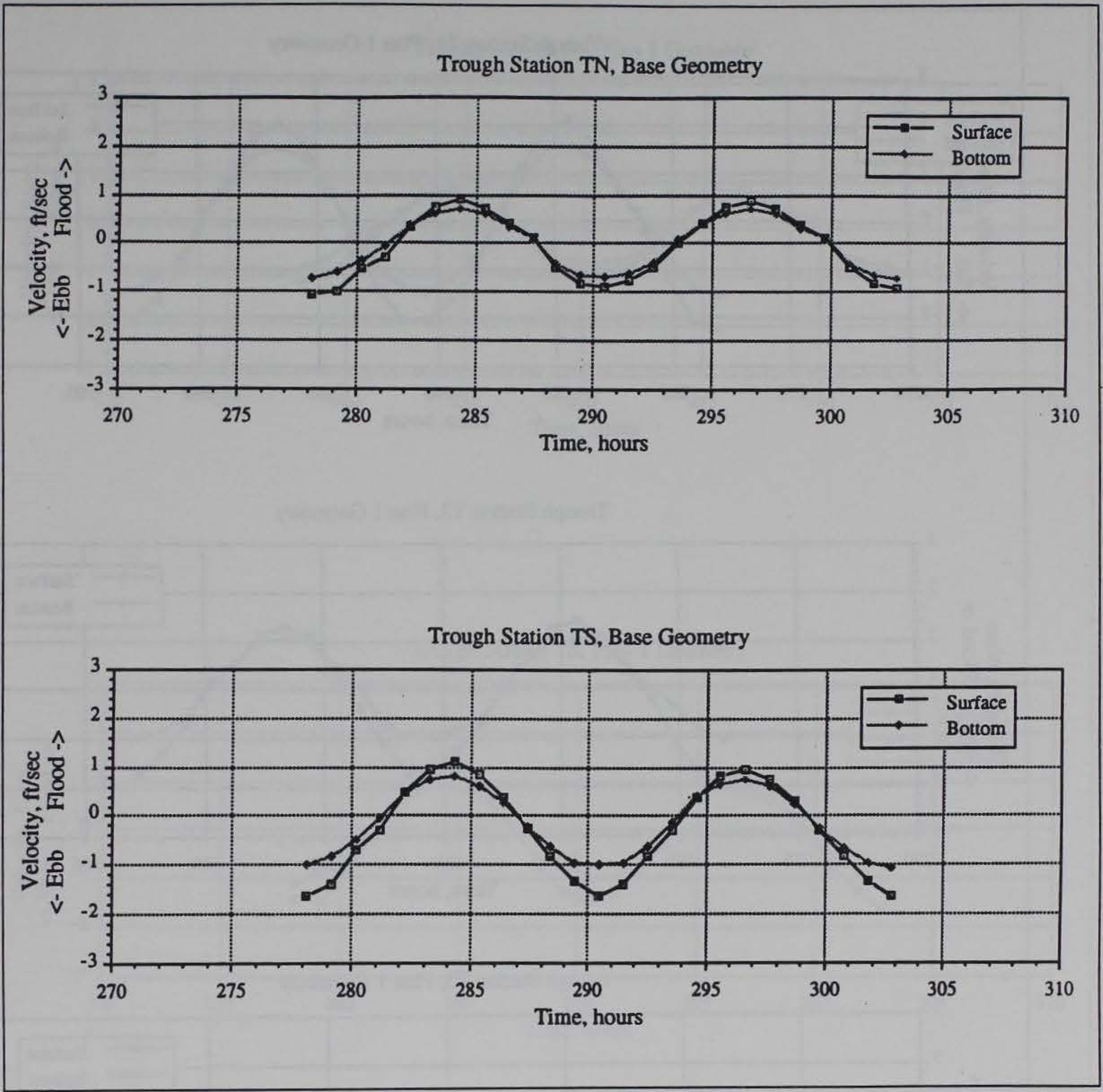


Figure 17. Base condition surface and bottom velocities, Stations TN and TS

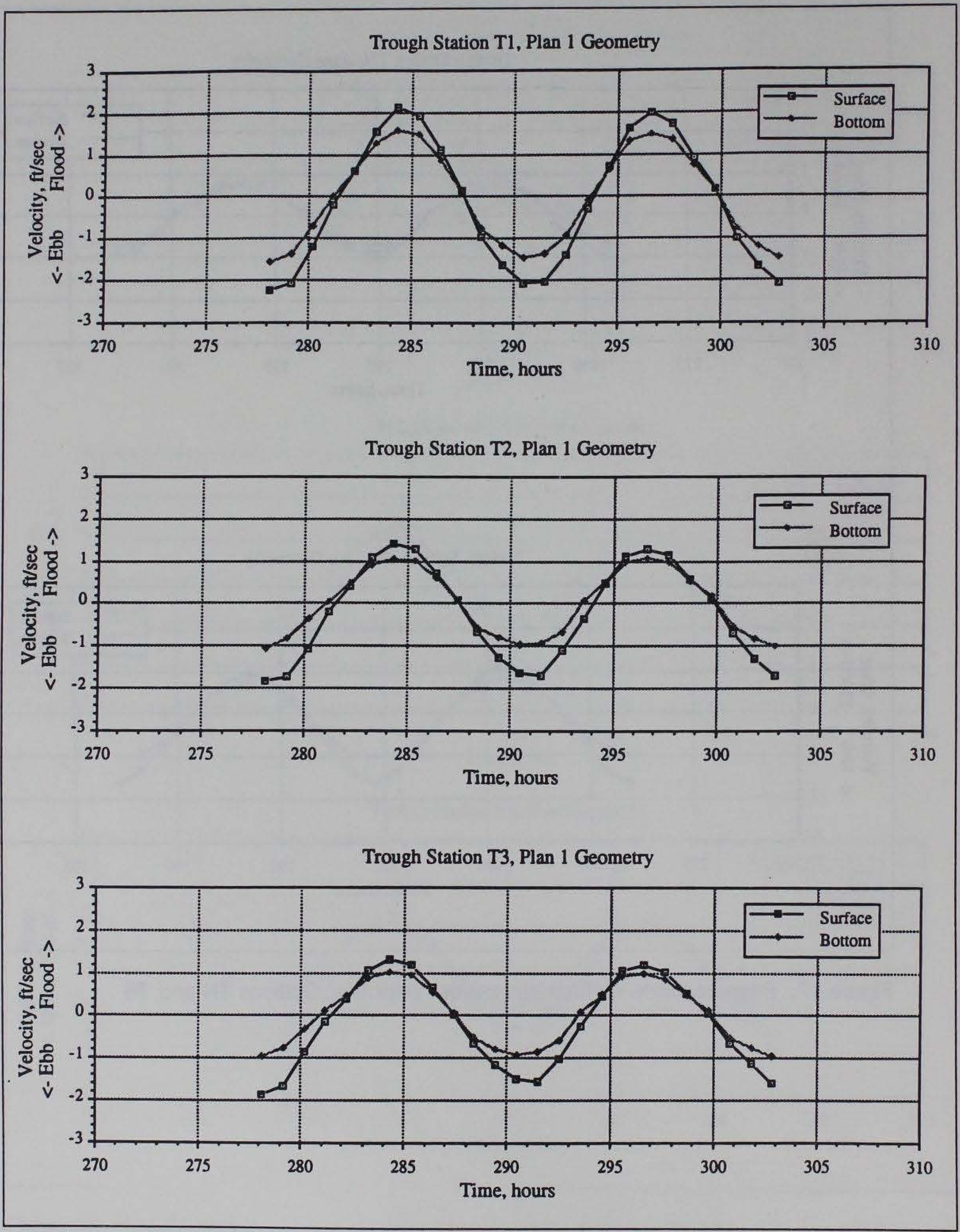


Figure 18. Plan 1 surface and bottom velocities, Stations T1-T3

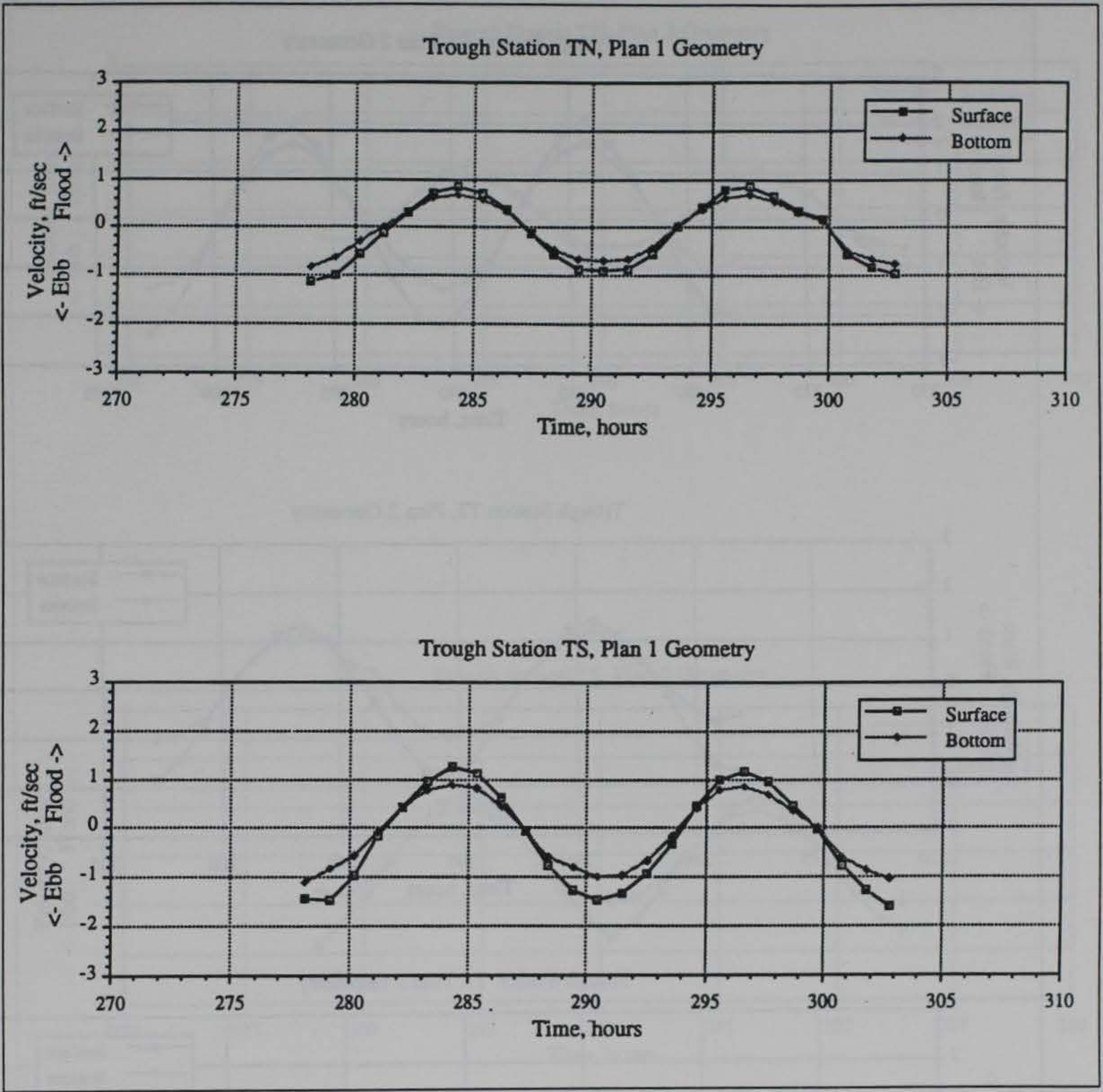


Figure 19. Plan 1 surface and bottom velocities, Stations TN and TS

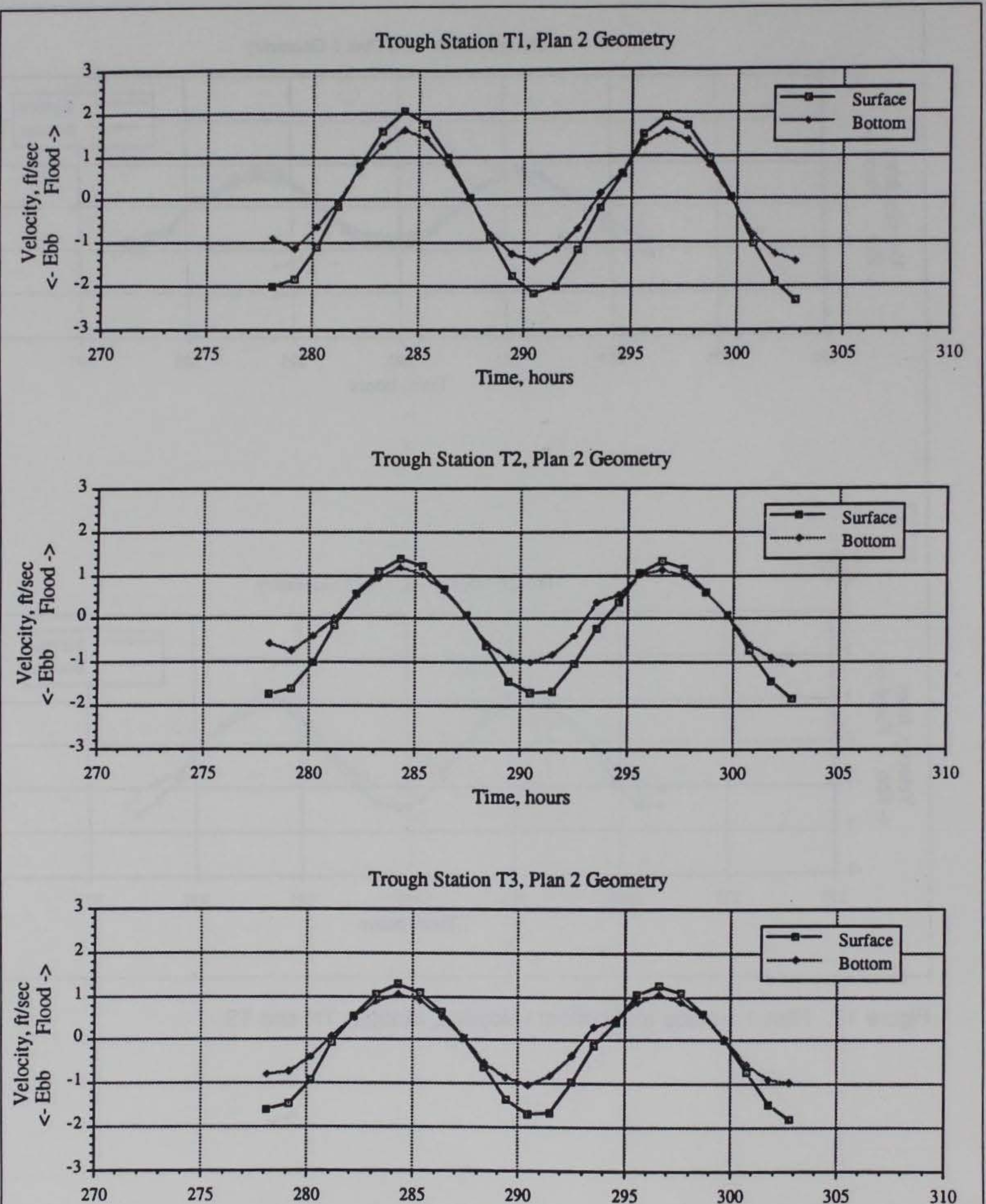


Figure 20. Plan 2 surface and bottom velocities, Stations T1-T3

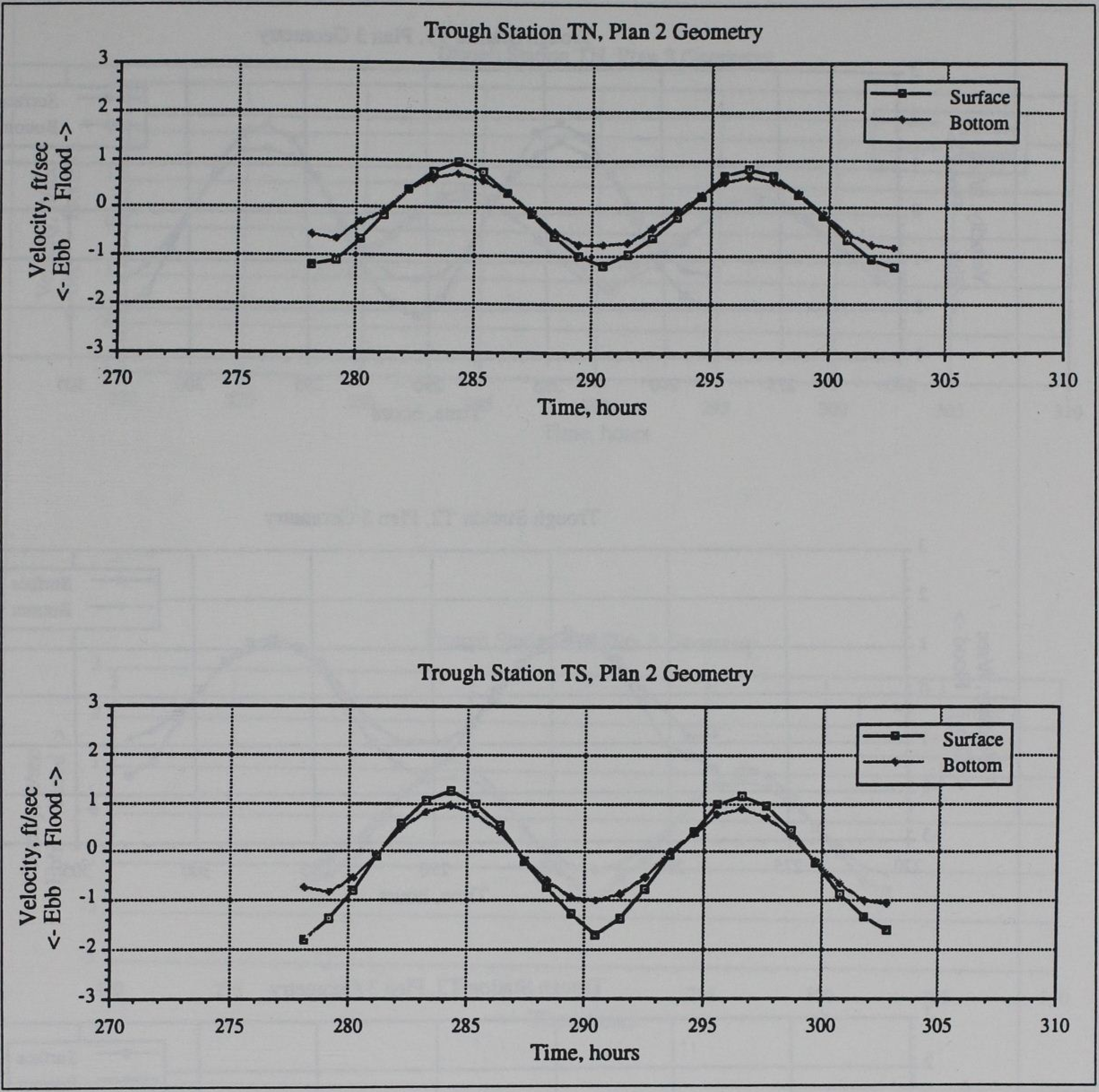


Figure 21. Plan 2 surface and bottom velocities, Stations TN and TS

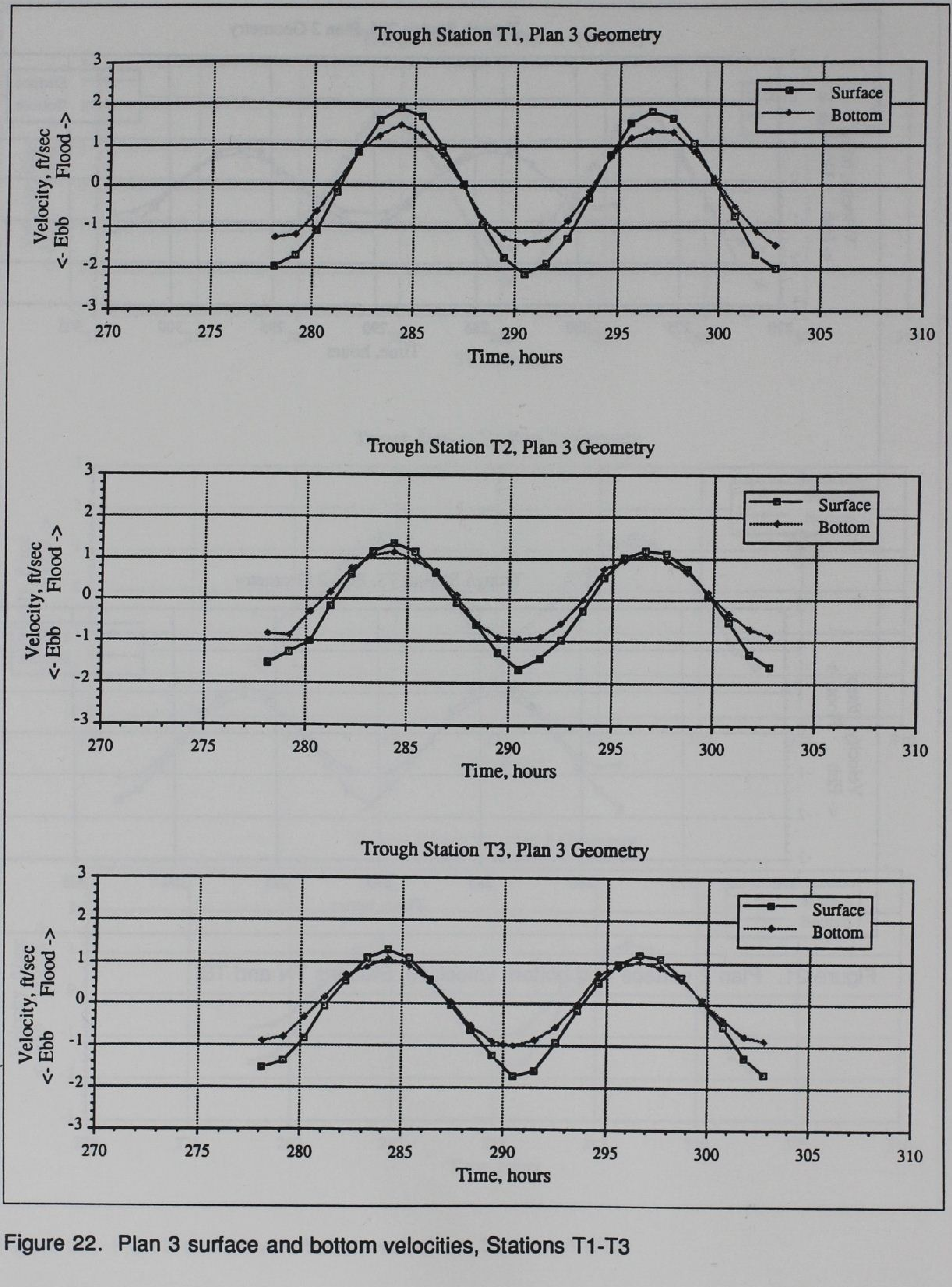


Figure 22. Plan 3 surface and bottom velocities, Stations T1-T3

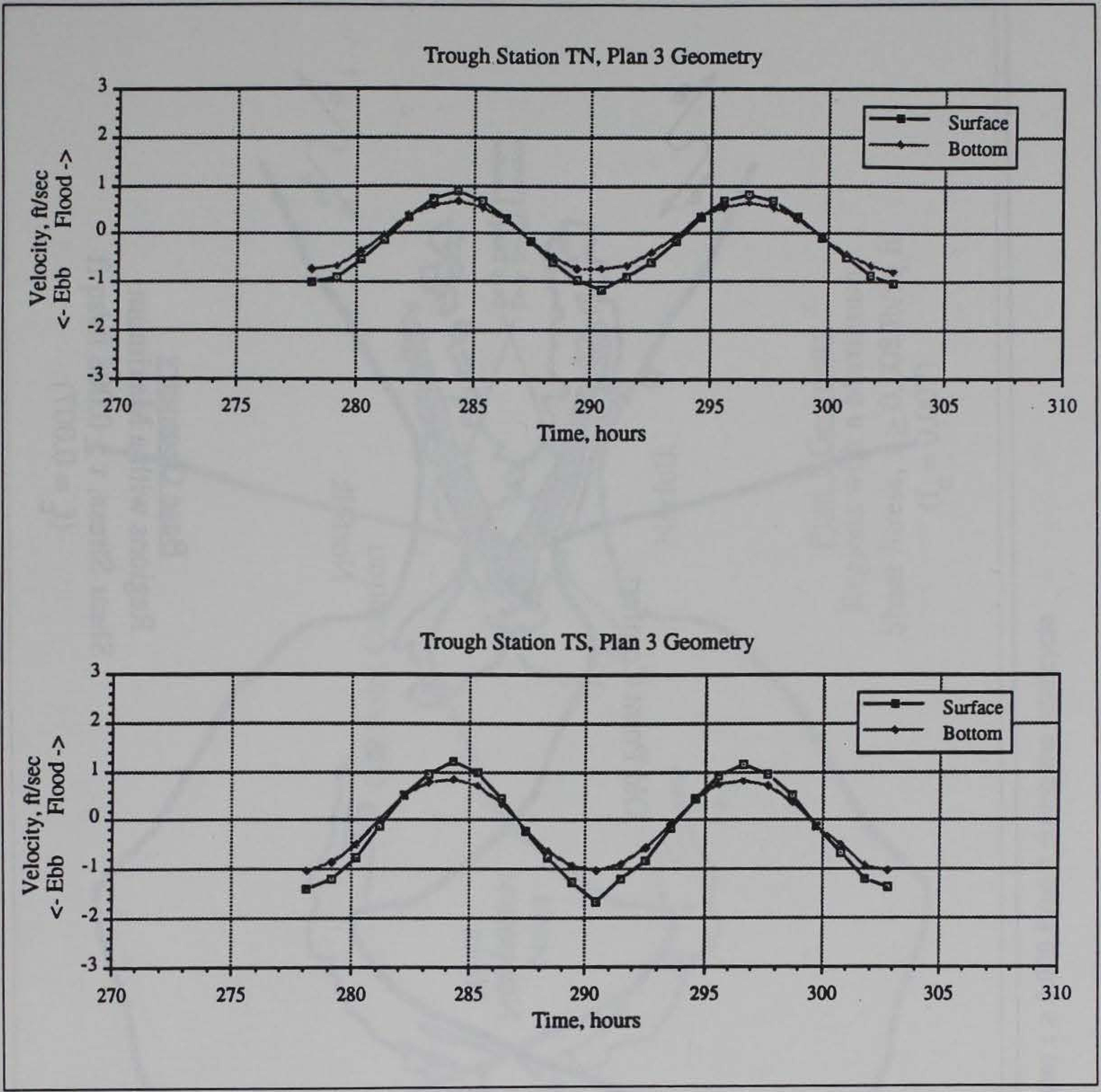


Figure 23. Plan 3 surface and bottom velocities, Stations TN and TS

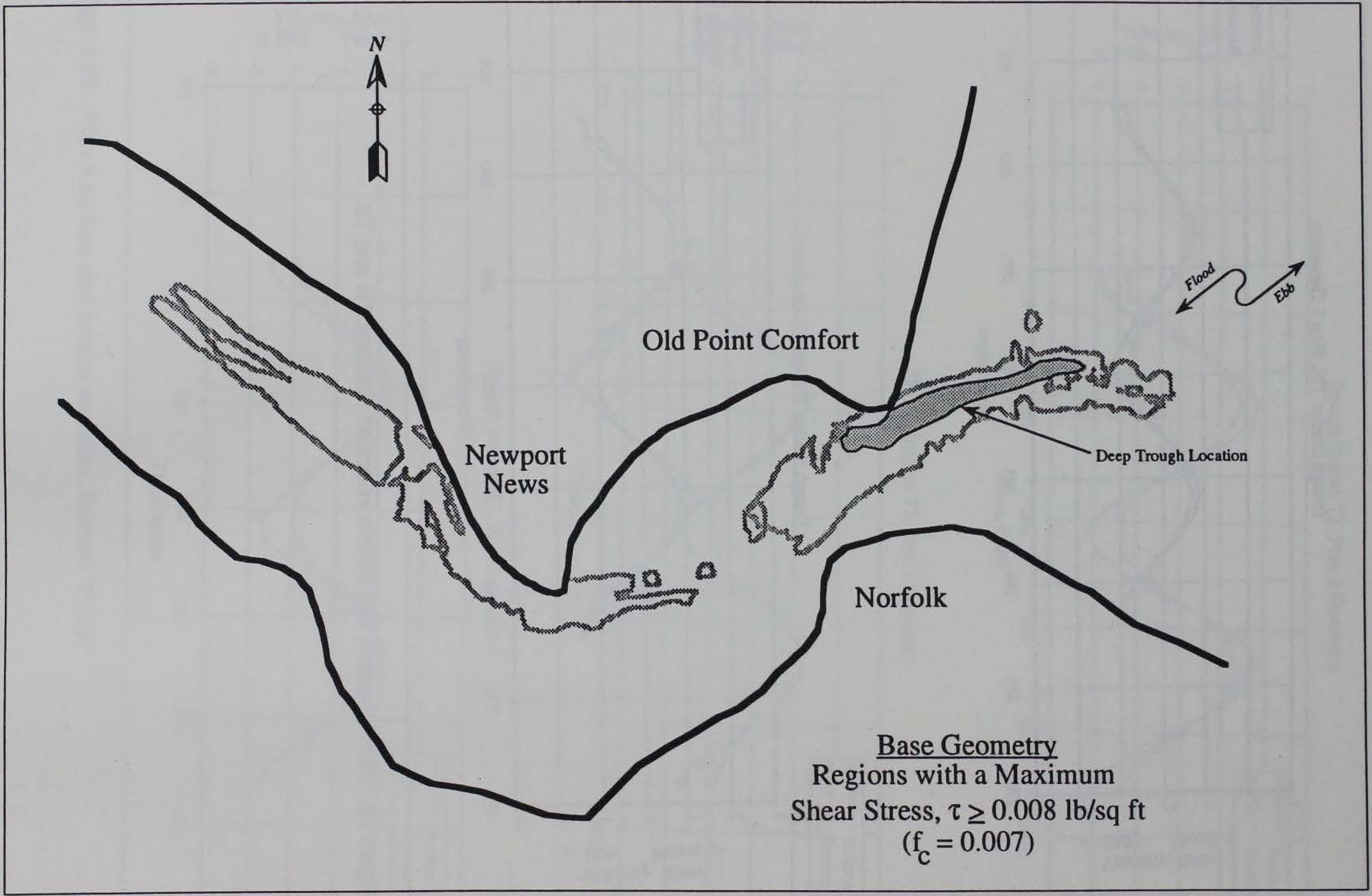


Figure 24. Base geometry - areas where $\tau \geq 0.008$ lb/sq ft during the tidal cycle

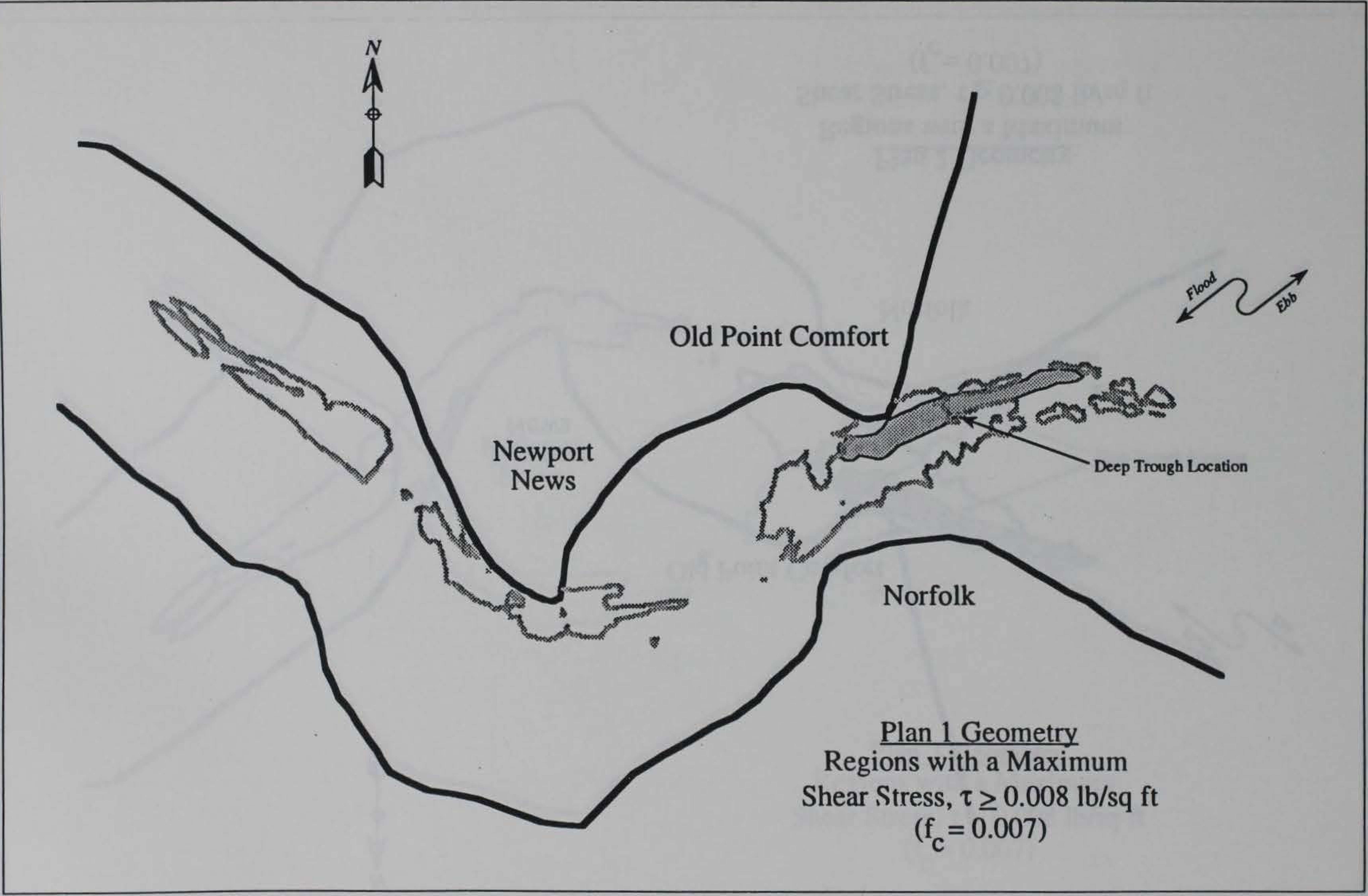


Figure 25. Plan 1 geometry - areas where $\tau \geq 0.008$ lb/sq ft during the tidal cycle

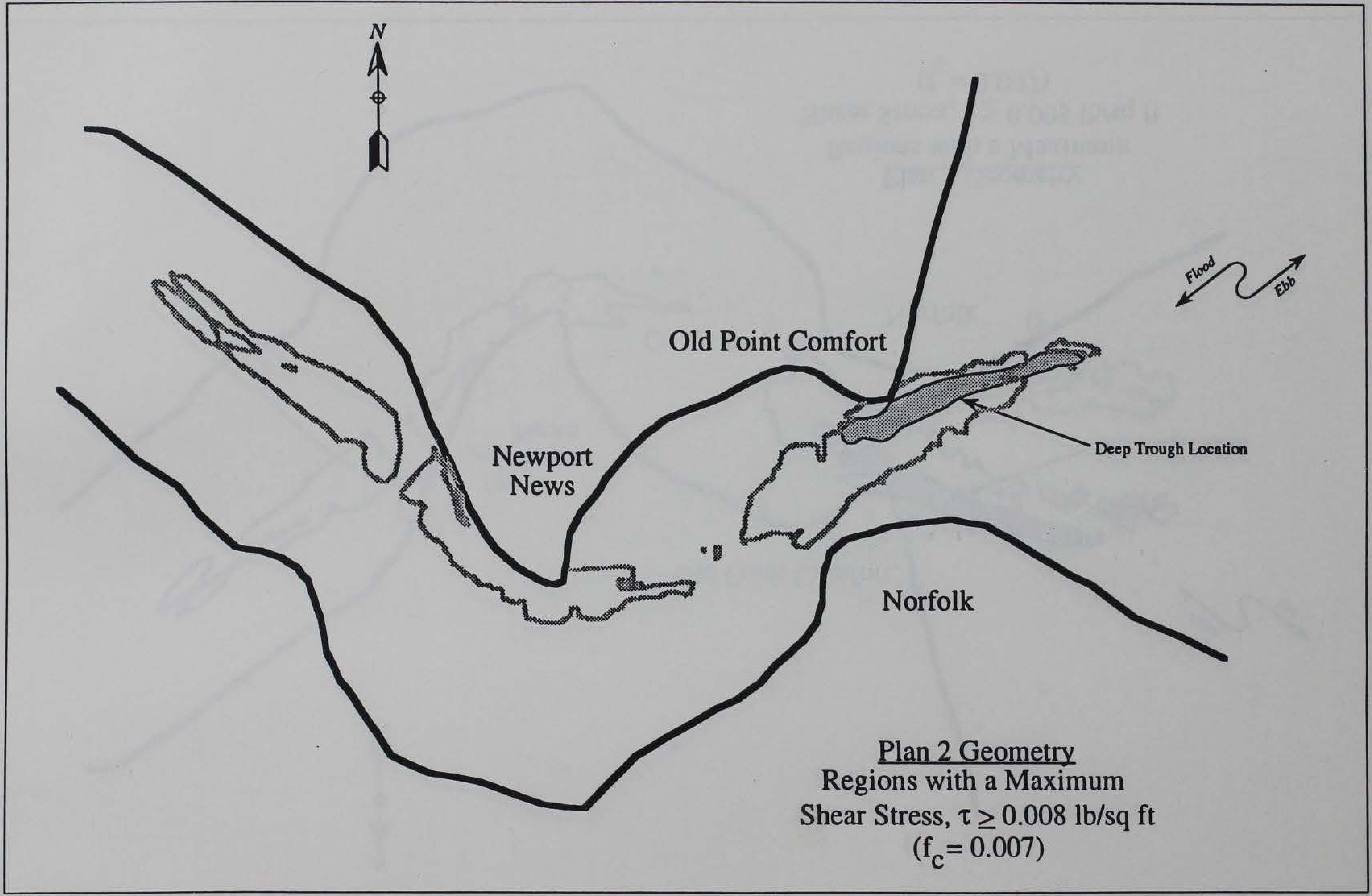


Figure 26. Plan 2 geometry - areas where $\tau \geq 0.008$ lb/sq ft during the tidal cycle

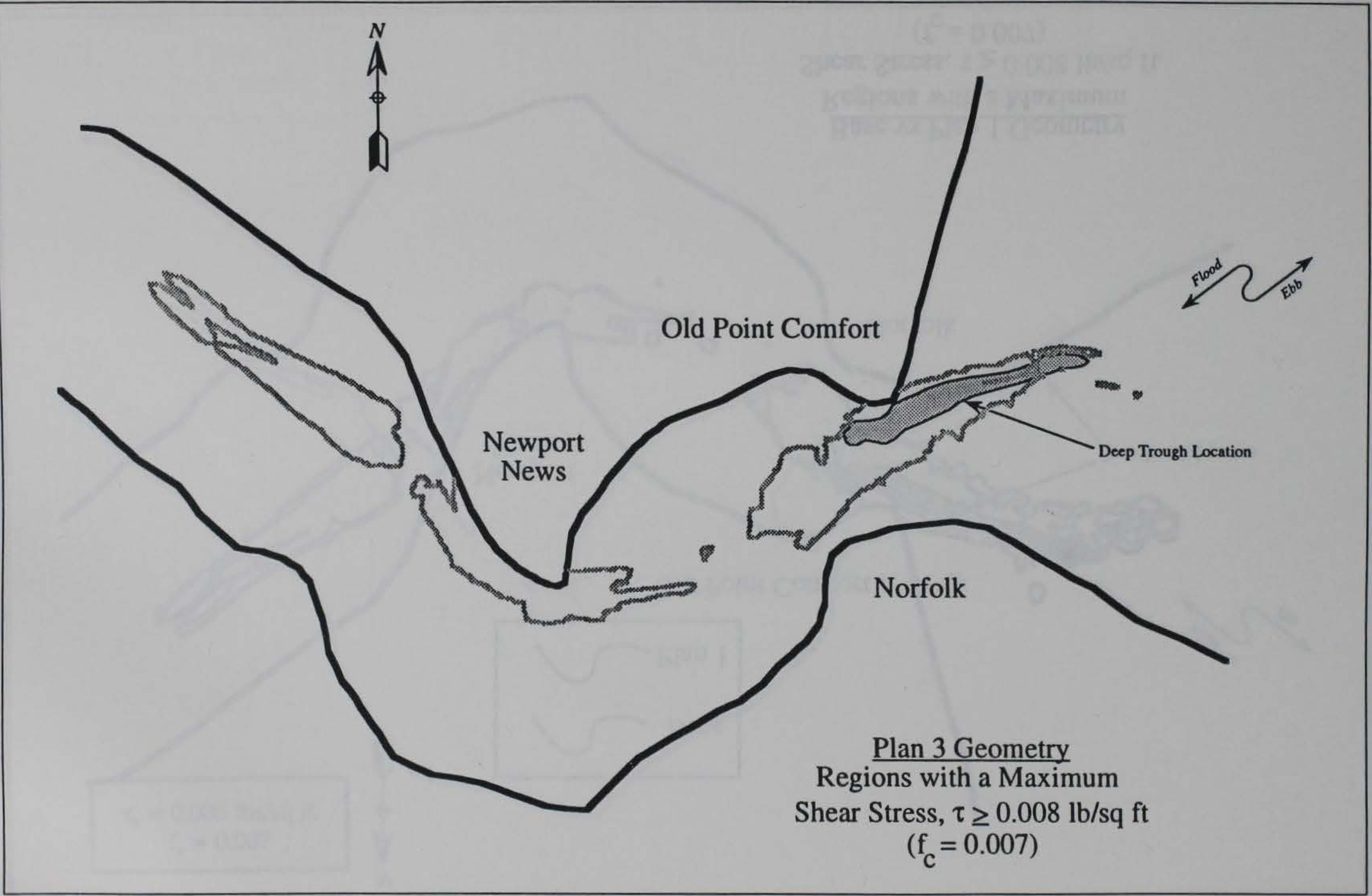


Figure 27. Plan 3 geometry - areas where $\tau \geq 0.008$ lb/sq ft during the tidal cycle

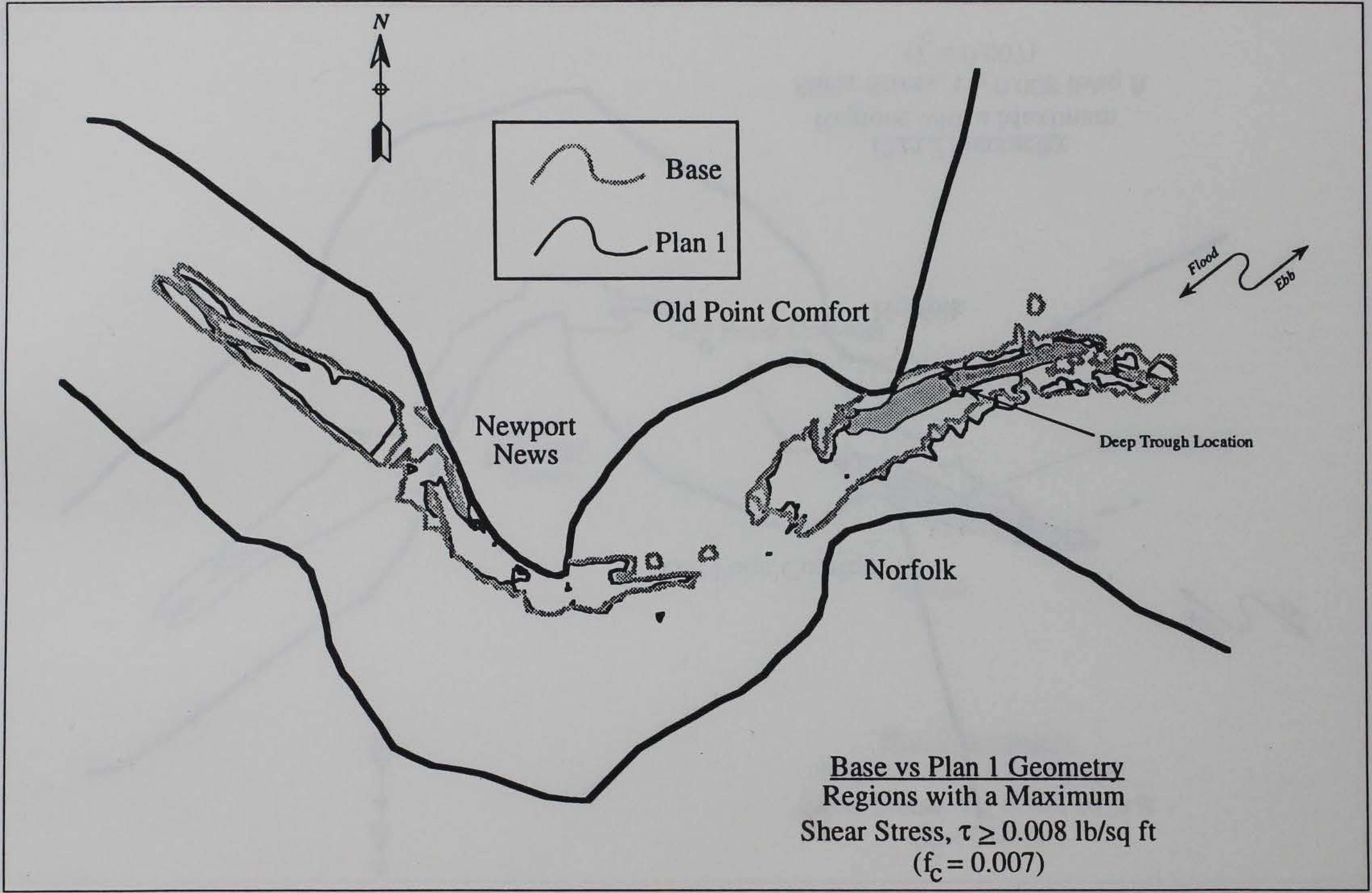


Figure 28. Base versus Plan 1 geometry - areas where $\tau \geq 0.008$ lb/sq ft during the tidal cycle

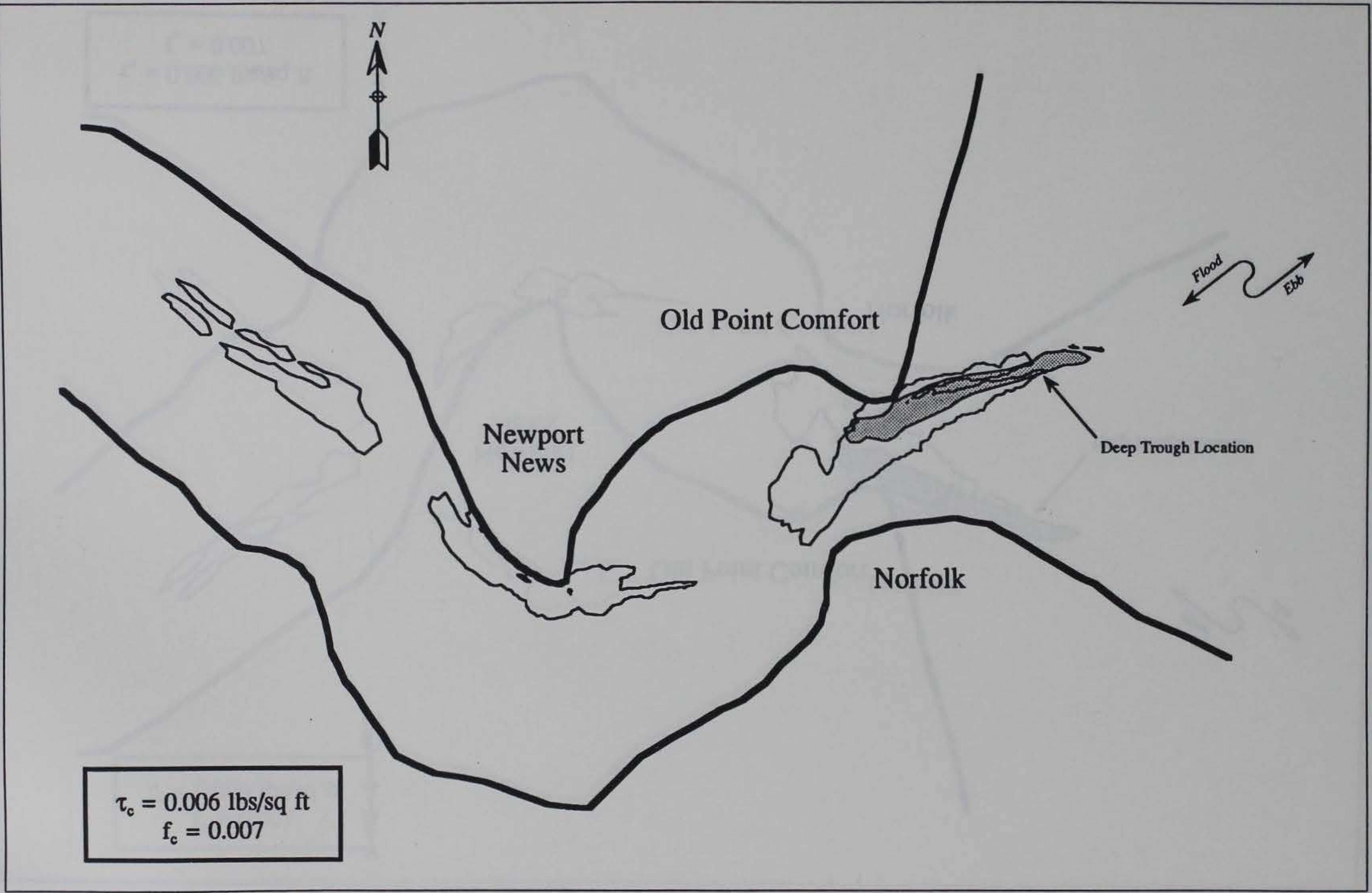


Figure 29. Base geometry region which scours at least 33 percent of the time

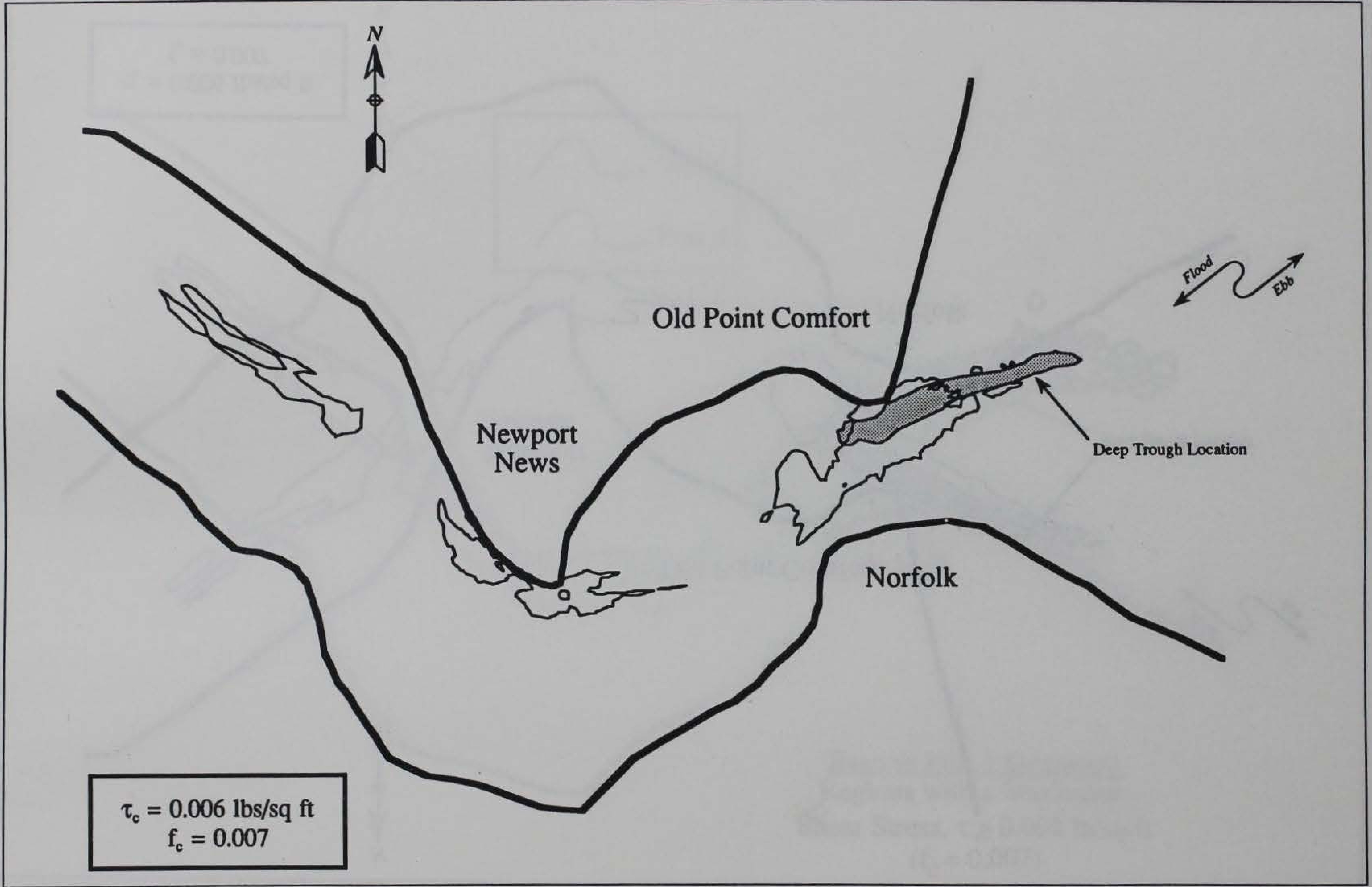


Figure 30. Plan 1 geometry region which scours at least 33 percent of the time

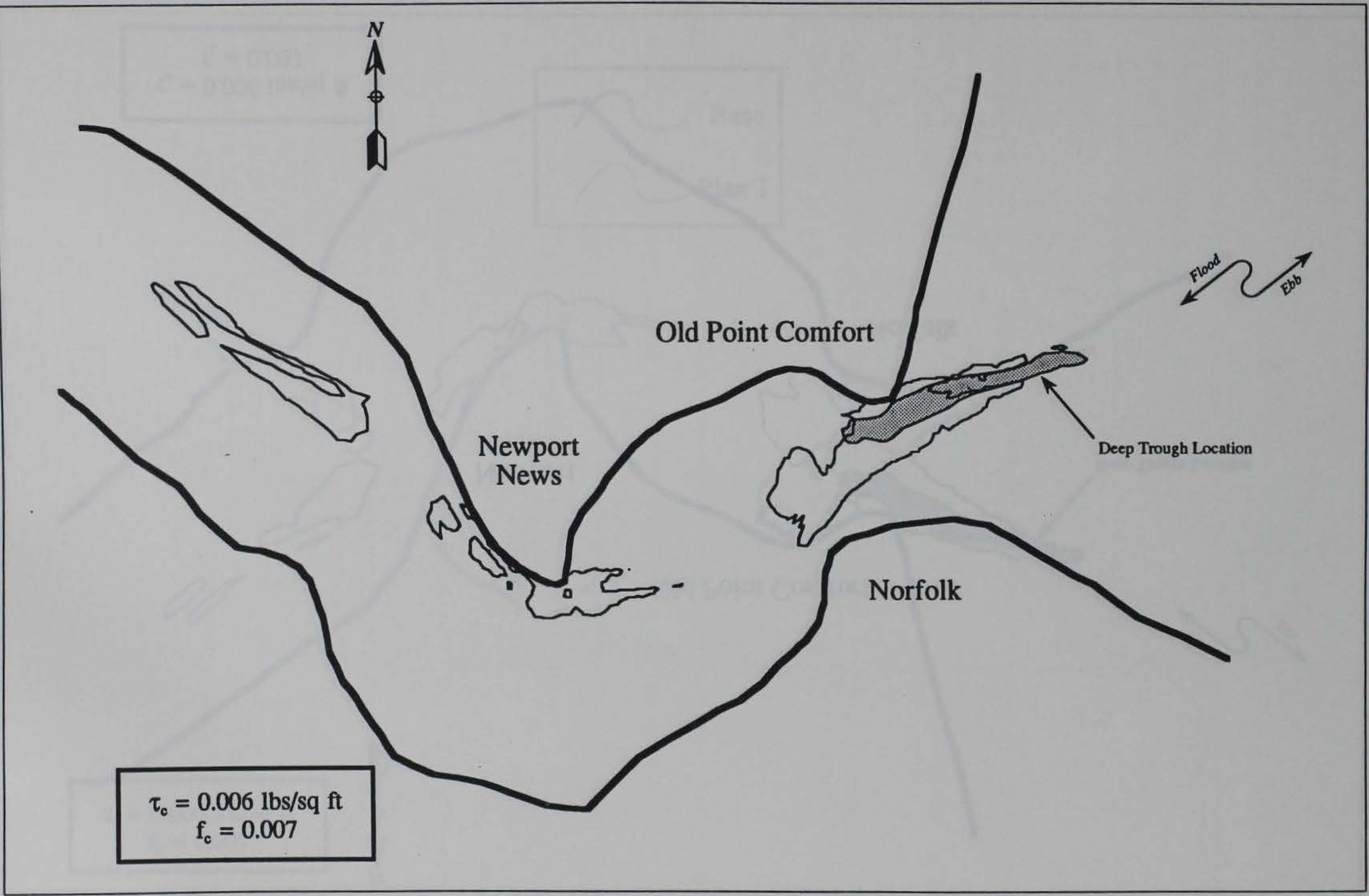


Figure 31. Plan 2 geometry region which scours at least 33 percent of the time

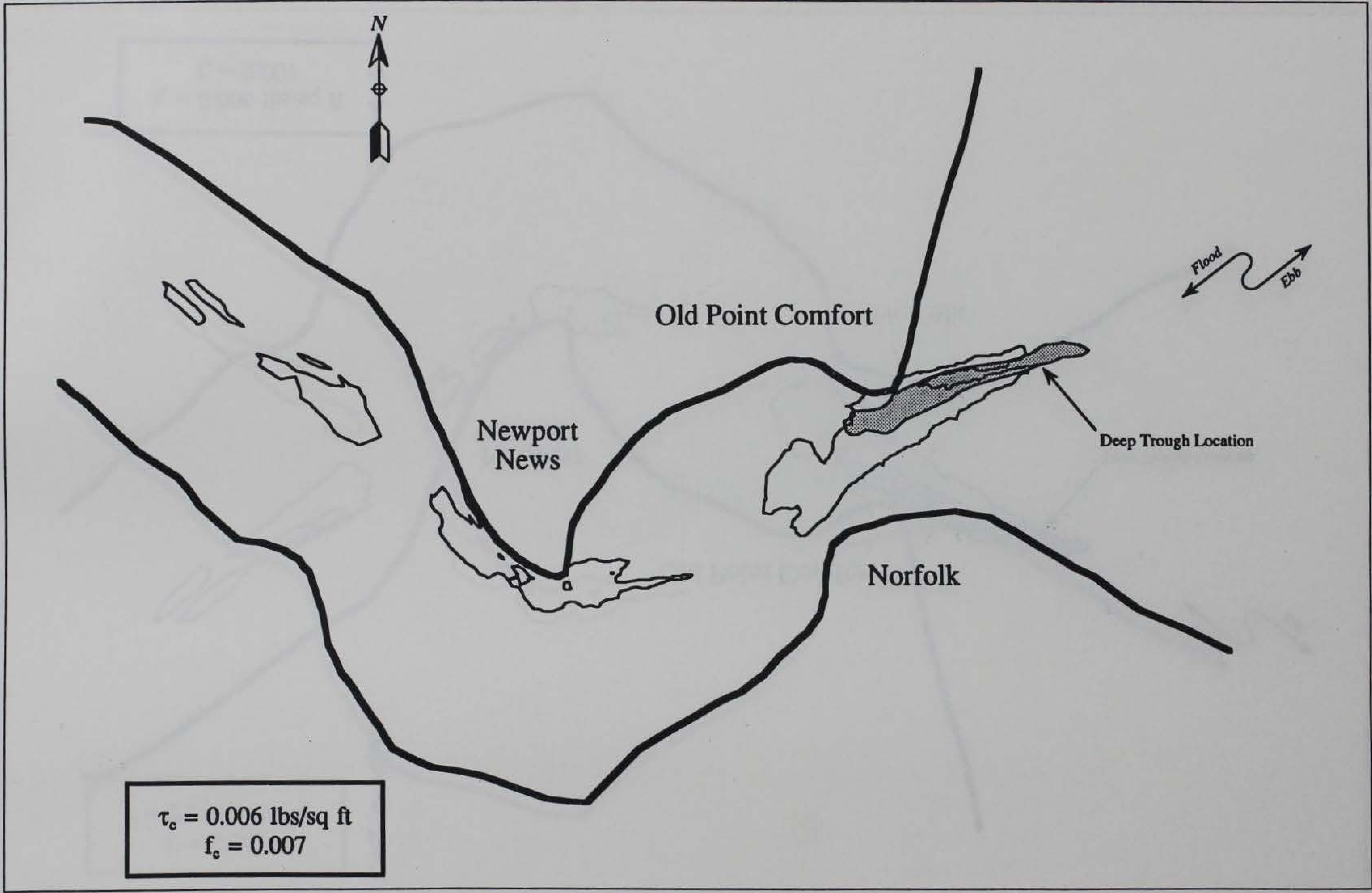


Figure 32. Plan 3 geometry region which scours at least 33 percent of the time

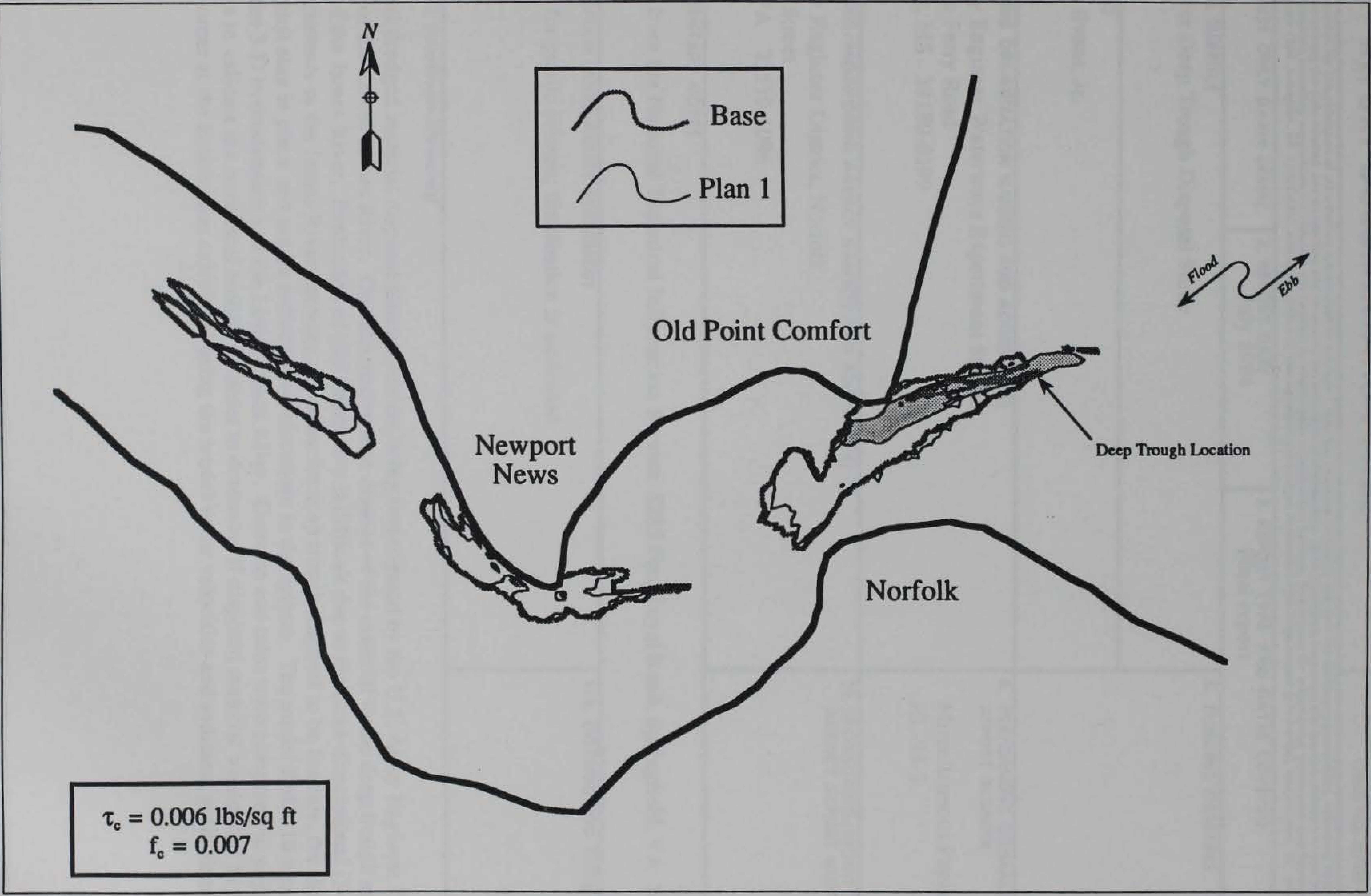


Figure 33. Base versus Plan 1 geometry region which scours at least 33 percent of the time

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13. ABSTRACT *(Maximum 200 words)*

Several dredged material disposal alternatives are being investigated by the U.S. Army Engineer District, Norfolk, for the Lower James River. One alternative is to dispose of the material in the deep trough at the entrance of the James River. Evaluation of this alternative is difficult due to the three-dimensional (3-D) nature of currents in the James River entrance. In order for deep trough disposal to be feasible, the disposed material must stay in place and not be redistributed elsewhere in the system. The model RMA-10 was used to simulate the 3-D hydrodynamics of the Lower James River. Currents and tides were compared to physical model data to validate the numerical model. In order to determine if disposed material would stay in place, the shear stress at the bottom was calculated using the model water velocities and sediment grain sizes.

14. SUBJECT TERMS See reverse.	**15. NUMBER OF PAGES** 46
	16. PRICE CODE

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14 (Concluded).

Dredge disposal
James River
Numerical hydrodynamic modeling
RMA-10
Sedimentation
Three-dimensional numerical hydrodynamic modeling