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IN COOPERATION WITH THE VERMONT AGENCY OF NATURAL RESOURCES,
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Application of a Sediment-Transport Model to Evaluate the Effect of Streambed-Management Practices on Flood Levels and Streambed Elevations at Selected Sites in Vermont

By Scott A. Olson

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CONVERSION FACTORS, SEA LEVEL, OTHER ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter
square foot (ft^2)	0.09290	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic feet per second (ft^3/s)	0.02832	cubic meter per second
foot per mile (ft/mi)	0.1894	meter per kilometer

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:
$°C = 5/9\ (°F - 32)$.

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

OTHER ABBREVIATIONS

BM	Bench Mark
C-RM	Cambridge, Vermont, elevation reference mark
ft/ft	foot per foot
FEMA	Federal Emergency Management Agency
M-RM	Montgomery, Vermont, elevation reference mark
yr	year
RR EXIT	Railroad exit section
USGS	U.S. Geological Survey
W-RM	Wolcott, Vermont, elevation reference mark
XS	cross section
NOAA	National Oceanic and Atmospheric Administration

In this report, the words "right" and "left" refer to directions that would be reported by an observer facing downstream.

Application of a Sediment-Transport Model to Evaluate the Effect of Streambed-Management Practices on Flood Levels and Streambed Elevations at Selected Sites in Vermont

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Abstract

In a study of sediment transport in three river reaches in northern Vermont affected by the flood of July 1997, three streambed management practices were evaluated to see what, if any, effect the practices had on the river channels during a 10- and 100-year recurrence interval flood. Results of the BRIdge Stream Tube model for Alluvial River Simulation indicated there were some decreases in the mean water-surface profile when a streambed-management practice of channel dredging 2 feet below the thalweg, prior to flooding, was followed as opposed to restricting the removal of any bed materials. The model, however, also showed severe erosion under some bridges during a flood if dredging was practiced. There were only minor differences, less than 1.5 feet on average, in the resulting water-surface profile between the models where scalping (removing) bars or other areas of decreased channel capacity was done prior to flooding and where the removal of bed material was restricted.

All profiles evaluated in this study did not result in changes that could be observed on existing maps. Thus, flood-boundary maps provided by Federal Emergency Management Agency's flood-insurance studies are considered to be valid.

INTRODUCTION

On July 25, 1997, the President declared a major disaster to exist in an area covering five counties in the State of Vermont as a result of widespread damage caused by excessive rainfall and flooding that began July 14, 1997. The storm produced between 4 and 8 in. of precipitation in northern Vermont, with the heaviest rainfall occurring during the early morning hours of July 15, 1997 (Federal Emergency Management Agency, 1997). The precipitation station operated by NOAA on Jay Peak, Jay, Vt., recorded 6.58 in. of rainfall (National Oceanic and Atmospheric Administration, 1997). The intense rainfall resulted in rapid runoff and severe flooding, especially in regions of steep topography. During the storm, streambed and streambank erosion and deposition were significant at several locations within the declared disaster area. Many citizens and local officials reported that the sediment deposited in stream channels constricted water flow and contributed to channel migration and elevated flood levels. Others attested that the amount of gravel in the channels would have little effect on the conveyance of such a large flood.

Since 1986, the State of Vermont's policy on streambed management restricts the removal of alluvial material (sand and gravel) from channels. The extent to which the policy affects flooding conditions during events of various magnitudes is unknown. The U.S. Geological Survey (USGS), in cooperation with the Vermont Agency of Natural Resources, Department of Environmental Conservation, began a study in October 1997, to evaluate the effect of various streambed-management practices on future flood hazards, and more specifically, the effect of restricting the extraction of alluvial material from stream channels. Three stream reaches that had been affected by the flood of July 1997, for which a flood-insurance-study model was available, and which covered a wide range of basin characteristics common to Vermont were selected for the study (fig. 1). The reaches selected were (1) a 4.3-mi reach of the Trout River in Montgomery, Vt., from 2,500 ft downstream of the State Route 118 bridge in Montgomery Center to the State Route 118 bridge in the Village of Montgomery; (2) a 6.5-mi reach of the Wild Branch in Wolcott, Vt., from the mouth to the upstream corporate limit; and (3) the entire 15.4-mi reach of the Lamoille River within Cambridge, Vt.

Purpose and Scope

This report describes the results of sediment-transport modeling to estimate the changes in channel configuration and degradation in three river reaches in Vermont. Included in the report are estimated profiles of the peak-water surface for the 10- and 100-yr floods that would result from the implementation of three streambed management practices including the effect of restricting the extraction of alluvial materials from the stream channels.

Cross sections were re-surveyed in the same locations as the cross sections of the existing flood-insurance studies for the three study reaches (Federal Emergency Management Agency, 1980 and 1982a-d). The water-surface profiles for the 10-yr and 100-yr recurrence-interval floods were recomputed using the new cross-section data to verify the water-surface profiles of the existing flood-insurance studies. Next, changes in channel configuration between the older cross sections and the newly surveyed cross sections were documented. The sediment-transport model, BRIdge Stream Tube model for Alluvial River Simulation (BRI-STARS; Molinas, 1997) was then calibrated to simulate these changes in channel configuration.

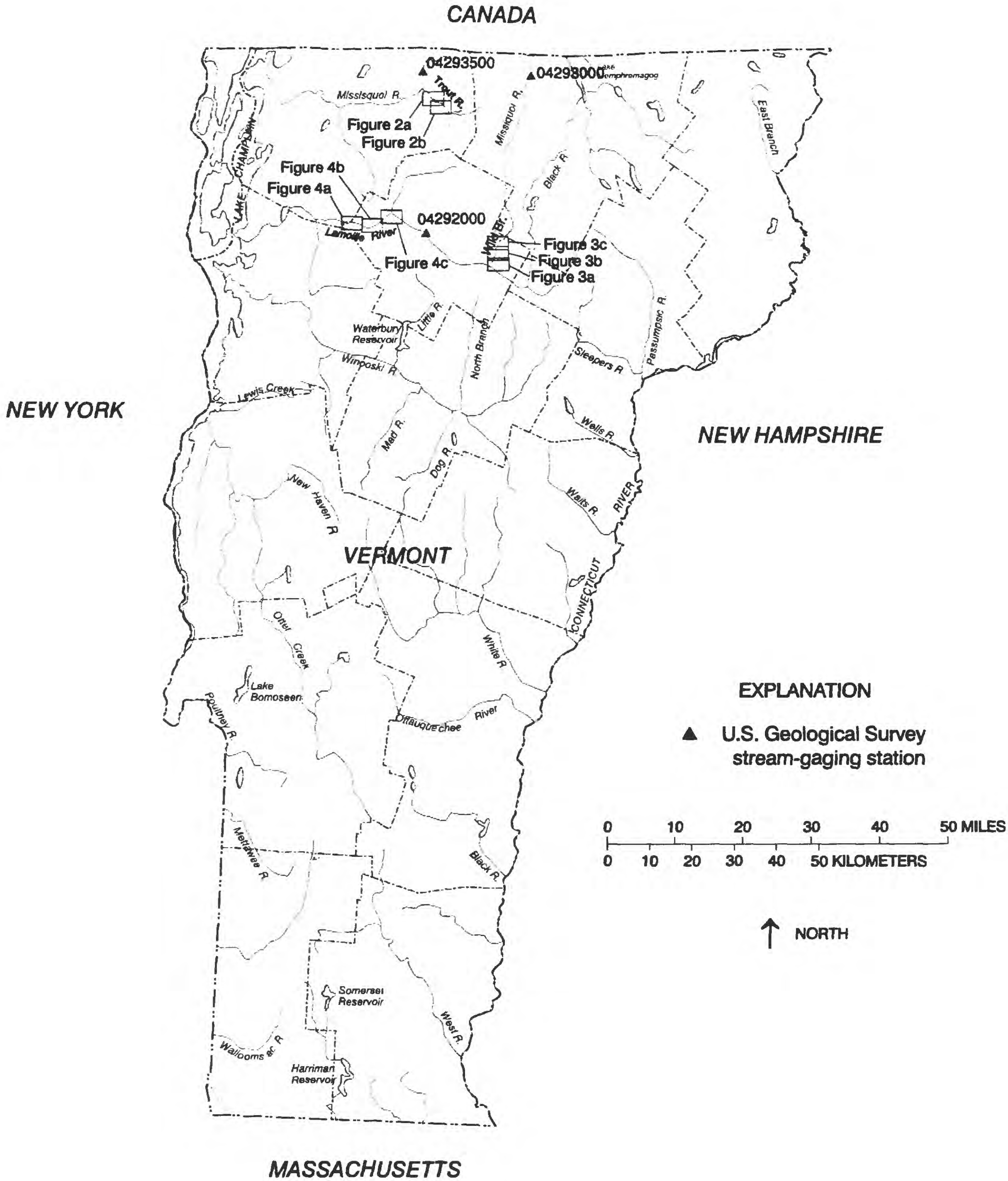
Finally, the post-flood cross sections were used as input into the calibrated BRI-STARS model and the model was used to estimate channel aggradation and degradation, and the peak water-surface profile for the 10- and 100-yr floods that would result from the implementation of three different streambed-management practices. The three practices included (1) no removal of bed material, (2) "scalping" or removing bars and other alluvial materials to increase the channel capacity, and (3) dredging the entire channel to two feet below the thalweg.

Description of Investigated Reaches

The Trout River (fig. 1) flows northwest through Montgomery, Vt., and is best defined as an upland stream of the Green Mountain physiographic region in the north-central part of the State. The mean channel slope of the reach investigated is 19 ft/mi; however, the headwaters are steep and extend to Jay Peak, which has an elevation of 3,860 ft. Montgomery Center has an elevation of approximately 530 ft. The drainage area of the Trout River at the State Route 118 crossing in Montgomery Center (fig. 2b) is 23.9 mi^2 and increases to 71.6 mi^2 at the State Route 118 crossing downstream of the Village of Montgomery (fig. 2a) (Federal Emergency Management Agency, 1980). Bed material is primarily gravel and cobble with some sand and some exposed bedrock.

The Wild Branch (fig. 1) flows south through Wolcott, Vt., along a relatively steep slope, averaging 40 ft/mi, and drains into the Lamoille River at an elevation of about 670 ft. Wolcott is in the north-central part of Vermont in the New England Upland physiographic province. The drainage area of the Wild Branch is 20.8 mi^2 upstream of North Wolcott (fig. 3c) and increases to 39.5 mi^2 at its mouth (fig. 3a) (Federal Emergency Management Agency, 1982d). Bed material ranges from sand to boulders with several locations of exposed bedrock.

The Lamoille River (fig. 1) flows west through Cambridge, Vt., along a relatively mild slope, averaging 2.3 ft/mi, with wide flood plains and steep valley walls. Cambridge is in the northwestern part of the state within the Green Mountain physiographic province. The river valley has an elevation of 460-470 ft and the headwaters and tributaries of the Lamoille River are best described as steep upland streams. The drainage area of the Lamoille River upstream of the confluence of the North Branch of the Lamoille River (fig. 4c) is 402 mi^2 and increases to 520 mi^2 at the downstream corporate limit (fig. 4a) (Federal Emergency Management Agency, 1982a-c). Bed material ranges from silt to coarse gravel with several sections having some cobbles or exposed bedrock.



Base from U.S. Geological Survey
1:2,000,000 digital line graph data

Figure 1. Locations of investigated reaches.

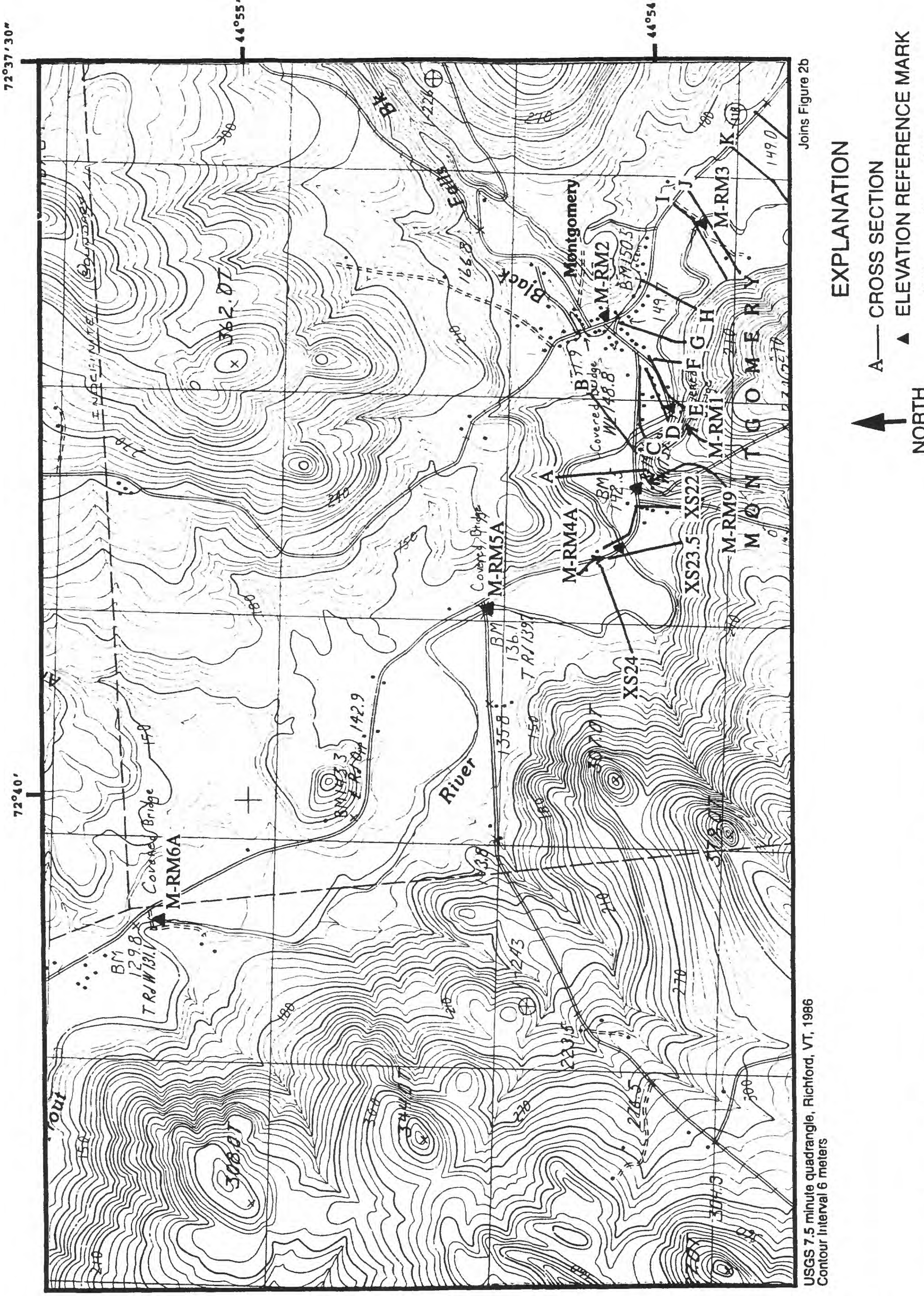
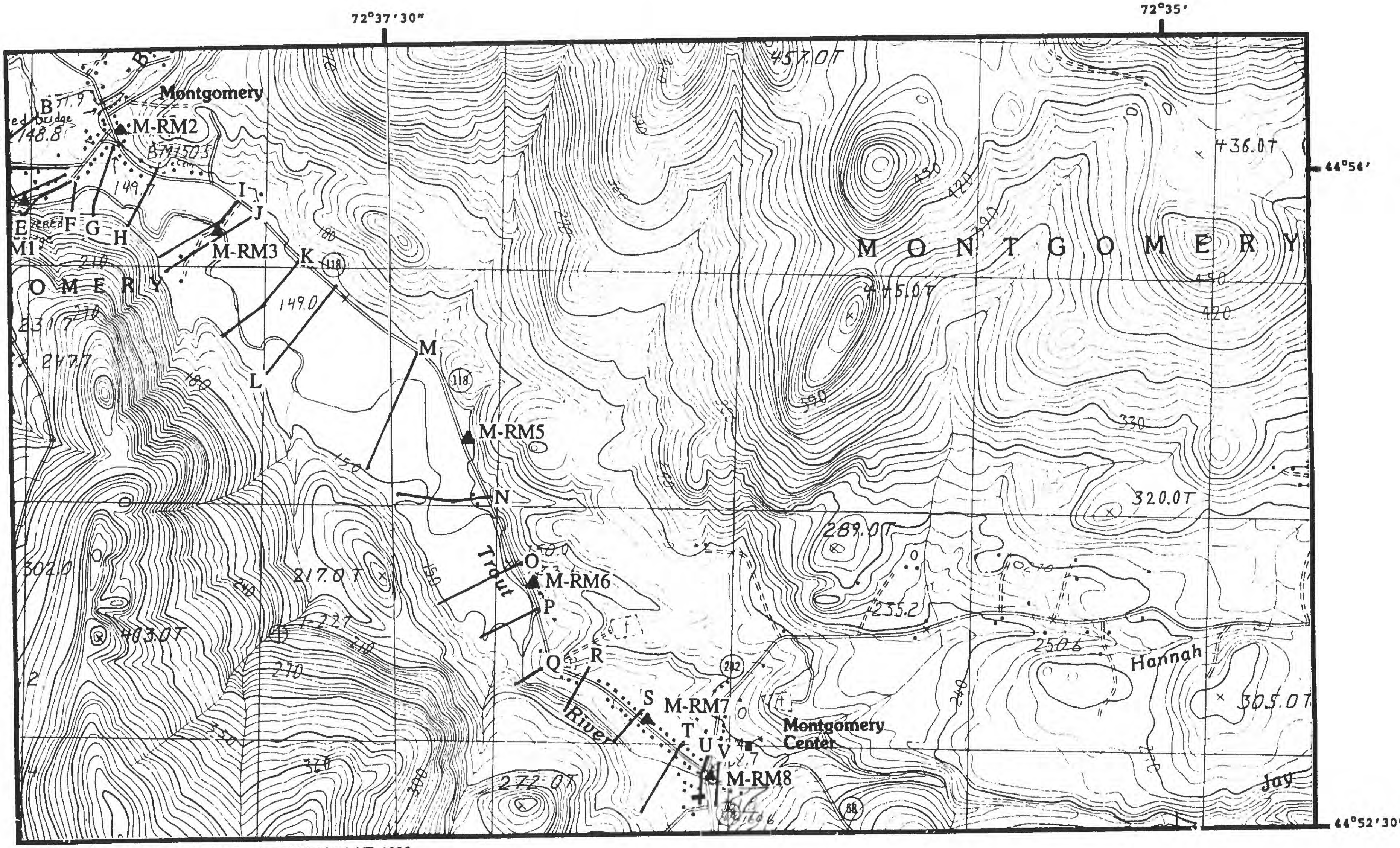


Figure 2a. Locations of cross sections in study reach in Montgomery, Vt.



USGS 7.5 minute quadrangle, Jay Peak and Richford, VT, 1986
Contour Interval 6 meters

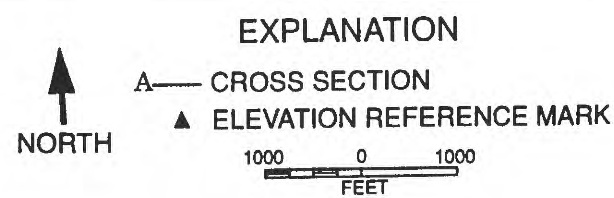


Figure 2b. Locations of cross sections in study reach in Montgomery, Vt.--Continued.

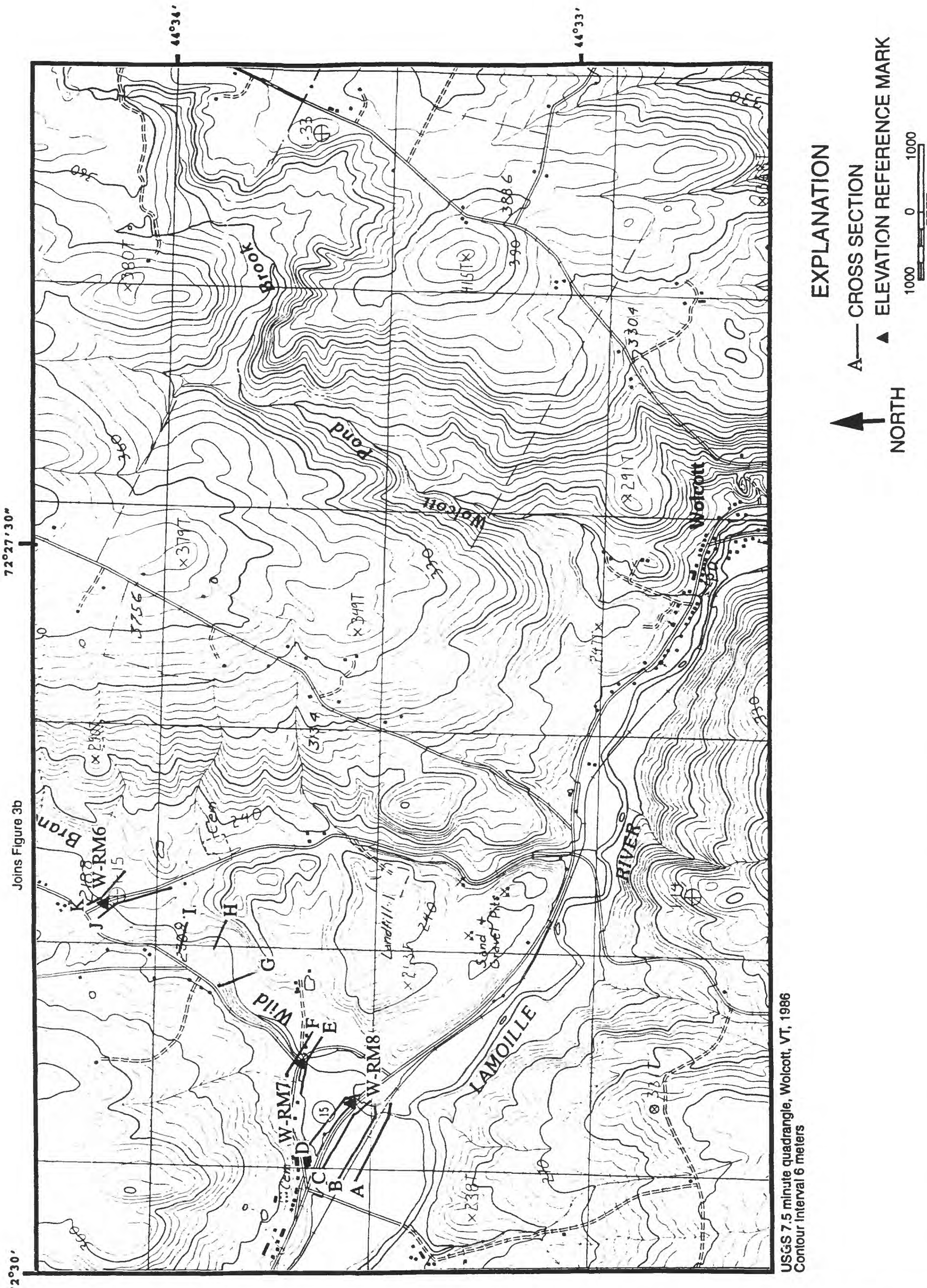


Figure 3a. Locations of cross sections in study reach in Wolcott, Vt..

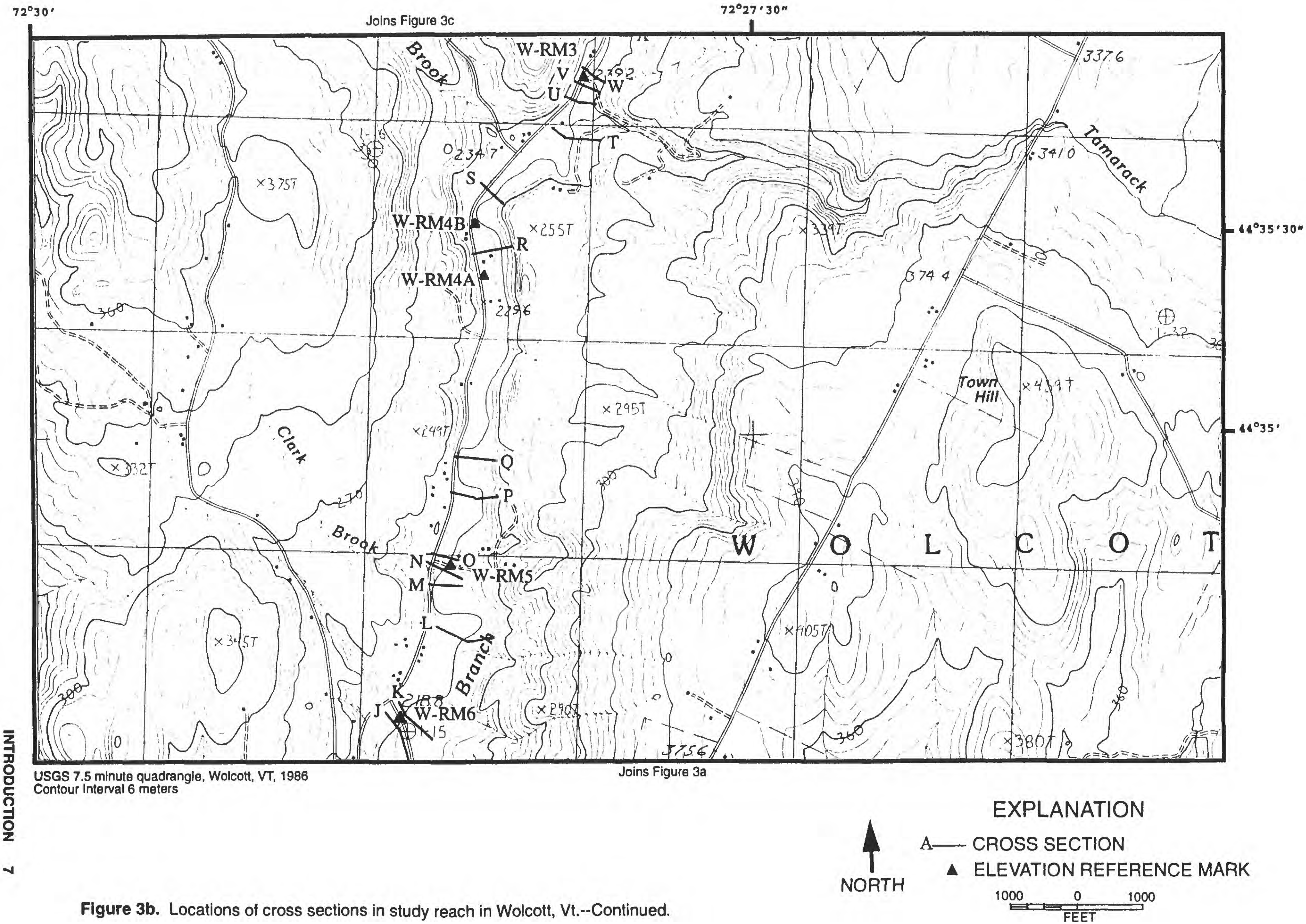


Figure 3b. Locations of cross sections in study reach in Wolcott, Vt.--Continued.

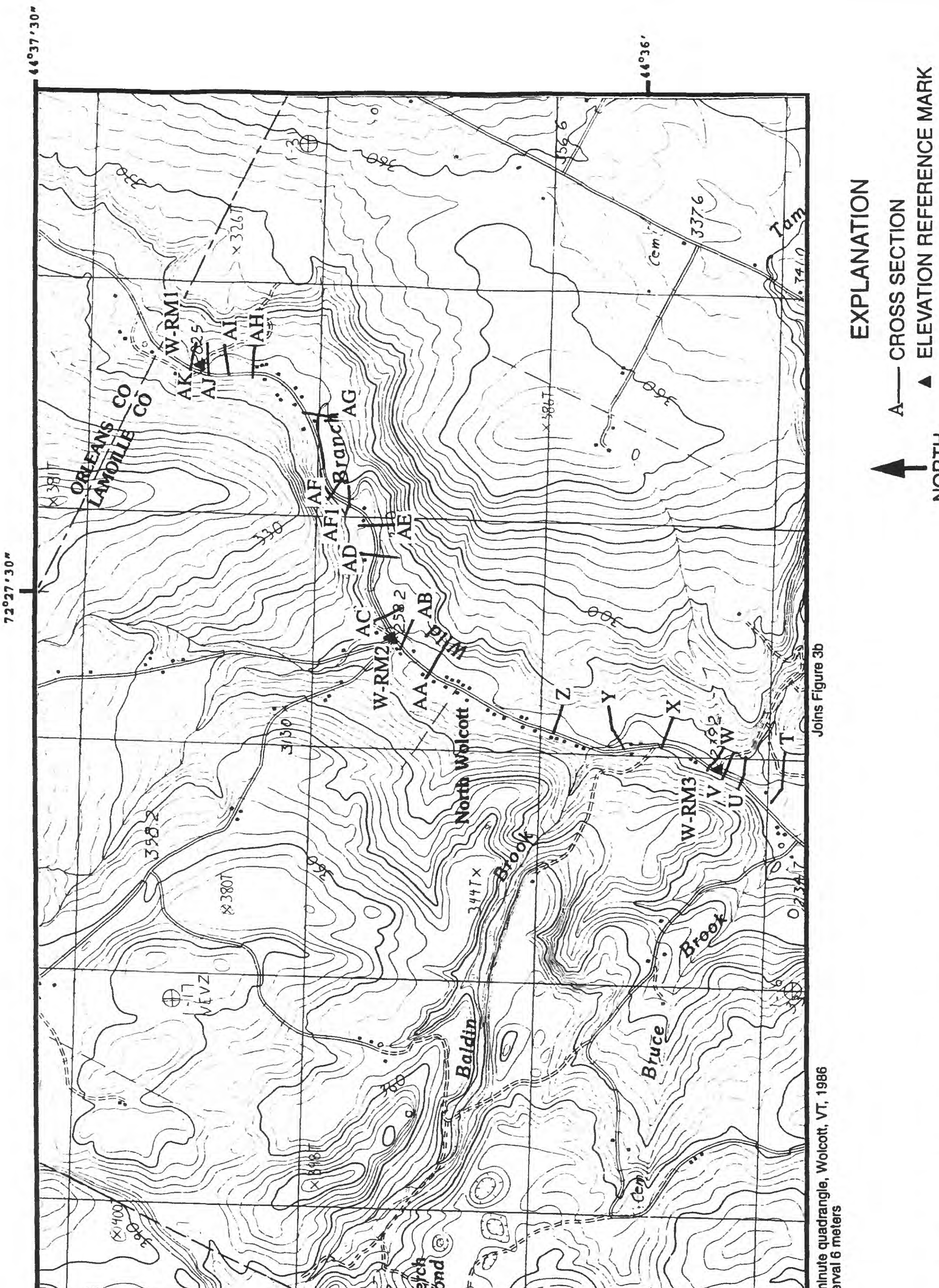
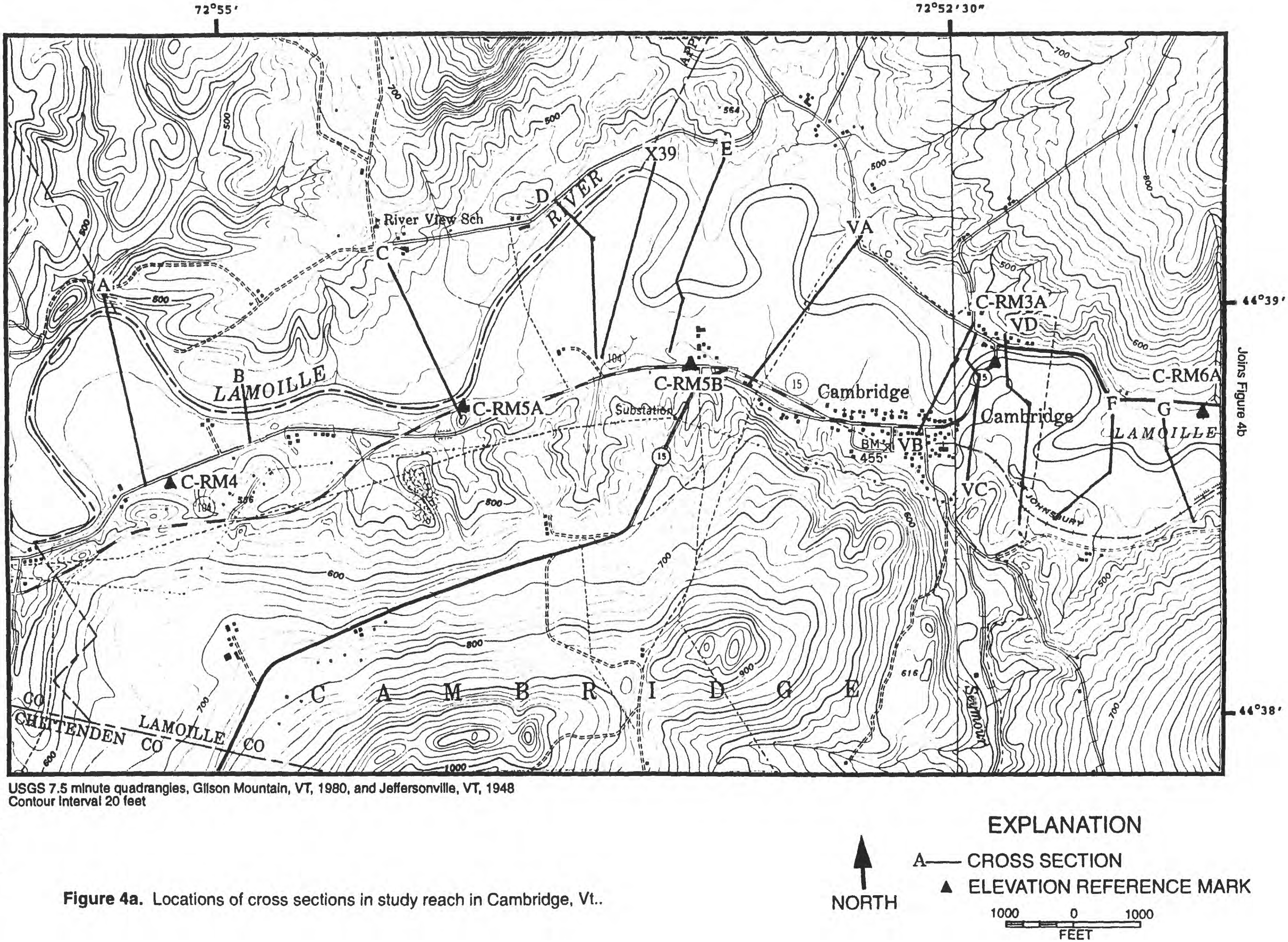


Figure 3c. Locations of cross sections in study reach in Wolcott, Vt.--Continued.



USGS 7.5 minute quadrangles, Gilson Mountain, VT, 1980, and Jeffersonville, VT, 1948
Contour interval 20 feet

Figure 4a. Locations of cross sections in study reach in Cambridge, Vt..

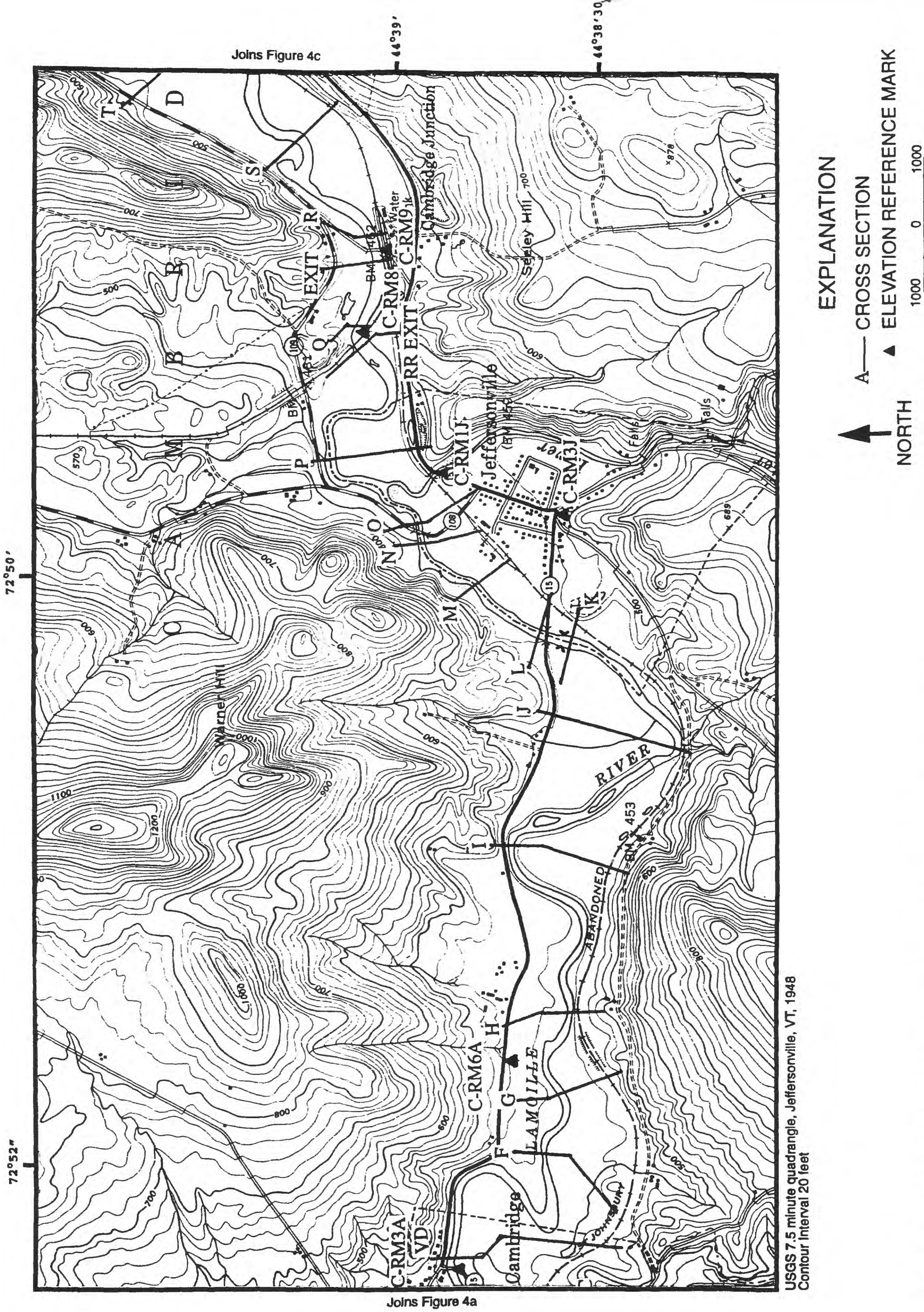
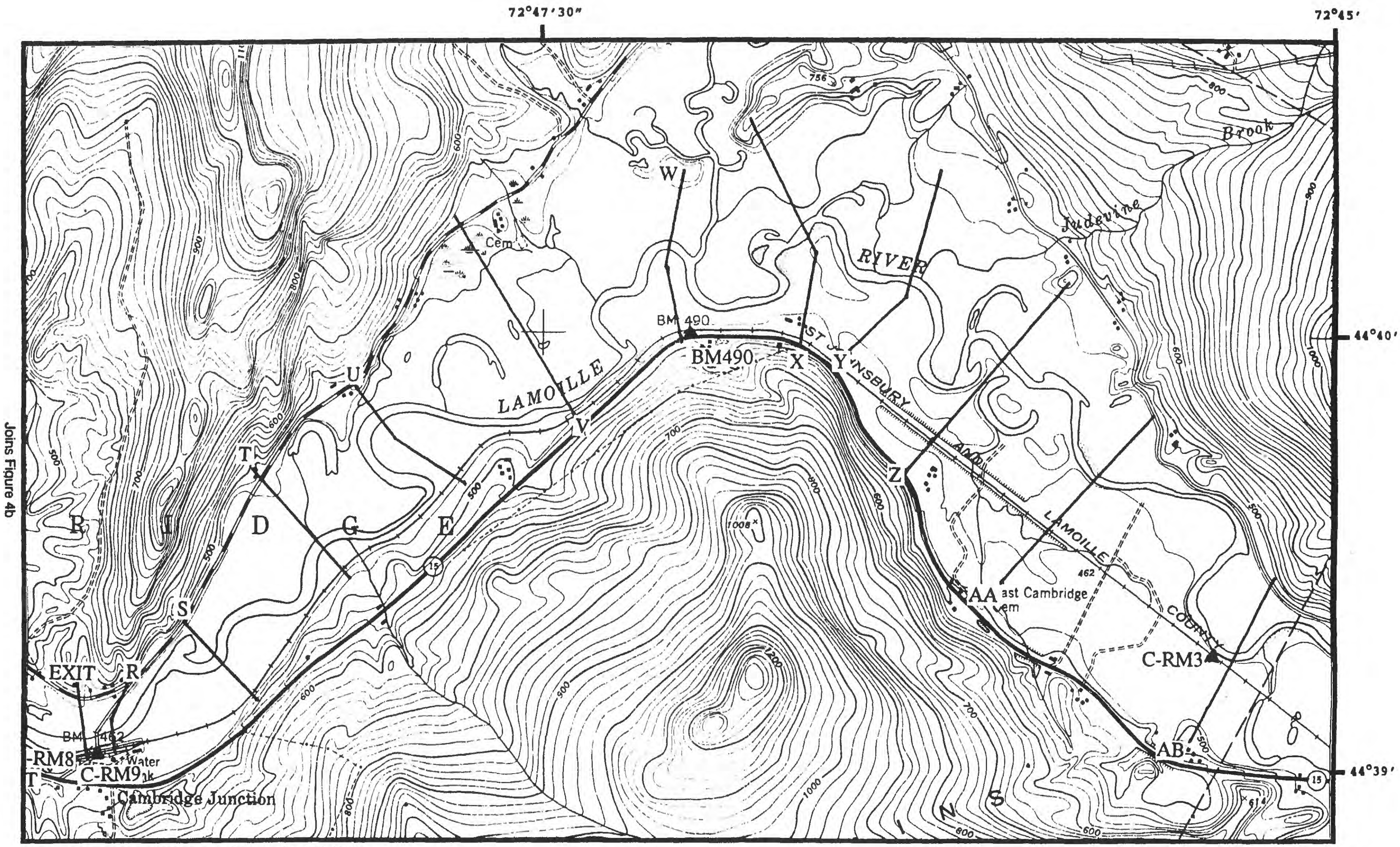


Figure 4b. Locations of cross sections in study reach in Cambridge, Vt.--Continued.



USGS 7.5 minute quadrangle, Jeffersonville, VT, 1948
Contour interval 20 feet

NORTH

EXPLANATION

A—— CROSS SECTION

▲ ELEVATION REFERENCE MARK

1000 0 1000
FEET

Figure 4c. Locations of cross sections in study reach in Cambridge, Vt.--Continued.

Acknowledgments

This report is the culmination of an intensive effort by dedicated personnel of the USGS. The following employees provided significant help collecting and analyzing the data and (or) preparing the report: Erick M. Boehmler, Robert O. Brown, Ronda L. Burns, Michael F. Coakley, Jon C. Denner, Robert H. Flynn, Debra H. Foster, Robert E. Hammond, Michael A. Ivanoff, Richard G. Kiah, William H. Kirby, Laura Medalie, Joseph R. Olimpio, Ann Marie Squillacci, Jerry E. Vaill, Jr., Emily C. Wild, and Chester Zenone.

METHODS OF FIELD DATA COLLECTION

Following the July 1997 flood, the USGS, in cooperation with FEMA, flagged and surveyed high-water elevations throughout the three study reaches. These data were crucial to the model calibrations.

Post-flood channel geometry was surveyed, insofar as possible, at the same location as the cross sections of the existing flood-insurance study of the corresponding community. The cross-section data from the existing flood-insurance study and the newly surveyed data will be referred to as the pre- and post-flood cross sections, respectively. This re-surveying of the cross sections allowed comparison of channel geometry and documentation of changes. There were limitations that affected this comparison. First, the exact location of the pre-flood cross sections were difficult to determine, especially at sections that did not have a nearby landmark such as a bridge, road, or channel bend. Secondly, the geometry of many of the pre-flood cross sections was determined by aerial photography techniques, and the streambed indicated was actually the water surface—with some sections having adjustments for depth. The pre- and post-1997 flood cross sections are shown in Appendix A.

Bed material size distribution was also determined at each cross section. At sections in which the median grain size of the bed material was greater than about 4 mm, the particle-size distribution was determined using a pebble count technique (Hayes, 1993). At sections with a median grain size less than 4 mm, the particle-size distribution was determined by sieving a grab sample collected at that section.

FIXED-BED WATER-SURFACE PROFILES

The cross sections surveyed after the 1997 flood were used as input to a fixed-bed step-backwater model to verify the existing flood insurance study profiles for the study reaches. Water-surface profiles for the 10- and 100-yr floods were updated by use of the Model for Water-Surface PROfile (WSPRO) Computations (Shearman, 1990).

The 10- and 100-yr flood discharges used in the WSPRO models were taken from existing flood-insurance-study models (Federal Emergency Management Agency, 1980 and 1982a-d). Starting water-surface elevation at the downstream end of each model was assumed to be normal depth for the Wolcott and Cambridge computations. Normal depth was computed by means of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990). The slope used was the energy-grade-line slope of the existing flood-insurance study at the appropriate section—0.00429 ft/ft for the Lamoille River and 0.00814 ft/ft for the Wild Branch. The starting water surface for the Montgomery computation was taken from a model (Robert Flynn, U.S. Geological Survey, oral commun., April 1999), for the reach of the Trout River in Montgomery immediately downstream of the sediment-transport study area.

Cross-section roughness factors (Manning's "n") were taken from the existing flood-insurance-study models and were updated at many of the sections on the basis of field observations, following the general guidelines of Arcement and Schneider (1989). The range of roughness values used can be found in table 1. The resulting 10- and 100-yr water-surface profiles are compared to the 10- and 100-yr water-surface profiles of the existing flood-insurance study in Appendix B. The comparisons of the water-surface profile computed from the re-surveyed cross section to the existing profile in the flood-insurance studies are shown in table 2. Although some local, significant

Table 1. Range of roughness coefficients (n) used in the Trout River, Wild Branch, and Lamoille River models

Studied reach (fig. 1)	Channel n-values	Overbank n-values
Trout River, Montgomery, Vt.	0.035-0.055	0.035-0.095
Wild Branch, Wolcott, Vt.	0.030-0.060	0.030-0.100
Lamoille River, Cambridge, Vt.	0.028-0.050	0.035-0.200

Table 2. Summary of the differences between water-surface profiles computed by fixed-bed models and the profile of existing flood-insurance studies in Vermont

[ft, foot; + indicates an elevation increase; river locations are shown on figure 1]

Studied reach and event	Maximum increase in peak water surface (ft)	Maximum decrease in peak water surface (ft)	Average change with respect to existing profile (ft)
Trout River, 10-year flood	3.1	2.8	+0.1
Trout River, 100-year flood	4.3	2.7	+0.0
Wild Branch, 10-year flood	4.2	2.8	+0.4
Wild Branch, 100-year flood	3.7	1.0	+0.8
Lamoille River, 10-year flood	2.8	1.2	+1.3
Lamoille River, 100-year flood	3.6	0.5	+1.6

discrepancies between the profiles are evident, the average difference between the water-surface elevation at corresponding cross sections ranged from 0.0 to 1.6 ft (table 2).

Changes in the water-surface profile cannot be attributed entirely to changes in the channel geometry. The HEC-2 model (U.S. Army Corps of Engineers, 1977) was used to compute the profile for the existing flood-insurance studies and WSPRO was used to compute the water-surface profiles with data from the re-surveyed cross sections. The two models do have some differences, particularly in the techniques used to compute a water-surface profile through a bridge opening. These different techniques used at bridges is the primary cause for the increase in the peak water surface in the Cambridge, Vt. water-surface profile of the Lamoille River.

SEDIMENT-TRANSPORT MODEL

The sediment-transport model BRI-STARS was used to evaluate the effect of streambed-management practices on future flood hazards. BRI-STARS is a movable bed model that can be applied to route water and sediment through natural river channels (Molinas, 1997). The model is composed of the following three major components: (1) step-backwater computations, (2) stream-tube computations, and (3) sediment-routing computations. Computations are defined by a hydrograph divided into time steps. At each time step, backwater computations are carried out for the entire reach. With the computed water-surface profile, lateral locations of each stream tube in each section are determined. With each stream tube treated as an independent channel, hydraulic variables are computed and sediment is routed through each tube. At the end of these computations, bed-material compositions are revised and channel-bed elevations are updated.

Because computer modeling of sediment transport is still in its developmental stages, the ability of models such as BRI-STARS to accurately simulate sediment transport processes and effects is limited. Some limitations are as follows: (1) computer-based models currently available do not incorporate an adequate treatment of armoring processes (Richardson and others, 1990); (2) BRI-STARS is not capable of computing pressure flow through bridges when the water surface is in contact with the low chord of the bridge; and (3) lateral movement and the formation of meander bends and bed forms cannot be adequately simulated.

Data requirements for BRI-STARS include channel geometry, bed-material distribution, water temperature, a flood hydrograph, a stage-discharge relation, a sediment-transport equation, and channel roughness data. These factors will be discussed in the following sections. A sediment-inflow hydrograph at the most upstream section also is needed; however, BRI-STARS can develop a sediment-inflow hydrograph based on the user-specified sediment-transport equation (Hilmes and Vaill, 1997).

Model Calibration

The first step in modeling sediment transport with BRI-STARS was to calibrate the models to simulate the channel changes observed between the pre-flood and post-flood cross sections. The accuracy of this simulation is limited by the lack of streambed definition in some of the pre-flood cross sections and the assumption that all observed channel modifications occurred during the July 1997 flood. Although significant channel modifications were observed following the July 1997 flood, the pre-flood sections were collected for flood insurance studies that were published in 1980 and 1982, and it is likely that some changes in channel configuration between the early 1980's and 1997 occurred during hydrologic events other than the July 1997 flood. However, these data are the only information available, and the cross sections from the existing flood insurance studies (Federal Emergency Management Agency, 1980 and 1982a-d) were used as the pre-flood condition in the BRI-STARS calibration. The models were also calibrated to the high-water profile of the July 1997 flood. With the pre- and post-streambed profiles and 1997 flood water-surface profile known, the flood discharges, the time step of the computations, the roughness coefficients, the coefficients of expansion and contraction, the sediment-transport equation, and the local energy-loss coefficients were selected to improve the simulation (table 3).

The final estimated discharges for the July 1997 flood determined from the calibration runs are listed in table 4. BRI-STARS also requires a flood hydrograph. A synthetic flood hydrograph was developed using the Soil Conservation Service dimensionless hydrograph (U.S. Bureau of Reclamation, 1974). For these intense events, the lag time, estimated by Snyder's method (Bedient and Huber, 1988), was assumed to approximate the time to the peak used in the time ratio of the dimensionless hydrograph. The resulting hydrographs are shown in figure 5.

The recurrence intervals of the estimated 1997 flood discharges are unknown; however, a comparison between these discharges and frequency data from the flood insurance studies (Federal Emergency Management Agency, 1980 and 1982a-d) indicates that the Trout River and the Wild Branch study reaches experienced a flood greater than a 100-yr event and the flood on Lamoille River in Cambridge was between a 10- and 100-yr event. Peak discharges of the 1997 flood at USGS stream-gaging stations near the study areas and the corresponding recurrence intervals of these peaks are listed in table 5 for comparison.

The sediment-transport equation used for each of the models was the Meyer-Peter Muller equation (Shen and Julien, 1993). This equation produced the best results and is the preferred equation when dealing with sediment that is relatively coarse such as gravel and cobble.

The final variables modified in calibration were the energy-loss coefficients. Because each reach studied had several bridges and the bridge routines in BRI-STARS can handle only one bridge per model run, those routines were not utilized. In addition, BRI-STARS' bridge routines cannot account for pressure flow—when the water surface is in contact with the bridge deck. Instead of using the bridge routines, an option that incorporates user-supplied local energy-loss coefficients at the bridge section was used. This technique was recommended for the BRI-STARS model before the bridge routines were incorporated (Molinas, 1989). The coefficients were adjusted until the losses through a bridge computed by BRI-STARS either matched the losses observed from the surveyed profile of the July 1997 flood or matched the results of the WSPRO model calibrated to the July 1997 flood at the bridge. Coefficients at bridges ranged from 0.0 to 1.5.

Table 3. Variables set during the calibration of the BRI-STARS model for the Trout River, Wild Branch, and Lamoille River, Vermont

[Meyer-Peter/Muller sediment-transport equation is from Shen and Julien, 1993]

Variable	Trout River, Montgomery	Wild Branch, Wolcott	Lamoille River, Cambridge
Coefficient of expansion	0.3	0.5	0.5
Coefficient of contraction	0.1	0.1	0.1
Time step length, hours	0.8	1.5	2.5
Water temperature, ^{o}F	70	70	70
Number of stream tubes	1	1	3
Sediment transport equation	Meyer-Peter/Muller	Meyer-Peter/Muller	Meyer-Peter/Muller

Table 4. Magnitude of flood discharges used in model simulations of the Trout River, Wild Branch and Lamoille River, Vermont

[mi^2, square miles; ft^3/s, cubic feet per second; locations are found in figures 1-4]

Flooding source	Drainage area (mi^2)	10-year discharge (ft^3/s)	100-year discharge (ft^3/s)	July 1997 flood discharge (ft^3/s)
Trout River				
Downstream of West Hill Brook	71.6	9,400	18,000	28,000
Upstream of West Hill Brook	59.0	7,600	14,500	22,000
Upstream of Black Falls Brook	48.4	6,100	11,500	17,500
Upstream of South Branch Trout River	23.9	3,550	7,600	12,000
Wild Branch				
At mouth	39.5	3,100	6,340	8,400
Upstream of Tamarack Brook	27.6	2,410	4,930	6,800
Upstream of North Wolcott	20.8	1,980	4,050	4,800
Lamoille River				
At downstream corporate limit	520	16,000	29,250	22,000
Upstream of Seymour River	489	15,000	26,250	19,000
Upstream of Brewster River	464	14,500	25,250	18,000
Upstream of North Branch Lamoille River	402	13,100	22,900	17,000

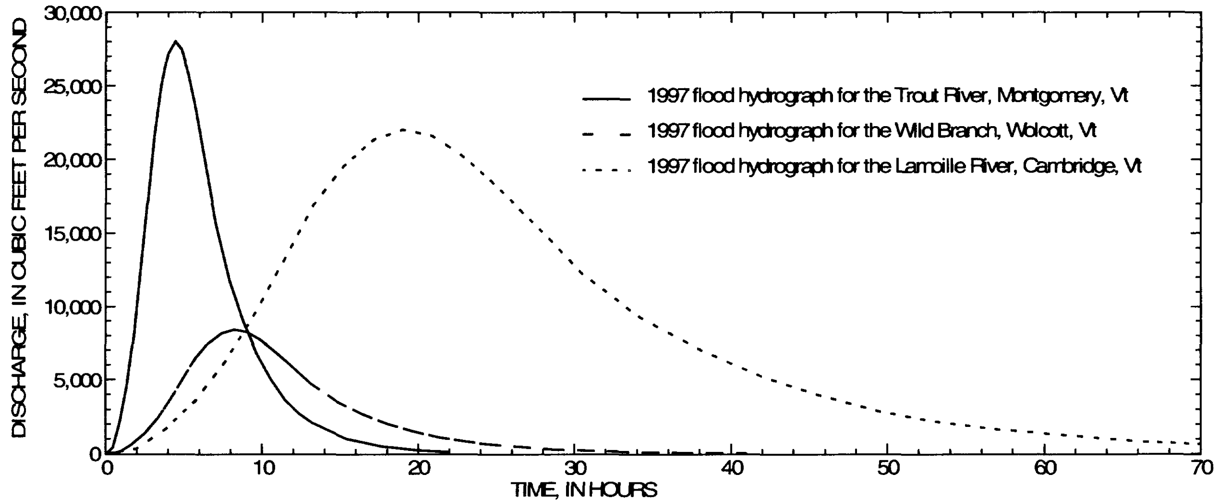


Figure 5. Estimated hydrographs for the 1997 flood at the downstream end of the study reaches for the Trout River, Wild Branch, and Lamoille River.

Table 5. Peak discharges and approximate recurrence intervals at selected U.S. Geological Survey stream-gaging stations in Vermont

[mi ^{2}, square mile; ft^3/s, cubic foot per second; (Coakley and others, 1998; Robert Hammond, U.S. Geological Survey, oral commun., March 16, 1998)]

Gaging station (fig.1)	Gaging station No.	Drainage area (mi^2)	1997 Event peak discharge (ft^3/s)	Approximate recurrence interval, in years
Lamoille River at Johnson, Vt.	04292000	310	12,900	10 to 25
Missisquoi River at North Troy, Vt.	04293000	131	8,940	100 to 200
Missisquoi River at East Berkshire, Vt.	04293500	479	17,500	25 to 50

Additional data required in the models, but not adjusted for calibration purposes, were the stage-discharge relation at the section farthest downstream and the bed-material-size distribution. The stage-discharge relation was assumed to be normal depth at any given rate of streamflow. The normal depth was computed on the basis of the instantaneous slope of the energy-grade line at the downstream-most section of the study reaches. The slope of the energy grade line was estimated from hydraulic data for the 1997 flood.

The bed-material-size data entered into the models were determined from the grain-size analysis of bed samples collected at each cross section after the 1997 flood. The bed material in the Trout River reach was primarily gravel and cobble with some sand and some exposed bedrock. The bed material in the Wild Branch reach ranged from sand to boulders with several locations of exposed bedrock. The bed material in the Lamoille River reach ranged from silt to coarse gravel with several sections having some cobbles or exposed bedrock.

The simulation results from the calibrated models are considered adequate. For the Trout River, the model simulated the final thalweg within 3.3 ft at 80 percent of the cross sections and the 1997 peak water surface within 2.8 ft at 80 percent of the cross sections. For the Wild Branch, BRI-STARS estimated the final thalweg within 3.2 ft at 76 percent of the cross sections and the 1997 peak water surface within 1.3 ft at 79 percent of the cross sections. For the Lamoille River, the model estimated the final thalweg within 4.0 ft at 74 percent of the cross sections and the 1997 peak water surface within 0.6 ft at 88 percent of the cross sections. Although BRI-STARS could not simulate the actual conditions with 100 percent accuracy, trends and patterns of aggradation and degradation were similar to what was observed after the flood of 1997.

Simulation of the Effects of Streambed-management Practices

Fluvial processes, such as erosion and deposition of materials by flowing water, are complex. A complete description of the fluvial processes in the three study reaches was beyond the scope of this investigation and beyond the capabilities of the model. Management of a channel in regards to this study refers only to the removal of streambed materials. Bank protection and other channel improvements were not considered. Three streambed-management practices were selected for evaluation in this study. The first practice was based on current State policy that restricts the removal of streambed materials from channels. The second practice evaluated was based on typical channel alterations and practices prior to 1986, when the current State policy took effect. The third practice was based upon the popular opinion that channels need to be dredged. The BRI-STARS model was used to determine the peak water-surface and the final streambed profiles for a 10- and a 100-yr flood in each reach that would result from the implementation of each of the management practices.

With the calibrated models established, the model input was modified to reflect the current channel geometry, a pre-flood streambed-management practice, and the 10- and 100-yr flood hydrographs. All other variables were kept constant. Modifying the model to reflect the current channel geometry was simply done by using as input the cross sections surveyed following the July 1997 flood. This modification represented the first streambed-management practice—no removal of bed material.

The second management practice included "scalping" or removing bars and other deposits in channels above the water surface—a common practice prior to the 1986 statute restricting such extraction. To simulate this practice, the model input was modified by editing cross-section geometry points of the model described in the previous paragraph on the basis of descriptions written by the surveyors and the elevation of the water surface at the time of the survey. The surveying was done during relatively low water.

The third streambed-management practice to be simulated was dredging of the entire channel. In the simulation, each channel was dredged two vertical feet below the thalweg and across the width of the channel, with side slope of 1.5 ft horizontal to 1.0 ft vertical. With additional input for each cross section, BRI-STARS has the capability to modify channel geometry to simulate this dredging prior to running the sediment transport routines (Albert Molinas, Hydrau-Tech, Inc., written commun., June 10, 1998).

The only other modification to the calibrated models was the hydrograph. The 10- and 100-yr peak discharges were taken from the flood-insurance studies for each river reach (Federal Emergency Management Agency, 1980 and 1982a-d). These peak discharges can be found in table 4. The hydrographs of the 10- and 100-yr floods were synthesized using the Soil Conservation Service dimensionless hydrograph (U.S. Bureau of Reclamation, 1974) and were used as input to the models. The same time-to-peak as estimated for the July 1997 flood was used for the 10- and 100-yr hydrograph synthesis. The hydrographs used in the models are displayed in figure 6.

Results of the model runs can be found in the Appendixes C-F. Appendix C contains, for each study reach, profiles of the current streambed thalweg, the 10- and 100-yr water surfaces from the fixed-bed models, the 10- and 100-yr peak water surfaces for the three streambed-management practices, and the streambed following 10- and 100-yr floods for the three streambed-management practices. Elevations of the water-surface profiles are listed in Appendix D. The tables in Appendix D show the peak water-surface elevations that could result at each cross section for a 10- and 100-yr flood after the streambed-management practice of restricting removal of bed material. For comparison, the differences of the peak water-surface elevations between restricting removal of bed material and scalping bars and dredging are also included in the tables.

Appendix E shows the cross-section geometry as it was following the 1997 flood, and the predicted channel geometry following a synthesized 10- and 100-yr flood for the three streambed-management practices. Channel geometries shown in Appendix E are after the event has occurred; channel geometry during the peak discharge may be different. Appendix F contains the elevations and descriptions of Elevation Reference Marks used in the study and displayed in figures 2-4.

SUMMARY AND CONCLUSIONS

A sediment transport study by the U.S. Geological Survey, in cooperation with the Vermont Agency of Natural Resources, began in October 1997, to evaluate the State of Vermont's policy on streambed management, which restricts the extraction of streambed materials from channels. The reaches included in this study were a 4.3-mi section of the Trout River in Montgomery, Vt., all 6.5 mi of the Wild Branch in Wolcott, Vt., and the entire 15.4-mi reach of the Lamoille River in Cambridge, Vt. All three reaches were affected by the July 1997 flood in northern Vermont. The current state policy on streambed management, as well as alternative practices, were evaluated using a sediment-transport model. The BRIdge Stream Tube model for Alluvial River Simulation was used to estimate degradation and aggradation of the streambed and to compute peak water-surface elevations for 10-yr and 100-yr recurrence-interval floods.

The model was calibrated using data for the flood of July 14-16, 1997, including channel-geometry data available at 110 cross sections for dates before and after the July 1997 flood. The calibrated model was then used to estimate aggradation, degradation, and the water-surface profile in each of the three study reaches for a 10- and a 100-yr flood following three different streambed-management practices: no removal of bed material, removal of bars and other alluvial materials that reduce channel area, and dredging the entire channel to 2 ft below the thalweg.

In general, some decrease in the water-surface elevation was realized when channel maintenance was done. In Montgomery, the water-surface elevations for

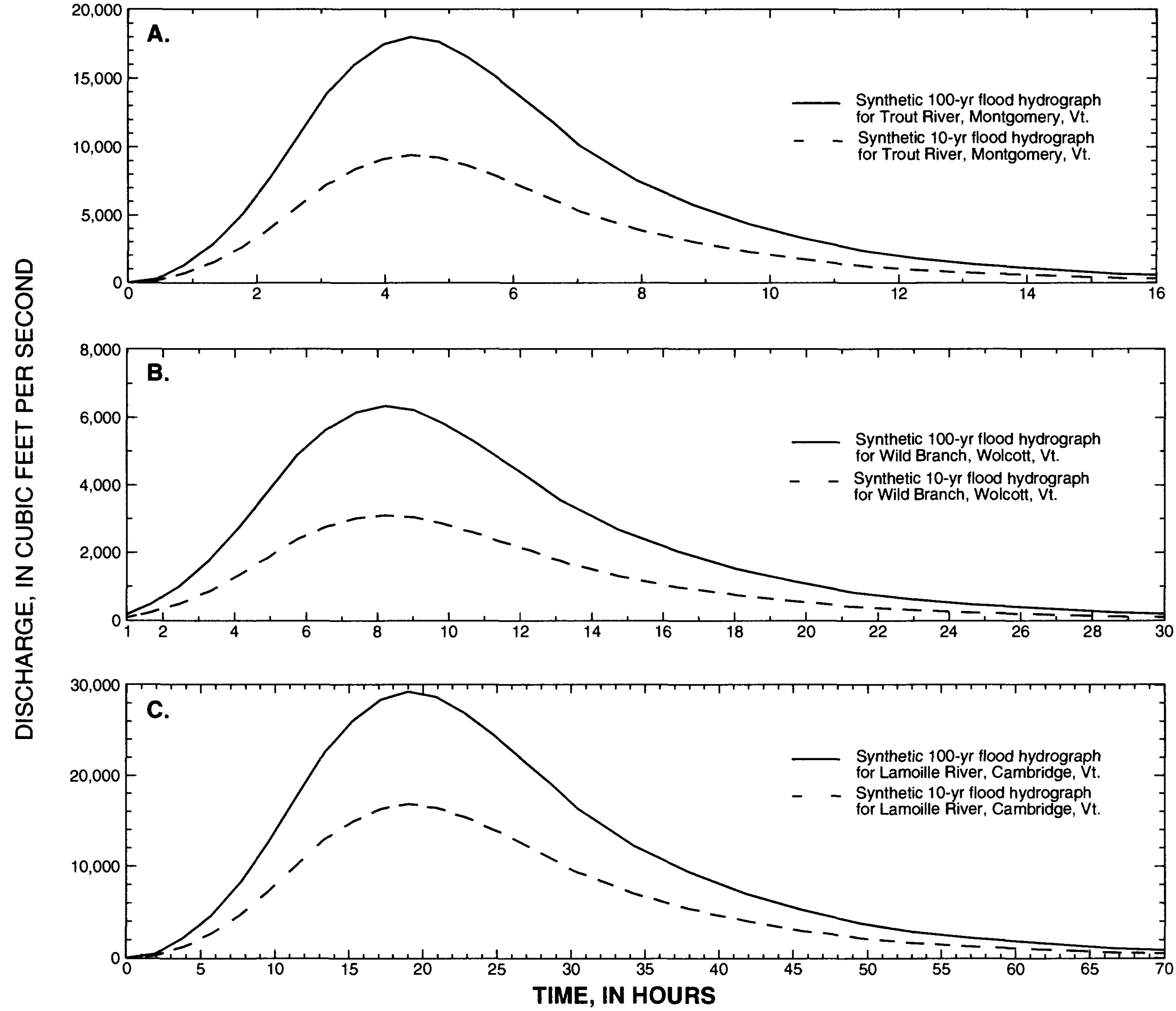


Figure 6. Synthetic 10- and 100-year flood hydrographs at the downstream end of the studied reach for the (A) Trout River, (B) Wild Branch, and (C) Lamoille River.

the simulation with bar material scalped or removed were, on average lower (-0.1 and -0.2 ft) than the water-surface elevations of the model with no channel maintenance on the Trout River for the 10- and 100-yr floods, respectively. The average water-surface elevation for the simulation in which the channel was dredged was lower (-1.5 and -1.1 ft) than the channel with no maintenance for the 10- and 100-yr floods, respectively.

In the town of Cambridge, the average difference in the water-surface elevation of the Lamoille River between the simulation in which bar material was scalped and the simulation with no channel maintenance was -0.1 ft for the 10- and 100-yr floods. The average difference in the water-surface elevation between the simulation in which the channel was dredged and the simulation with no channel maintenance was -1.4 and -1.0 ft for the 10- and 100-yr floods, respectively.

The Wild Branch models for Wolcott did not have decreased water-surface elevations at the cross sections, on average, that the other modelled reaches had for the simulated practices of channel management. The average difference in the water-surface elevation between the model with scalped bars and the model with no channel maintenance was +0.1 and 0.0 ft for the 10- and 100-yr events, respectively. The average difference in the water-surface elevation between the model, for a dredged channel and the model with no channel maintenance was 0.0- and -0.5 ft for the 10- and 100-yr floods, respectively.

Rivers continually change position and shape as a result of hydraulic forces. Rates of change are variable. Furthermore, a river may maintain stability for long periods of time and then experience rapid movement. For example, the sinuosity, width, and depth of a channel can change to compensate for an unusually large hydrologic event. The effect of the changes in the channel geometry on the peak water-surface elevations can vary, however. Comparing average change in water surface between the pre- and post-1997 flood fixed-bed models of the study area, the profiles are not significantly affected by the change in channel geometry. This was expected, because most of the flood waters are conveyed by the flood plains, especially during the larger 100-yr flood.

From the movable-bed models, there were some decreases in the mean water-surface profile when a streambed-management practice of channel dredging, prior to flooding, was followed as opposed to restricting the removal of any bed materials. The model, however, showed severe erosion under some bridges during a flood if dredging was practiced. There were only minor differences, less than 1.5 ft on average, in the resulting water-surface profile between the models where scalping (removing) bars or other areas of decreased channel capacity was done prior to flooding and where the removal of bed material was restricted. All profiles evaluated in this study did not result in changes that could be observed on existing maps. Thus, flood-boundary maps were not developed and the flood-boundary maps provided by Federal Emergency Management Agency's flood-insurance studies are considered to be valid.

The models used in this study provide information on the effect of streambed-management practices on the water-surface profile of a flood and on the bed profile following a flood. The management practices evaluated in this study would have local effects on flooding that are beyond the scope of this study. Investigations of channel stability and stream restoration are currently being undertaken by the Vermont Agency of Natural Resources.

SELECTED REFERENCES

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Bedient, P.B., and Huber, W.C., 1988, Hydrology and floodplain analysis: Reading, Mass., Addison-Wesley Publishing Company, 650 p.

Coakley, M.F., Kiah, R.G., Keirstead, Chandlee, and Brown, R.O., 1998, Water Resources Data, New Hampshire and Vermont, Water Year 1997: U.S. Geological Survey Water-Data Report NH-VT-97-1, p. 106-111.

Colby, B.R., 1961, Effect of depth of flow on discharge of bed material: U.S. Geological Survey Water-Supply Paper 1498-D, 12 p.

Federal Emergency Management Agency, 1980, Flood insurance study, Town of Montgomery, Franklin County, Vermont: Washington, D.C., June 1980, 17 p.

———1982a, Flood insurance study, Town of Cambridge, Lamoille County, Vermont: Washington, D.C., December 15, 1982, 18 p.

———1982b, Flood insurance study, Village of Cambridge, Lamoille County, Vermont: Washington, D.C., December 1, 1982, 15 p.

———1982c, Flood insurance study, Village of Jeffersonville, Lamoille County, Vermont: Washington, D.C., December 15, 1982, 15 p.

———1982d, Flood insurance study, Town of Wolcott, Lamoille County, Vermont: Washington, D.C., February 2, 1982, 17 p.

———1997, Mitigation strategy report in response to the July 25, 1997 Disaster Declaration for the State of Vermont: Boston, Mass., July 1997.

Hayes, D.C.,1993, Site selection and collection of bridge-scour data in Delaware, Maryland, and Virginia: U.S. Geological Survey Water-Resources Investigation Report 93-4017, 23 p.

Hilmes, M.M., and Vaill, J.E., 1997, Estimates of bridge scour at two sites on the Virgin River, Southeastern Nevada, using a sediment-transport model and historical geomorphic data: U.S. Geological Survey Water-Resources Investigations Report 97-4073, 72 p.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Chang, F., 1995, Stream stability at highway structures: Federal Highway Administration Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Maidment, D.R., 1992, Handbook of hydrology: New York, McGraw-Hill, Inc.

Molinas, Albert, and Santoro, V.C., 1989, Bri-Stars Model and its applications, *in* Proceedings of the bridge scour symposium: Federal Highway Administration Publication FHWA-RD-90-035, p. 256-271.

Molinas, Albert, and Wu, Baosheng, 1997, User's primer for Bri-Stars (BRIdge Stream Tube model for Alluvial Simulation): Fort Collins, Colo., Federal Highway Administration Project No. DTFH61-93-C-00068, Hydrau-Tech, Inc., 43 p.

National Oceanic and Atmospheric Administration, 1997, Climatological data, New England, July 1997: National Climatic Data Center, v. 109, no. 7.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

Ritter, D.F., 1984, Process geomorphology: Debuque, Iowa, W.C. Brown Co., 603 p.

Shearman, J.O., 1990, User's manual for WSPRO—a computer model for water-surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

Shen, H.W., and Julien, P.Y., 1993, Erosion and sediment transport—*in* Maidment, D.R., ed., Handbook of Hydrology: New York, McGraw Hill, chap. 12, p. 12.1-12.55.

U.S. Army Corps of Engineers, 1977, HEC-2 Water-surface profiles, Generalized Computer Program, Davis, Calif., Hydrologic Information Center.

U.S. Bureau of Reclamation, 1974, Design of small dams: U.S. Government Printing Office, p. 38-93.

U.S. Geological Survey, 1948a, Gilson Mountain, Vermont, 7.5-minute series quadrangle map: U.S. Geological Survey Topographic Map, Photorevised 1980, scale 1:24,000.

———1948b, Jeffersonville, Vermont, 7.5-minute series quadrangle map: U.S. Geological Survey Topographic Maps, scale 1:24,000.

———1986a, Jay Peak, Vermont, 7.5-minute series quadrangle map: U.S. Geological Survey Topographic Map, scale 1:24,000.

———1986b, Richford, Vermont, 7.5-minute series quadrangle map: U.S. Geological Survey Topographic Map, scale 1:24,000.

———1986c, Wolcott, Vermont, 7.5-minute series quadrangle map: U.S. Geological Survey Topographic Map, scale 1:24,000.

Yuzyk, T.R., 1986, Bed material sampling in gravel-bed streams: Environment Canada—Water Survey of Canada Publication IWD-HQ-WRB-SS-86-8, 47 p.

APPENDIX A:
Pre- and Post-1997 Flood Cross Sections

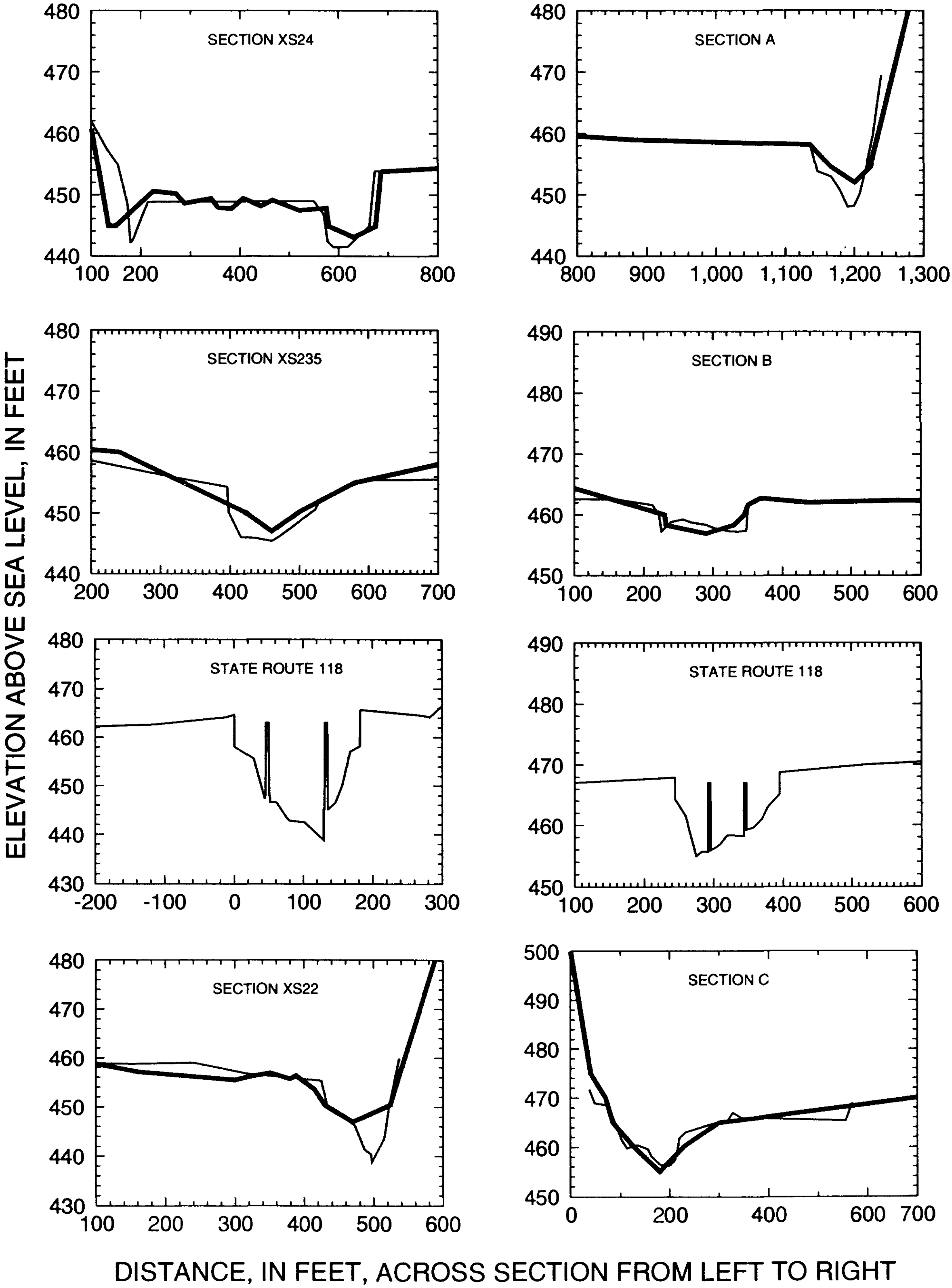
EXPLANATION

▬▬ Cross section from the 1980 or 1982 Flood Insurance Study

—— Cross section as surveyed following the 1997 flood

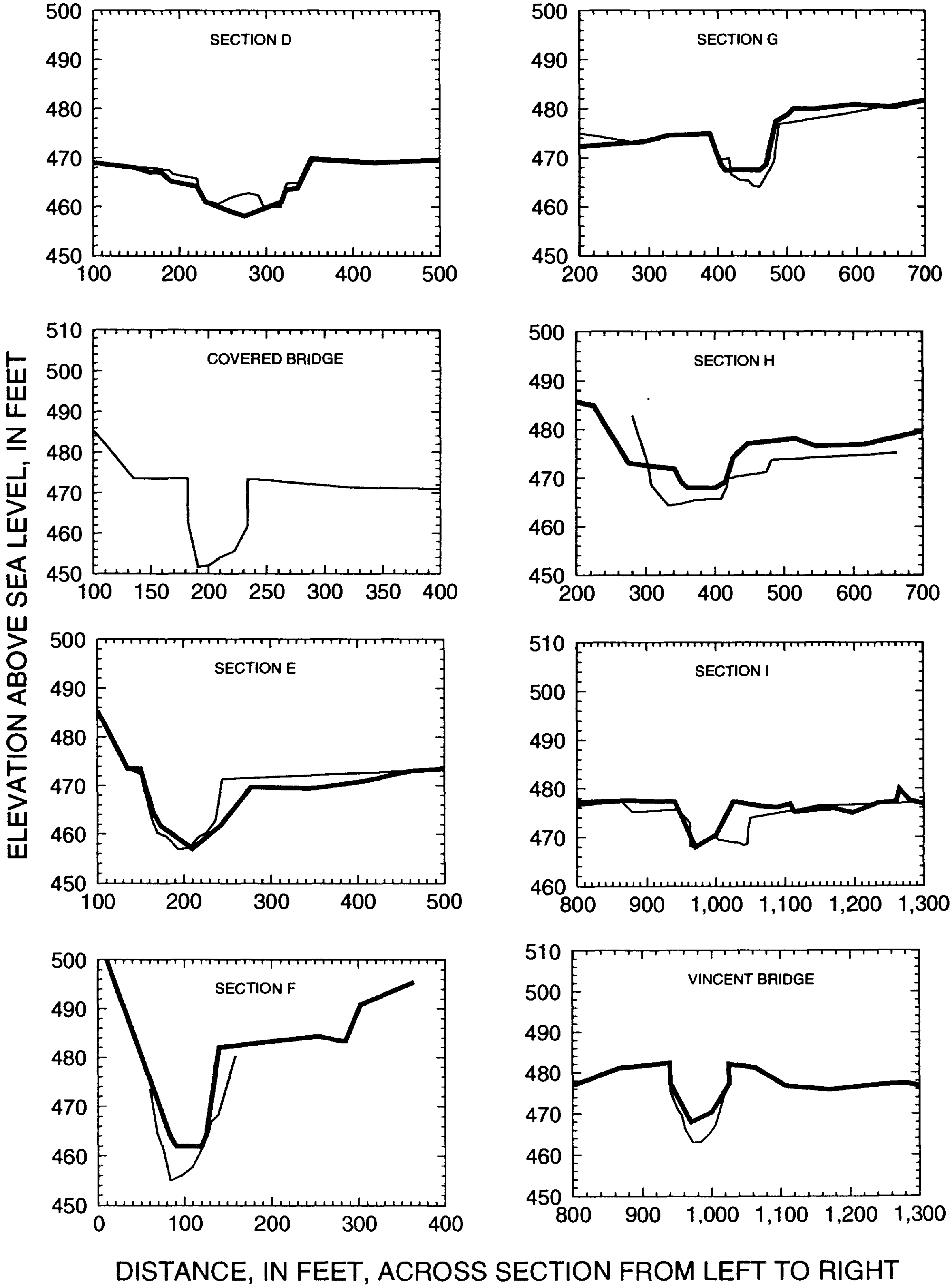
Pre- and Post-1997 Flood Cross Sections

Trout River, Montgomery, Vermont



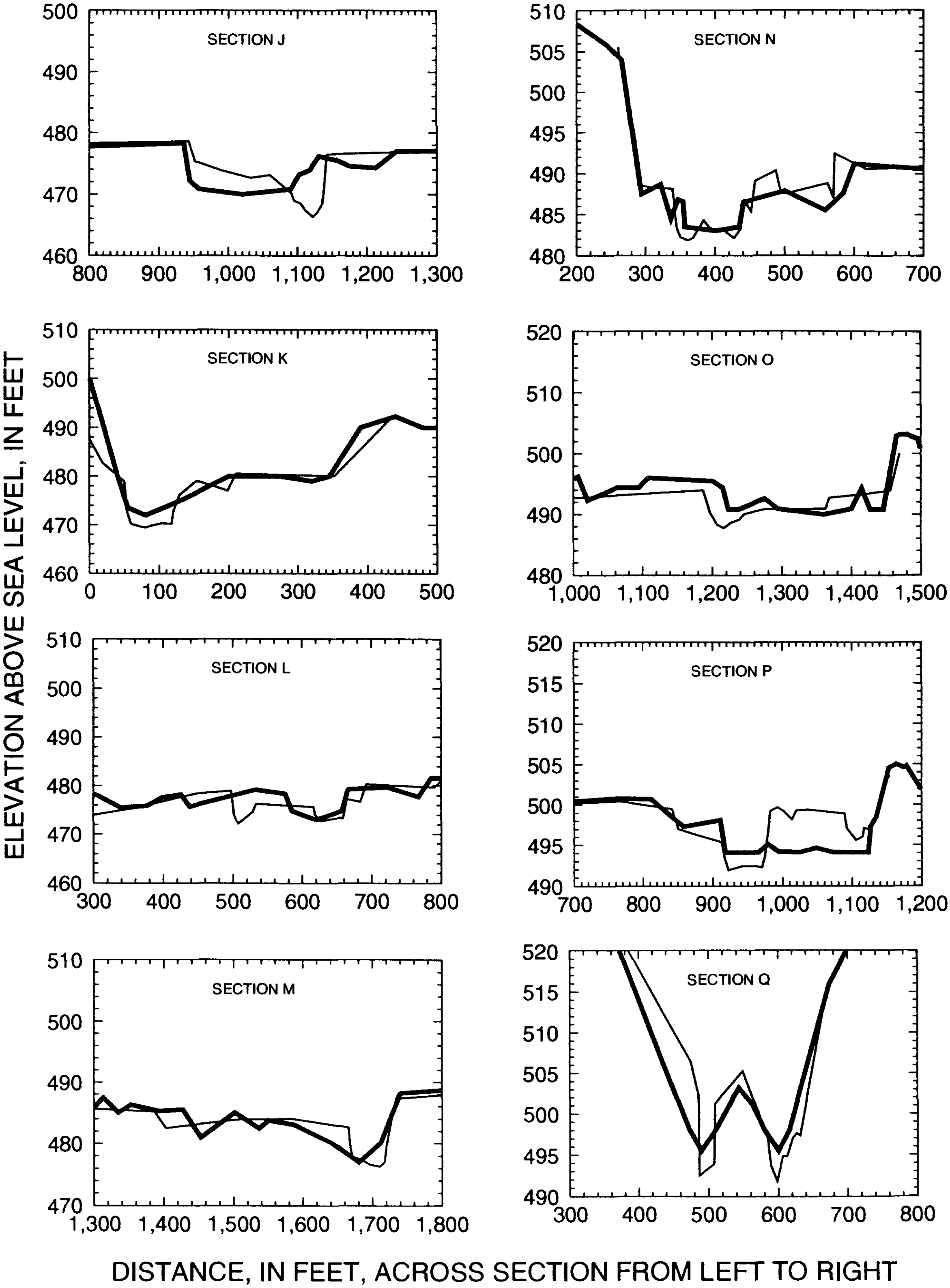
Pre- and Post-1997 Flood Cross Sections

Trout River, Montgomery, Vermont



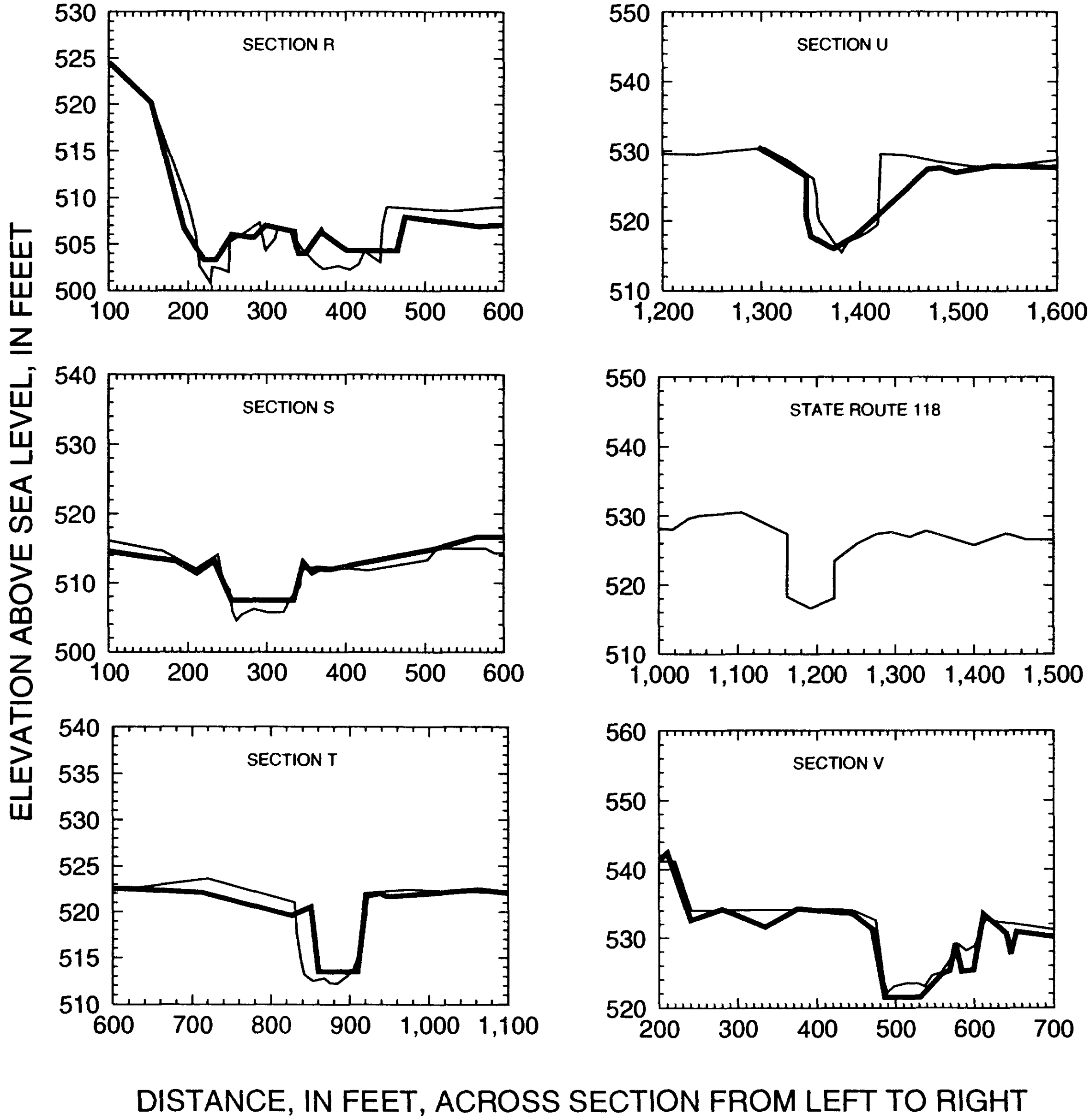
Pre- and Post-1997 Flood Cross Sections

Trout River, Montgomery, Vermont



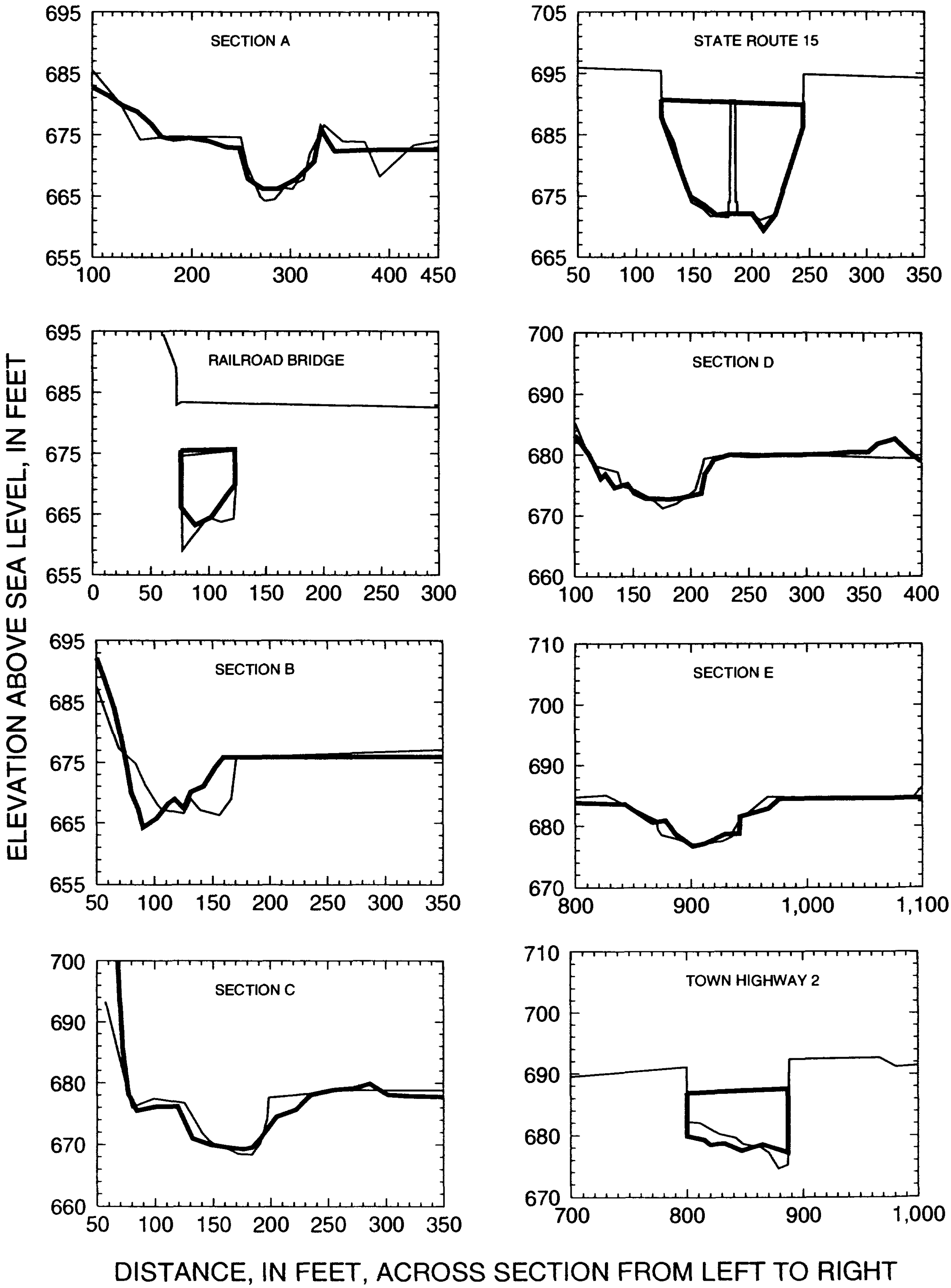
Pre- and Post-1997 Flood Cross Sections

Trout River, Montgomery, Vermont



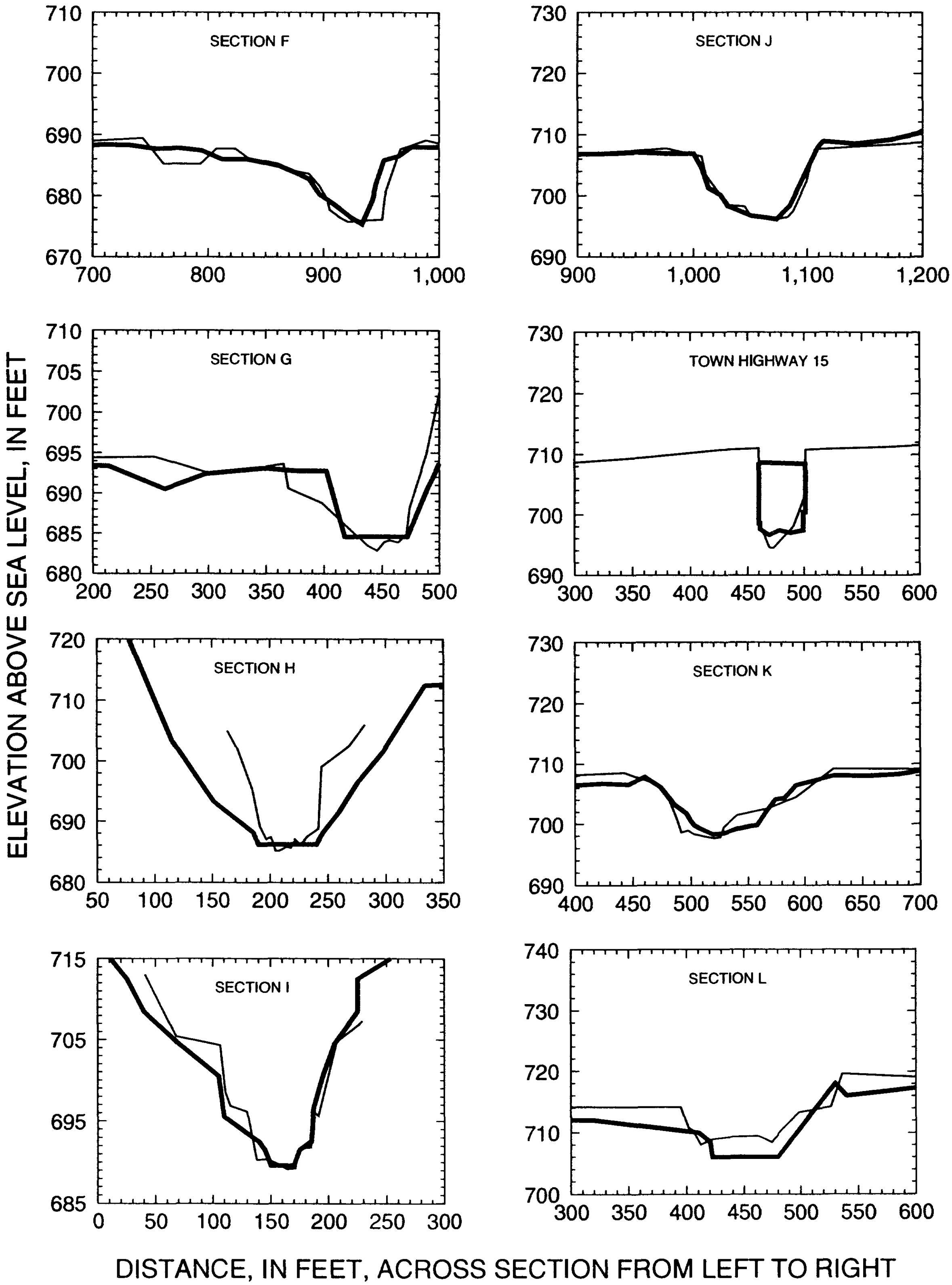
Pre- and Post-1997 Flood Cross Sections

Wild Branch, Wolcott, Vermont



Pre- and Post-1997 Flood Cross Sections

Wild Branch, Wolcott, Vermont



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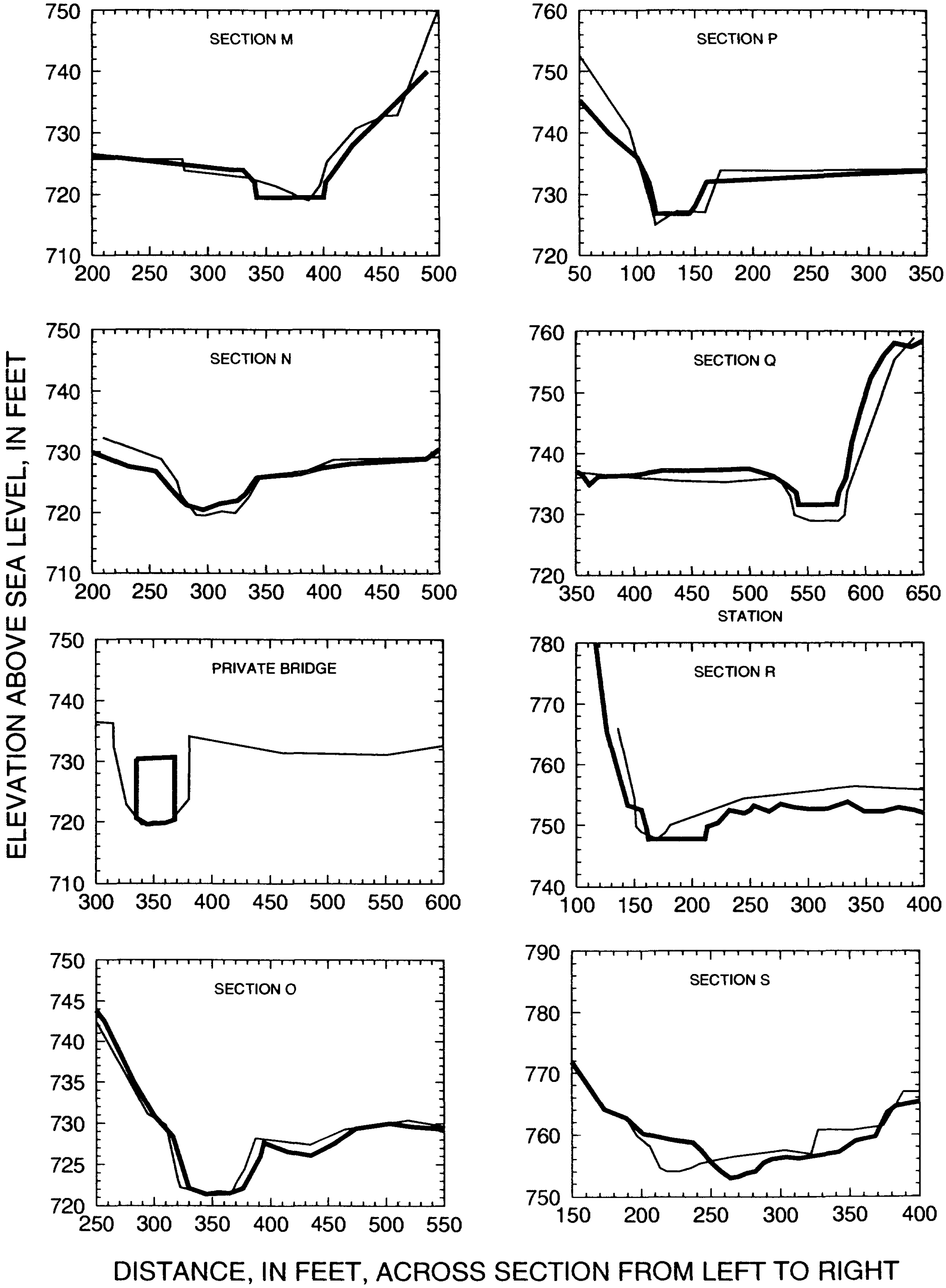
Wild Branch, Wolcott, Vermont



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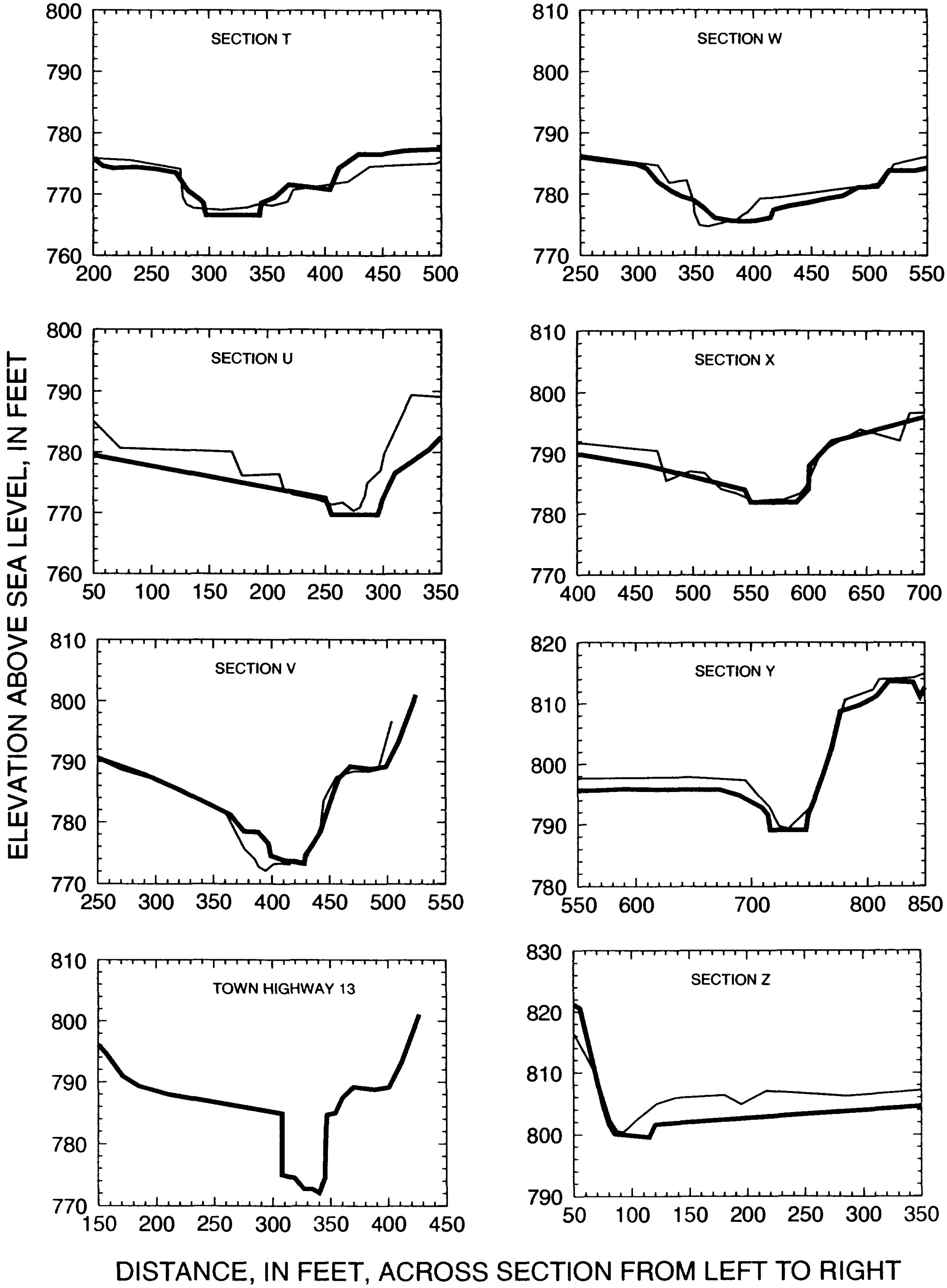
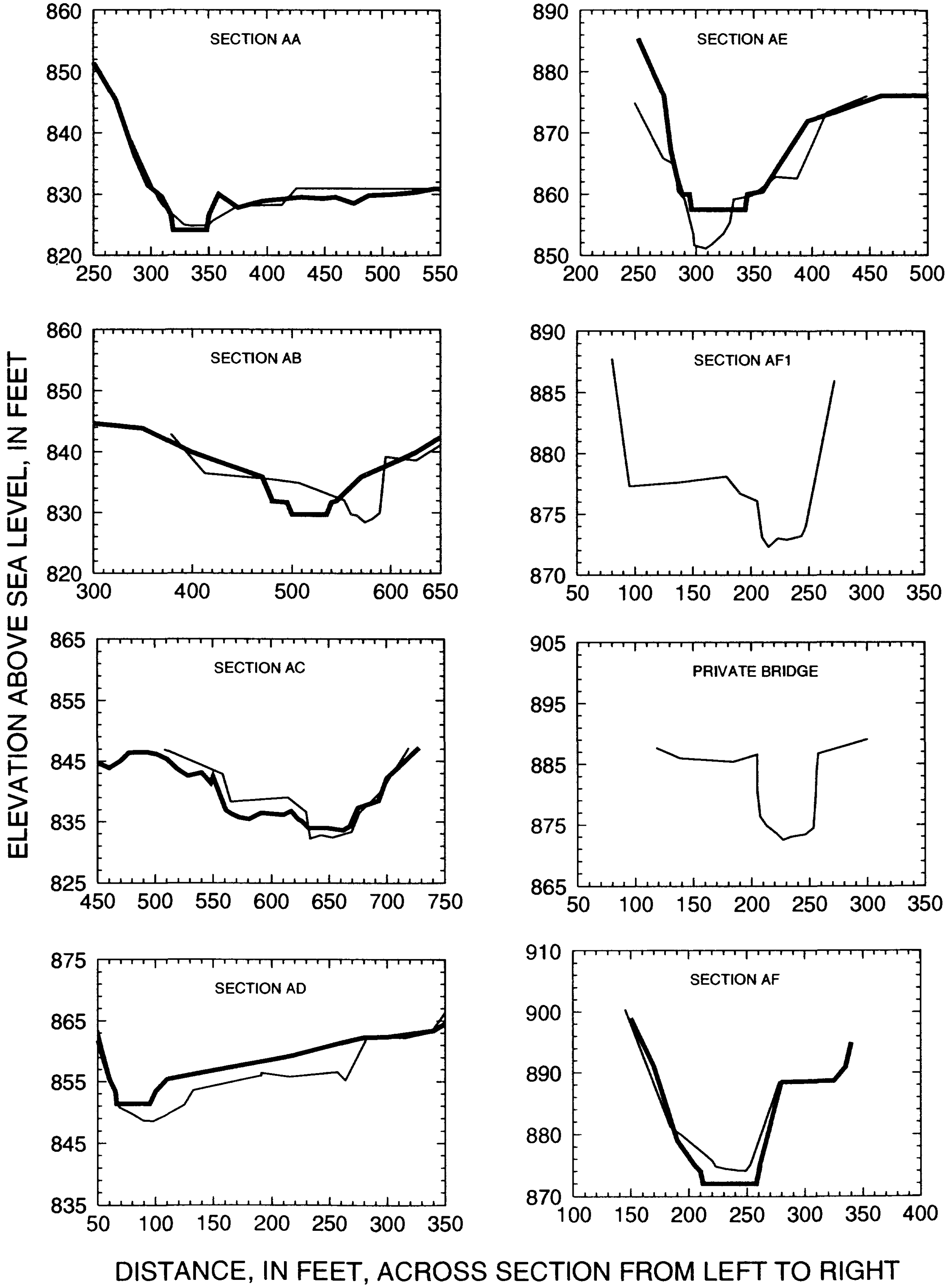
Wild Branch, Wolcott, Vermont



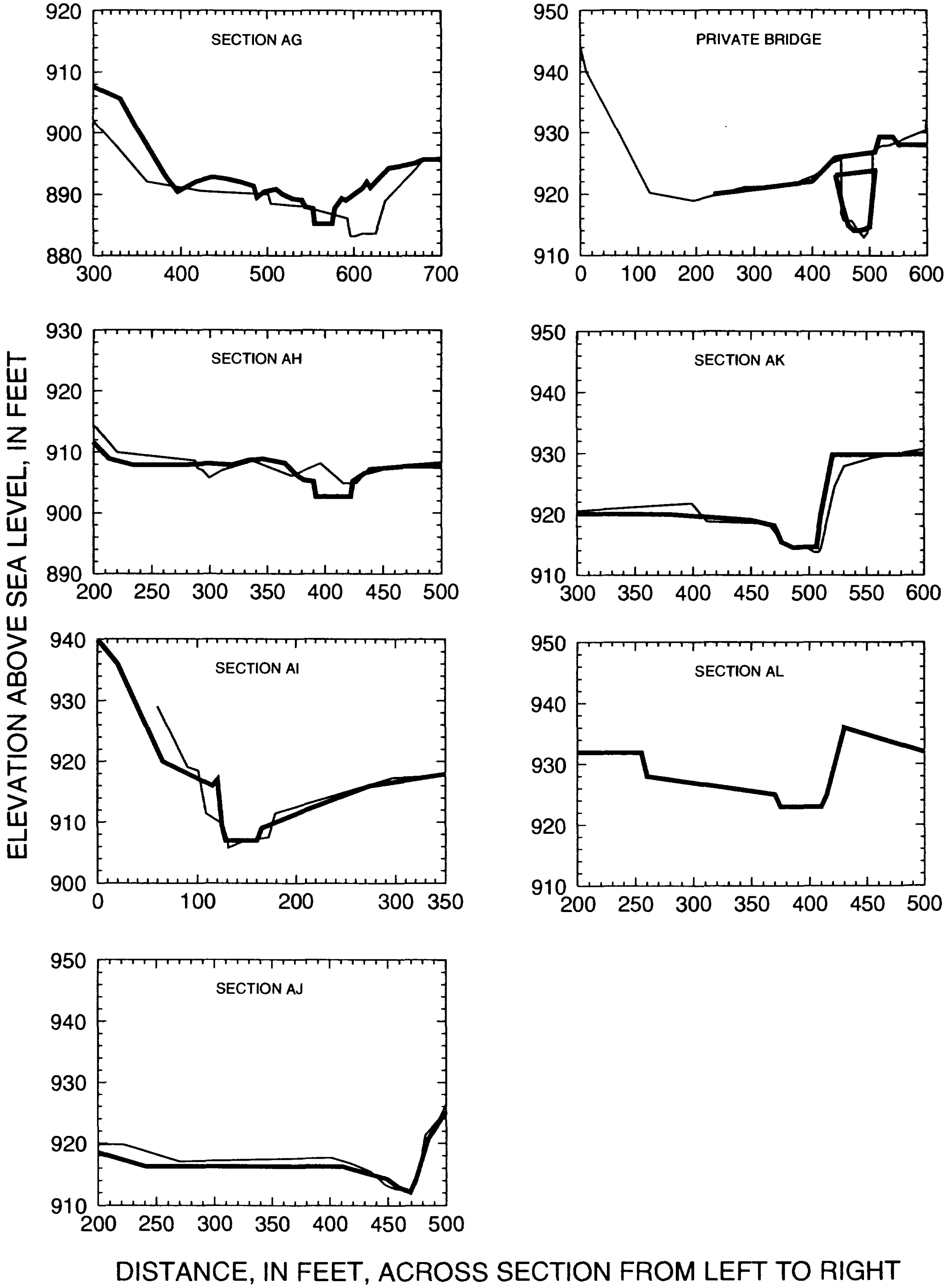
Pre- and Post-1997 Flood Cross Sections

Wild Branch, Wolcott, Vermont



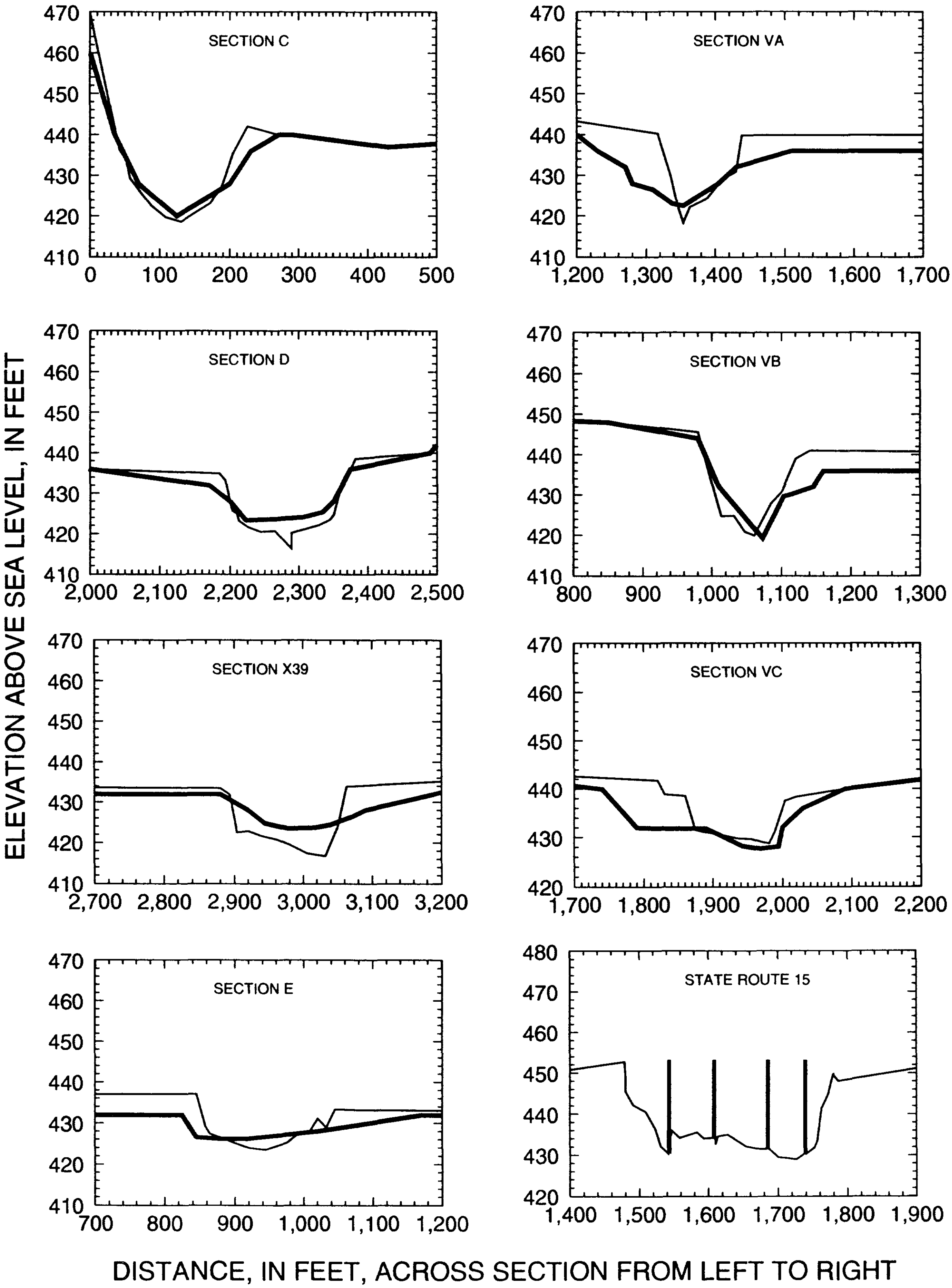
Pre- and Post-1997 Flood Cross Sections

Wild Branch, Wolcott, Vermont



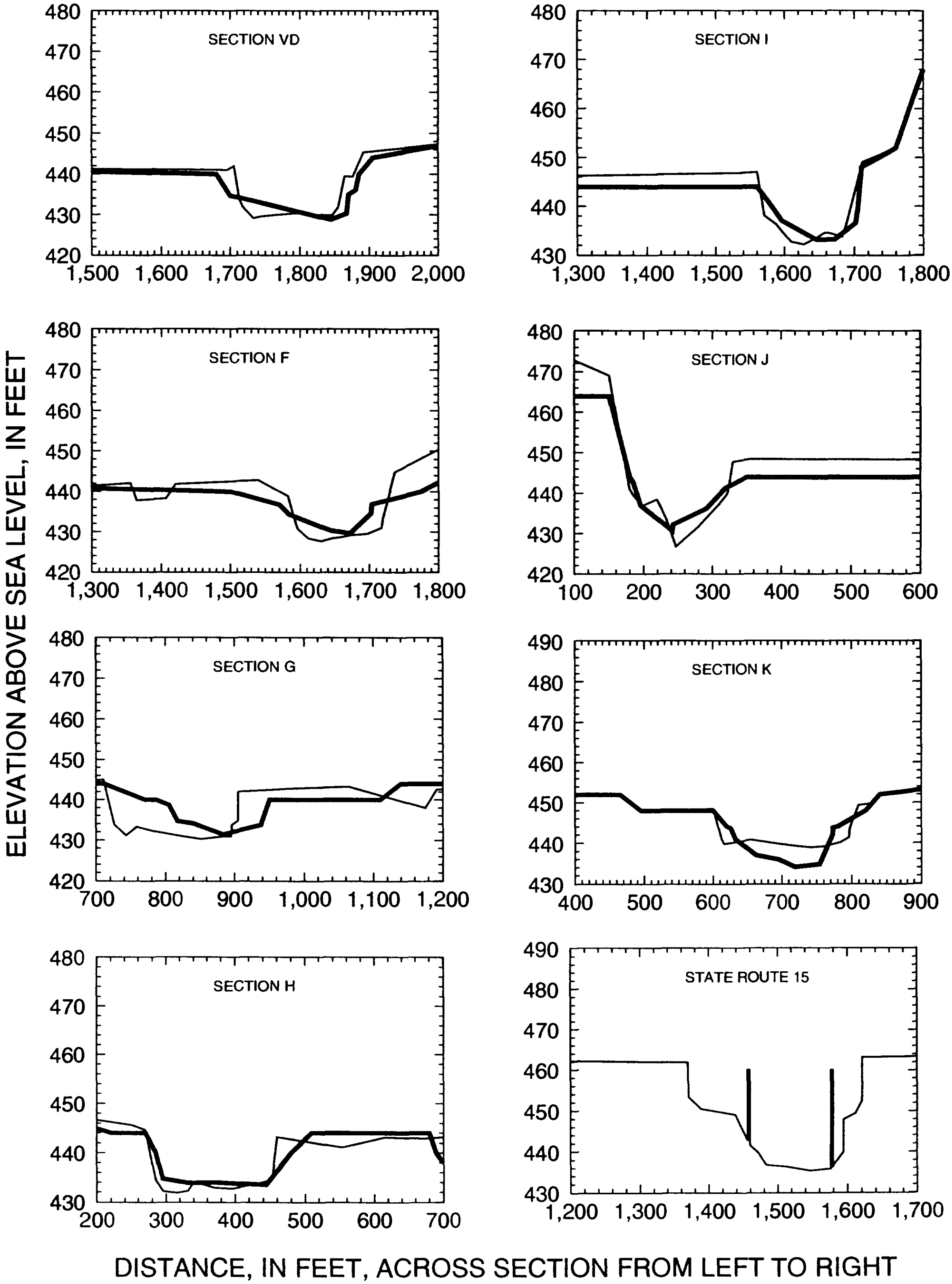
Pre- and Post-1997 Flood Cross Sections

Lamoille River, Cambridge, Vermont



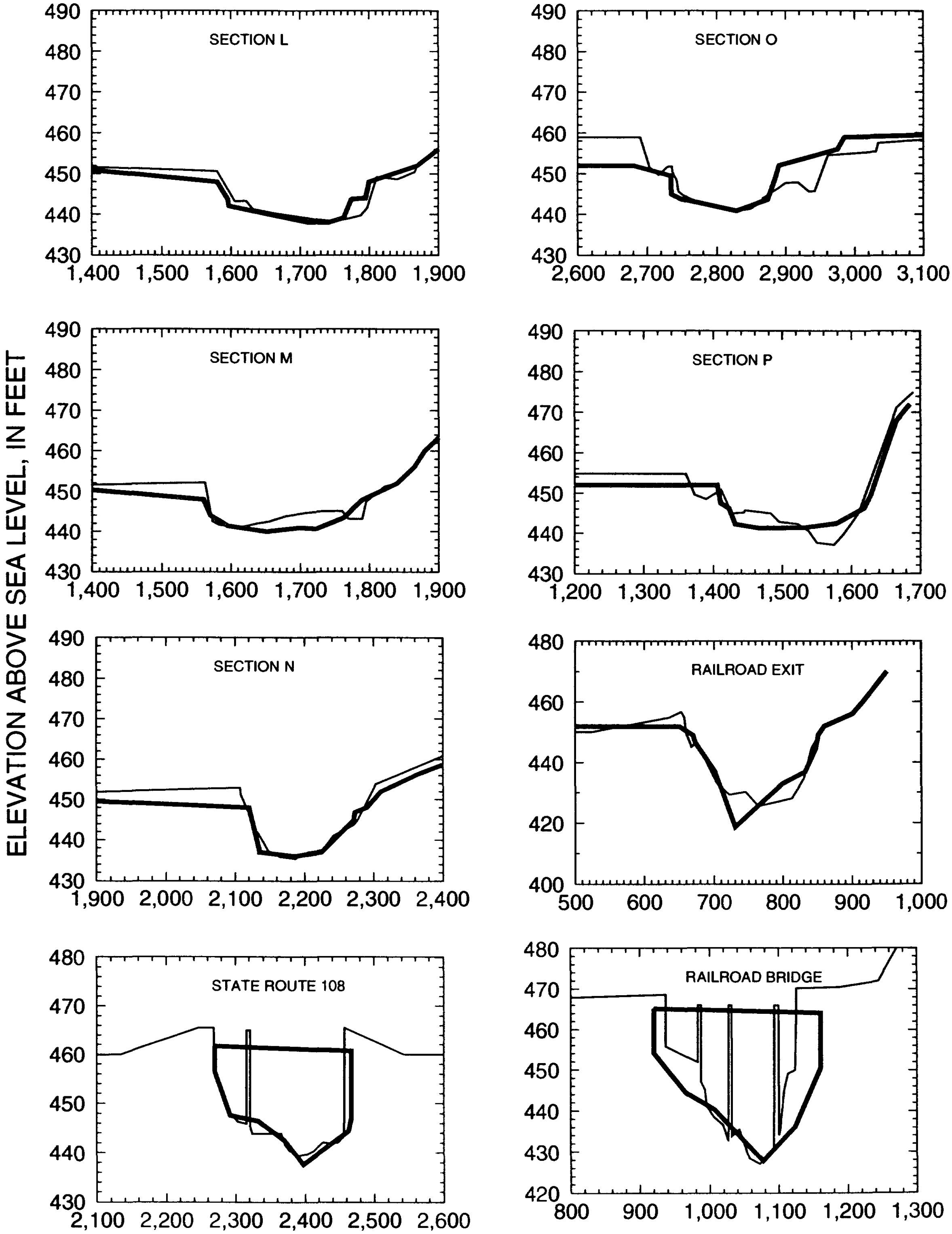
Pre- and Post-1997 Flood Cross Sections

Lamoille River, Cambridge, Vermont



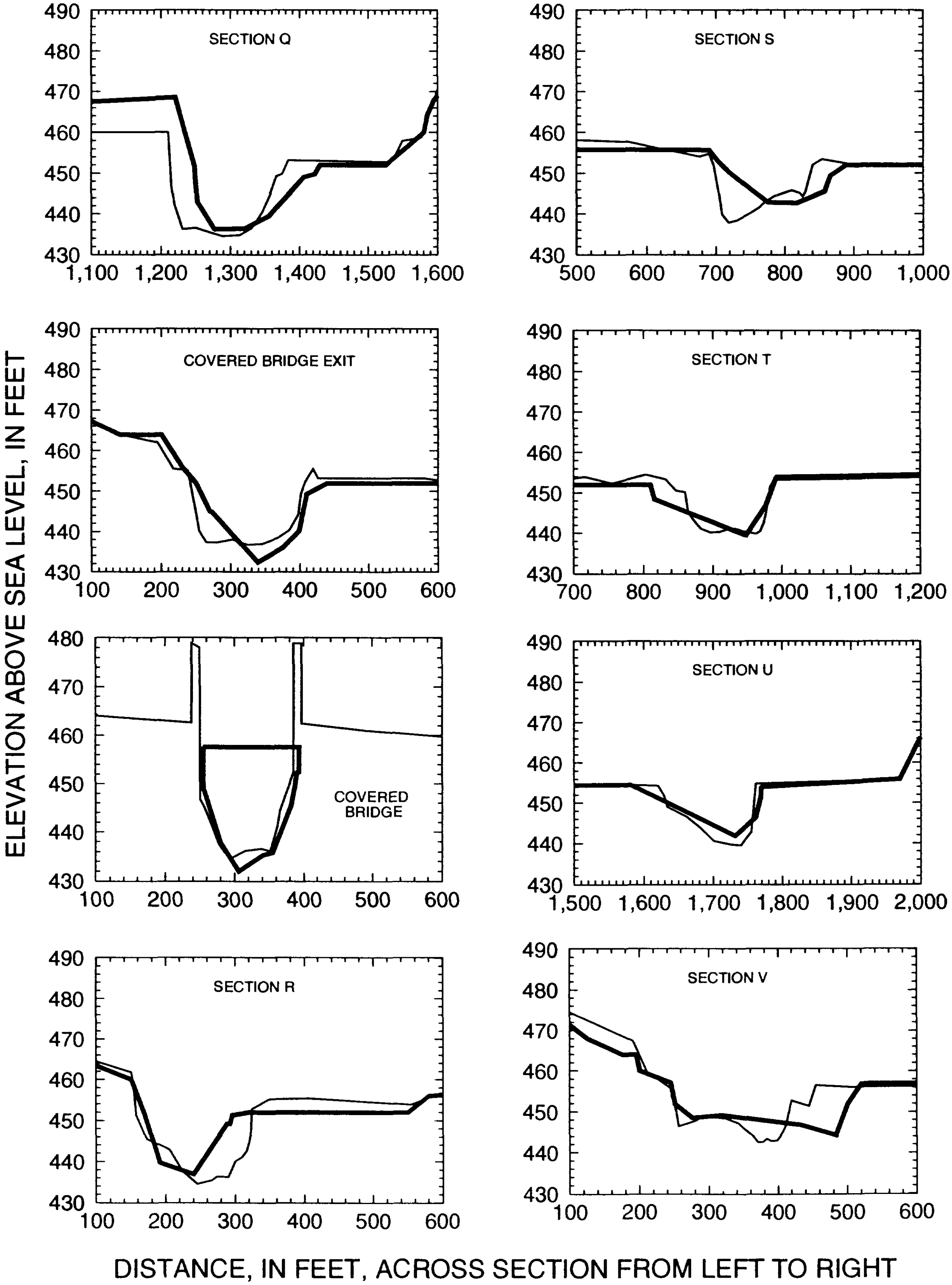
Pre- and Post-1997 Flood Cross Sections

Lamoille River, Cambridge, Vermont



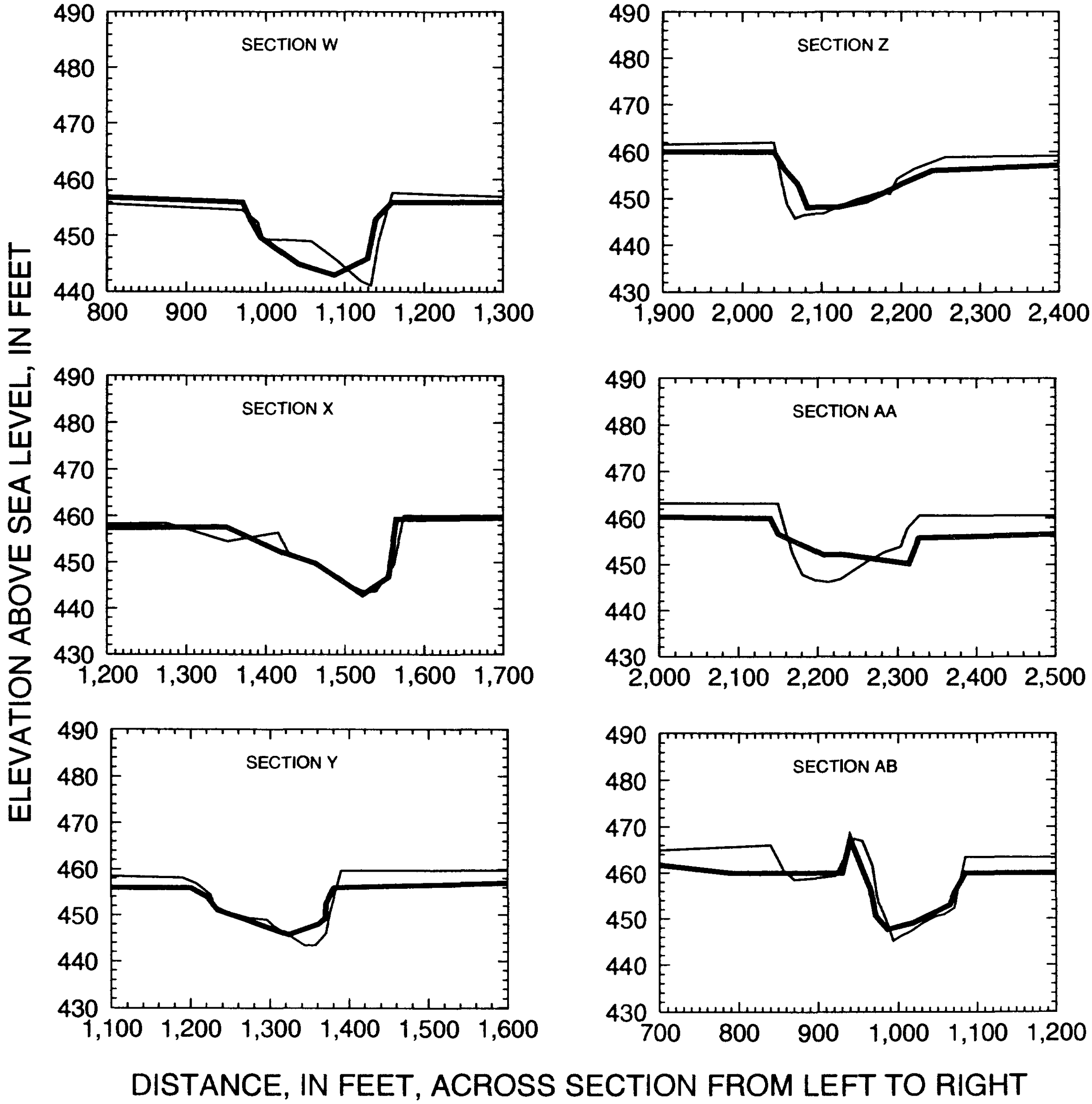
Pre- and Post-1997 Flood Cross Sections

Lamoille River, Cambridge, Vermont



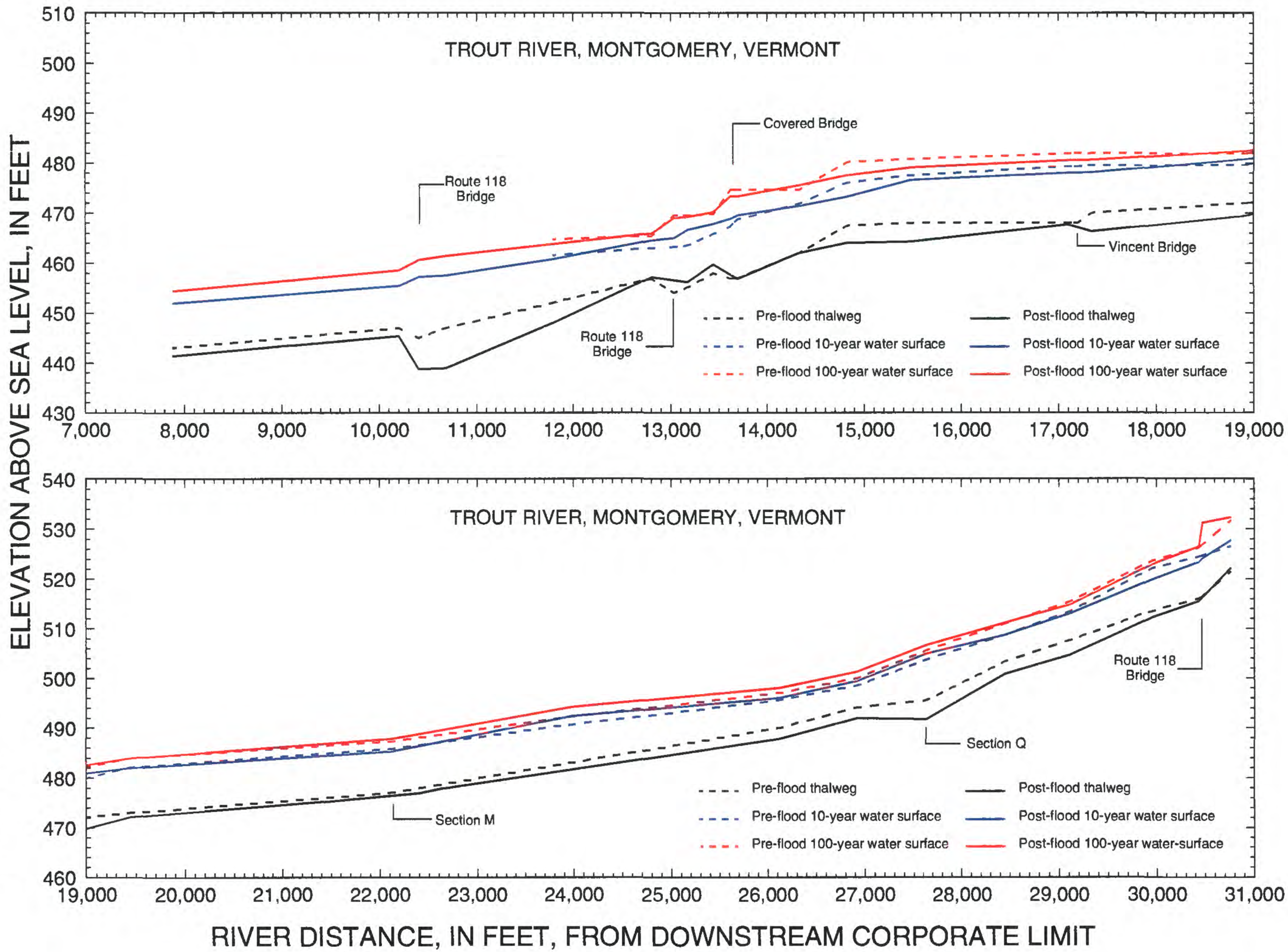
Pre- and Post-1997 Flood Cross Sections

Lamoille River, Cambridge, Vermont

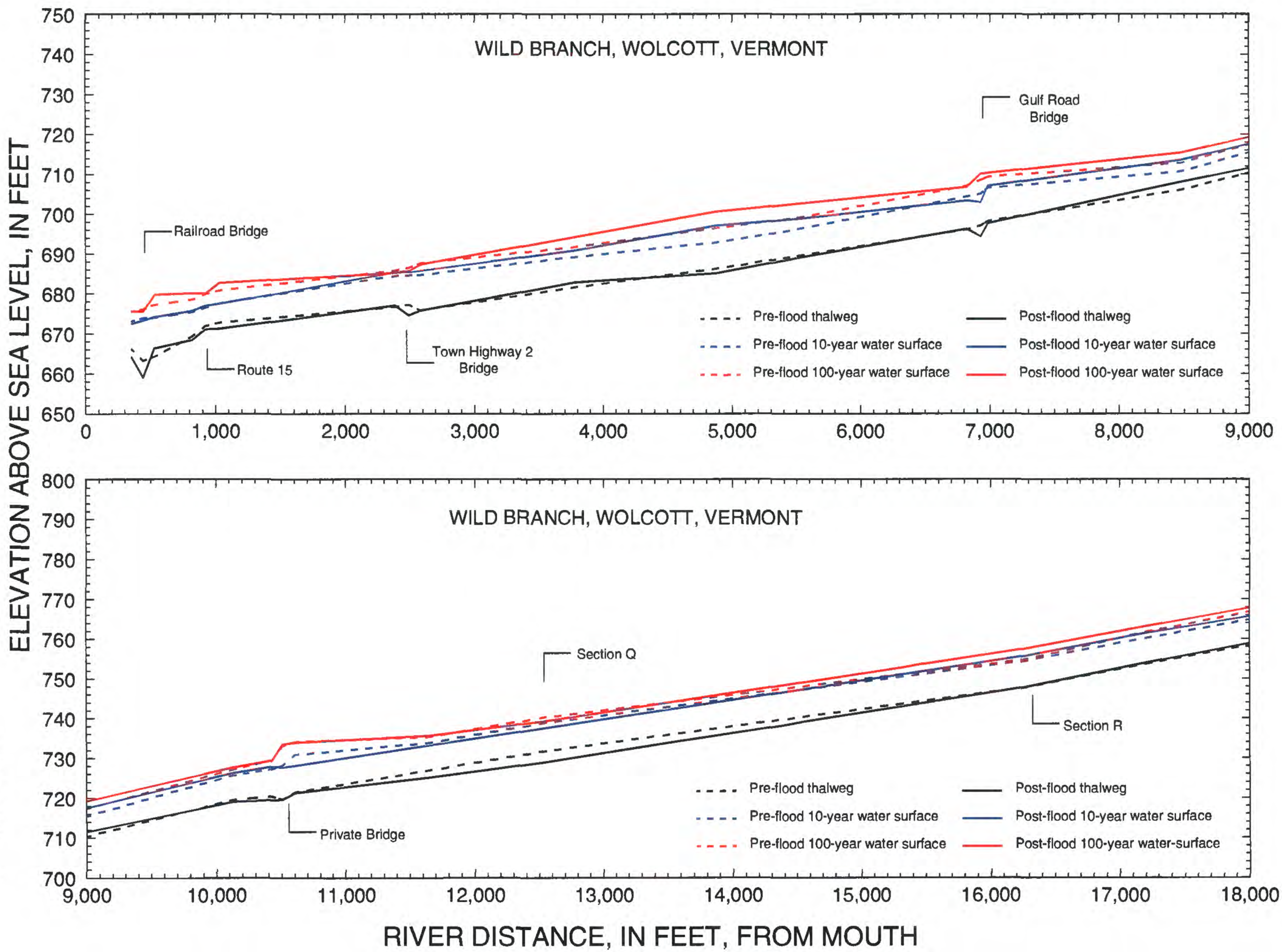


APPENDIX B:
Pre- and Post-flood of 1997
Profiles from Fixed-bed Models

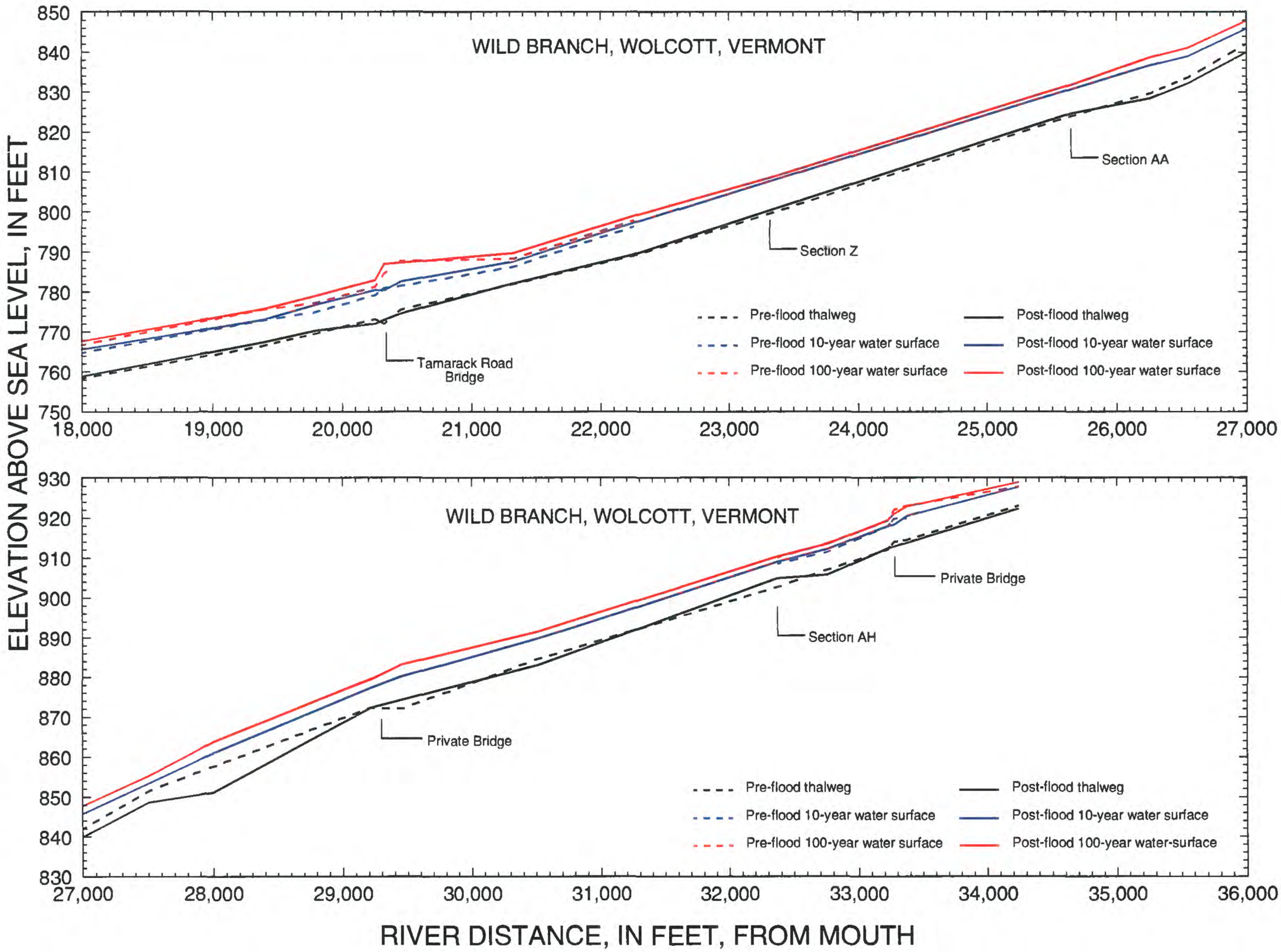
Pre- and Post-Flood of 1997 Profiles from Fixed-Bed Models



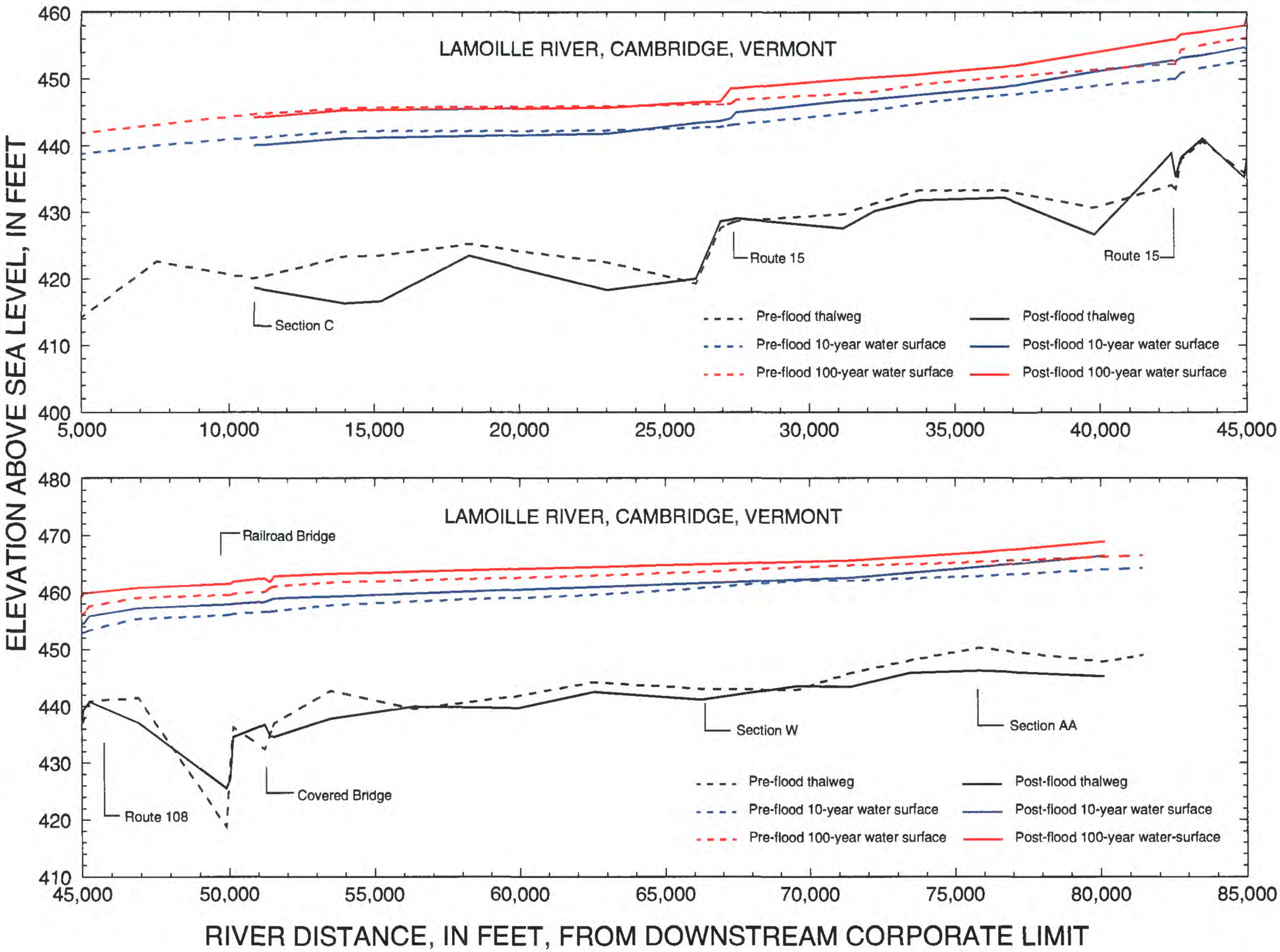
Pre- and Post-Flood of 1997 Profiles from Fixed-Bed Models



Pre- and Post-Flood of 1997 Profiles from Fixed-Bed Models

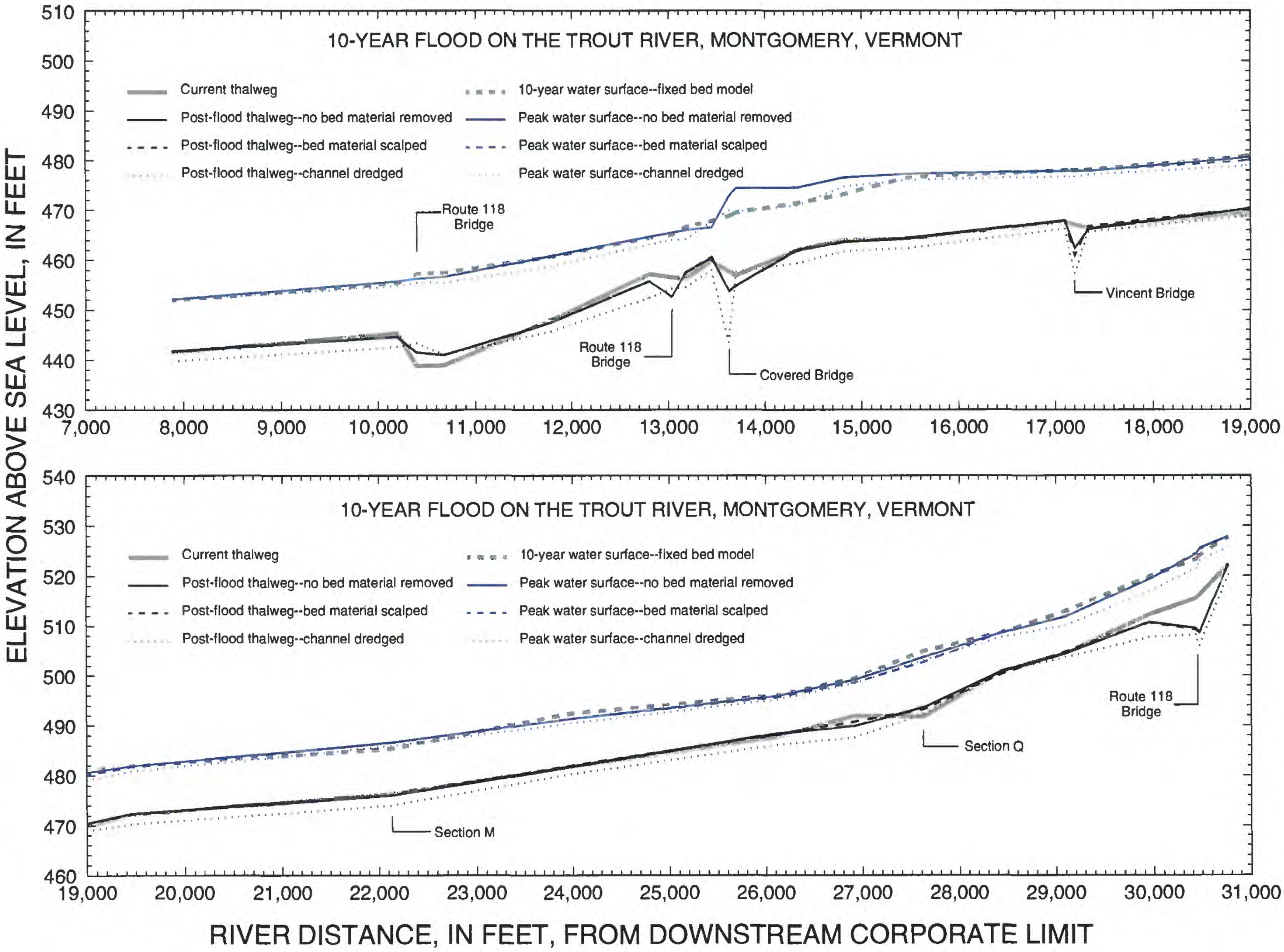


Pre- and Post-Flood of 1997 Profiles from Fixed-Bed Models

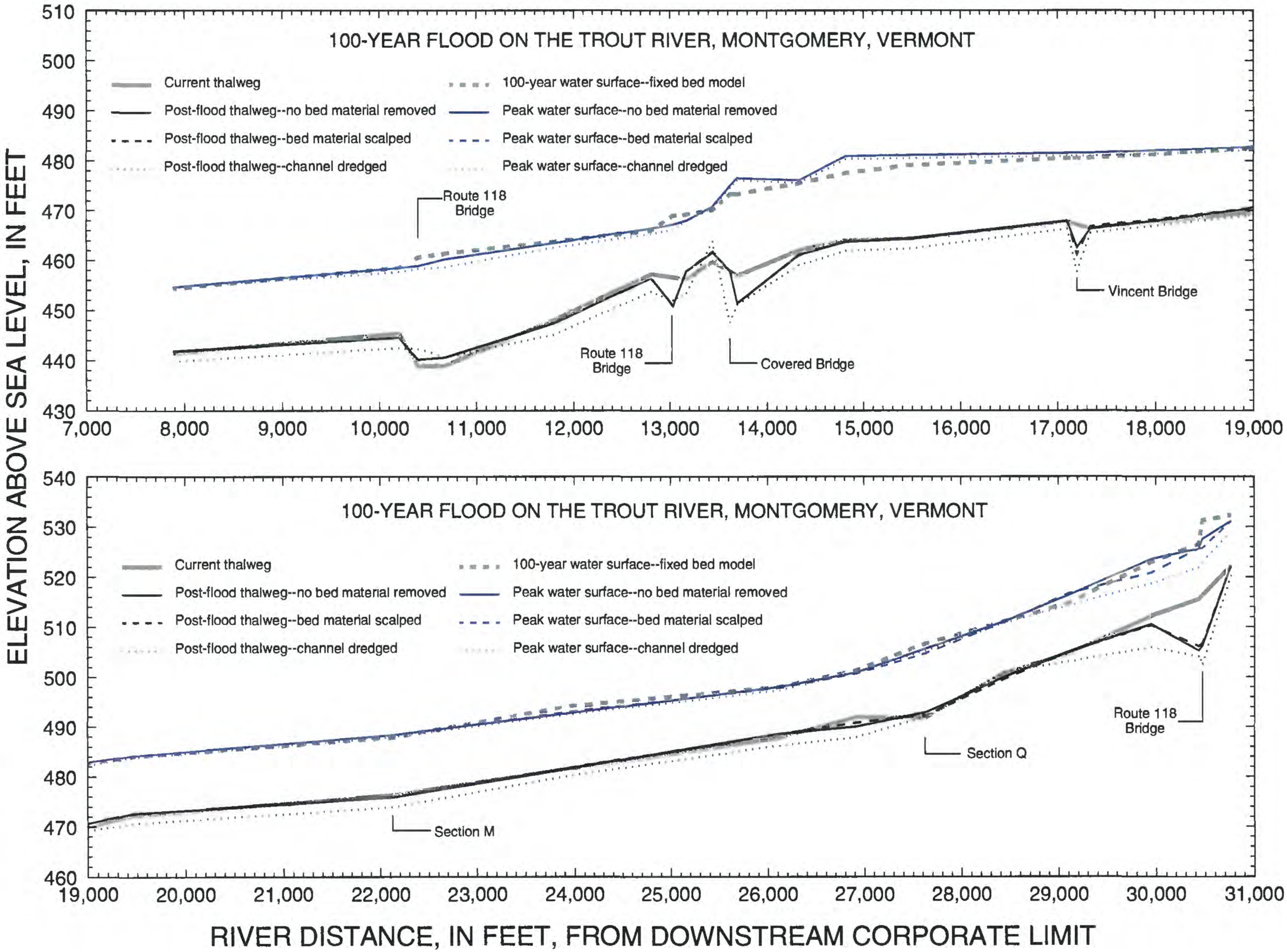


APPENDIX C:
Movable-bed Model Results—Profiles

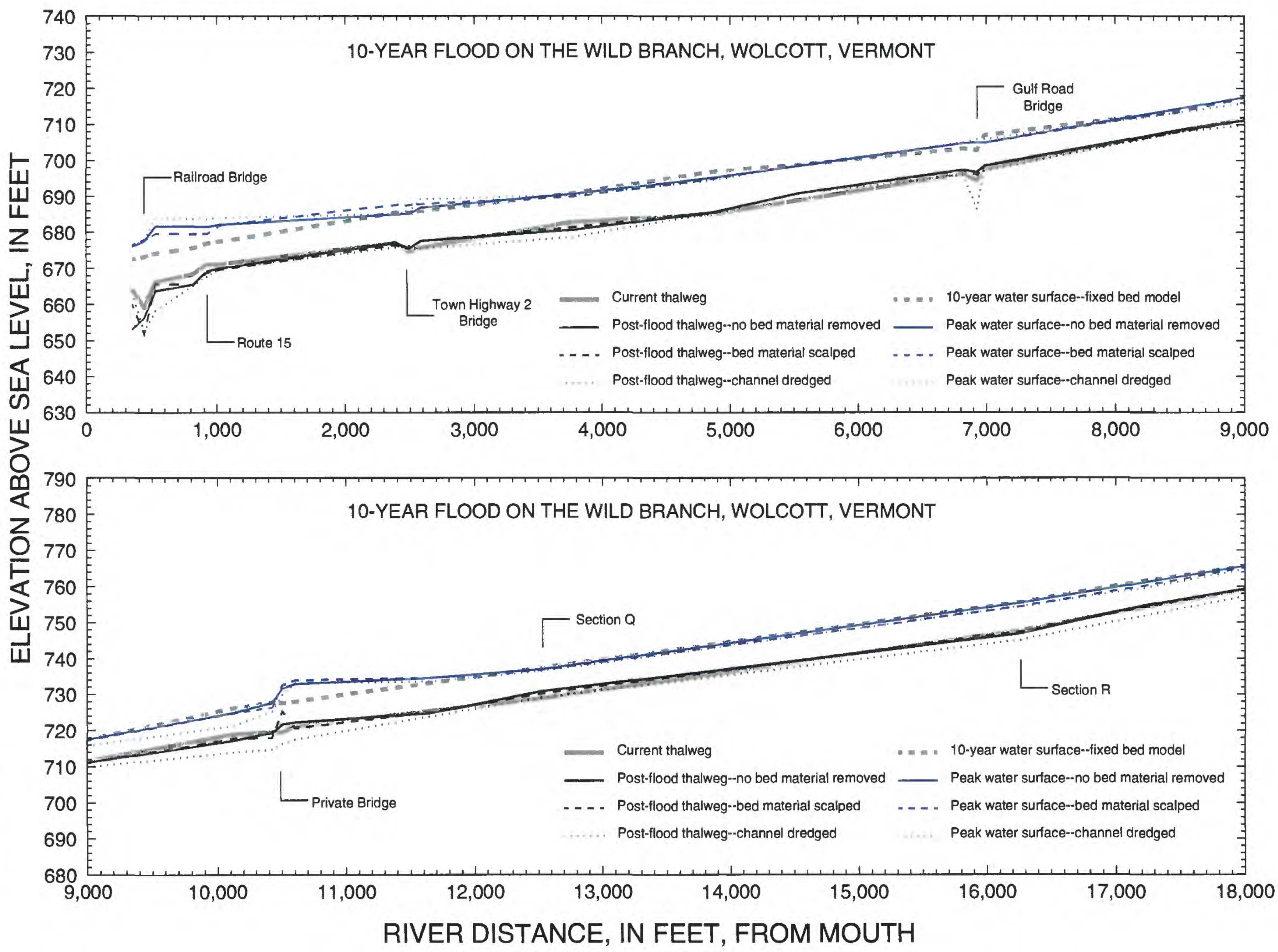
Movable Bed Model Results



Movable Bed Model Results



Movable Bed Model Results



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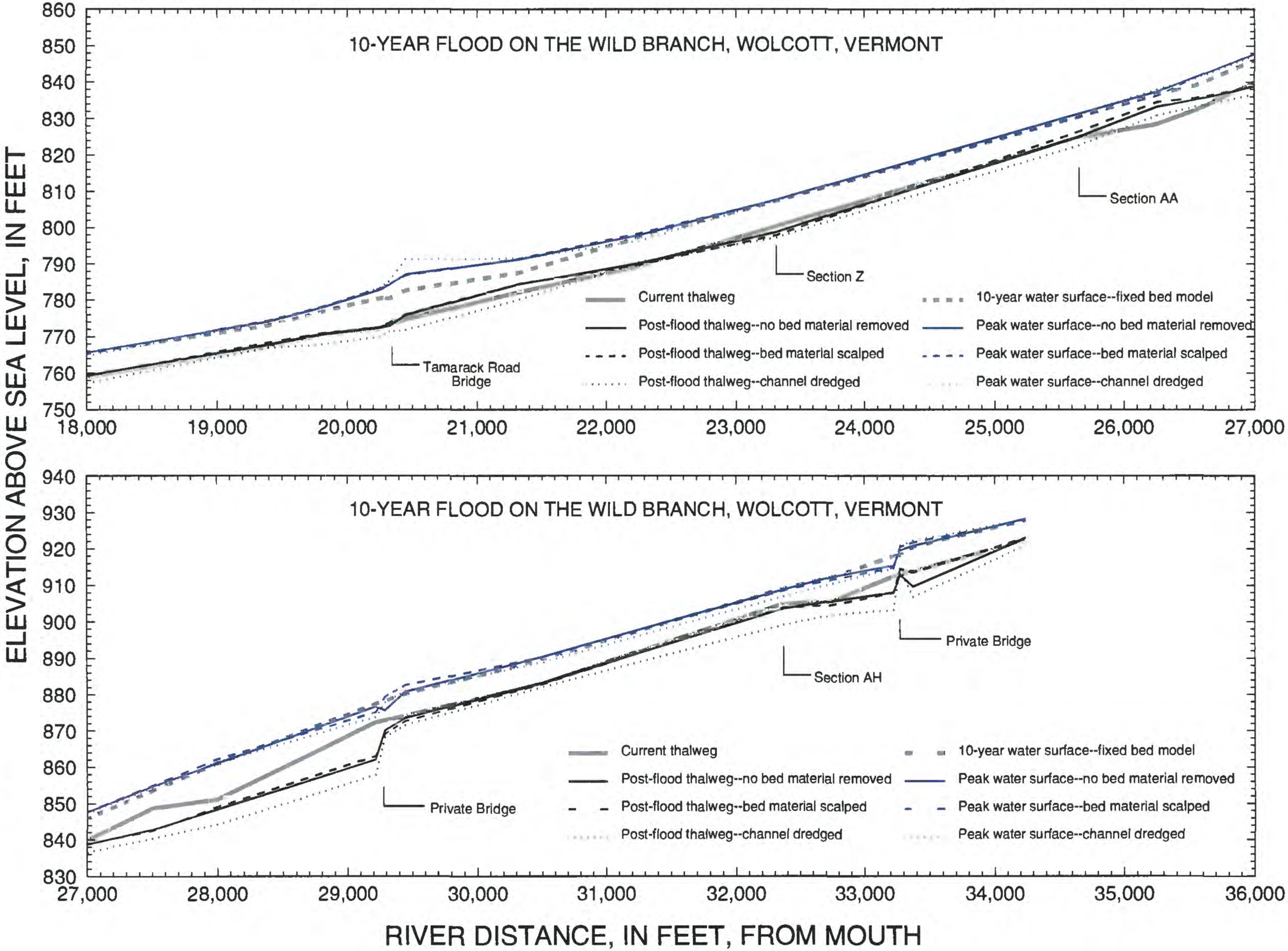

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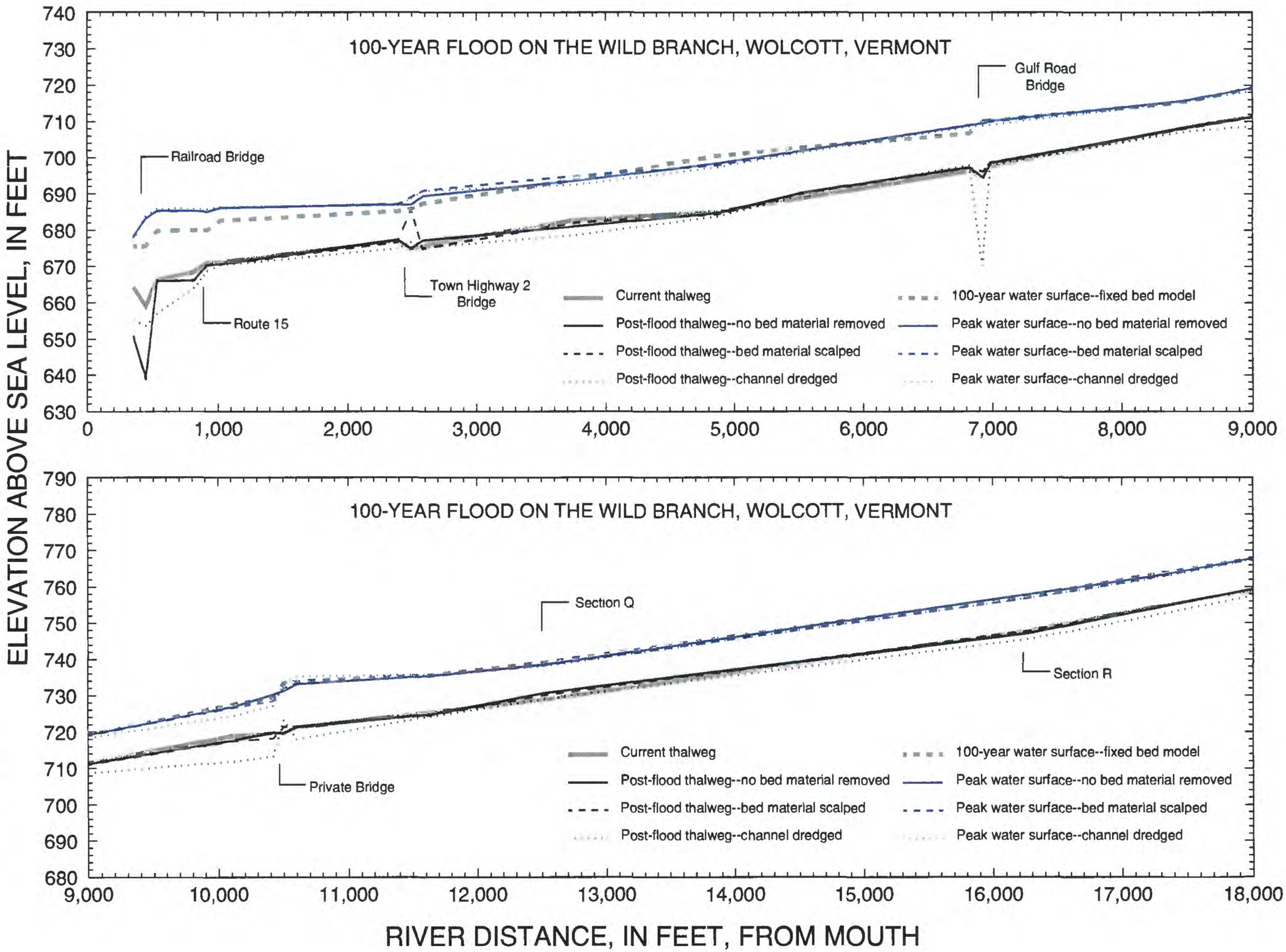

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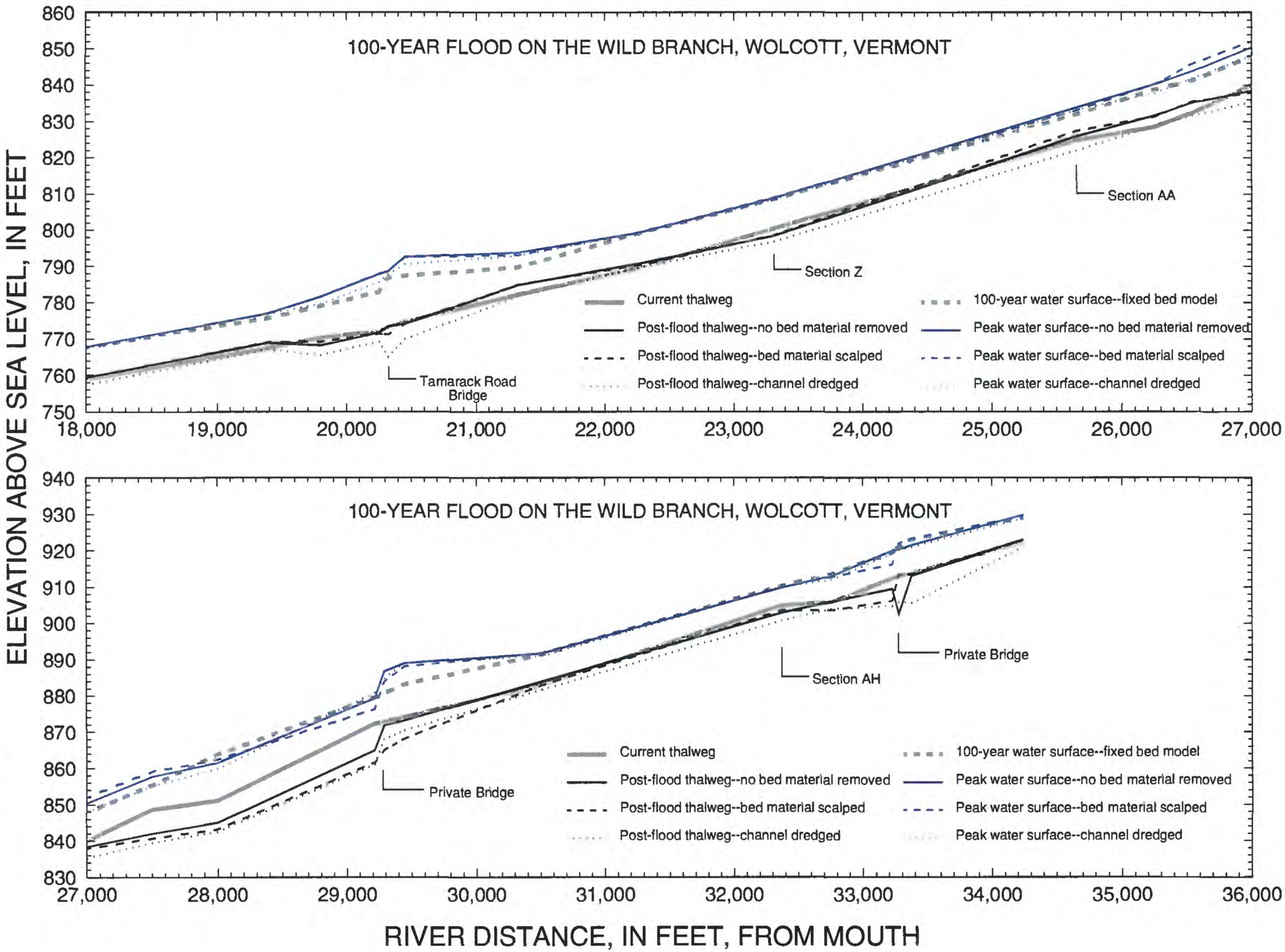

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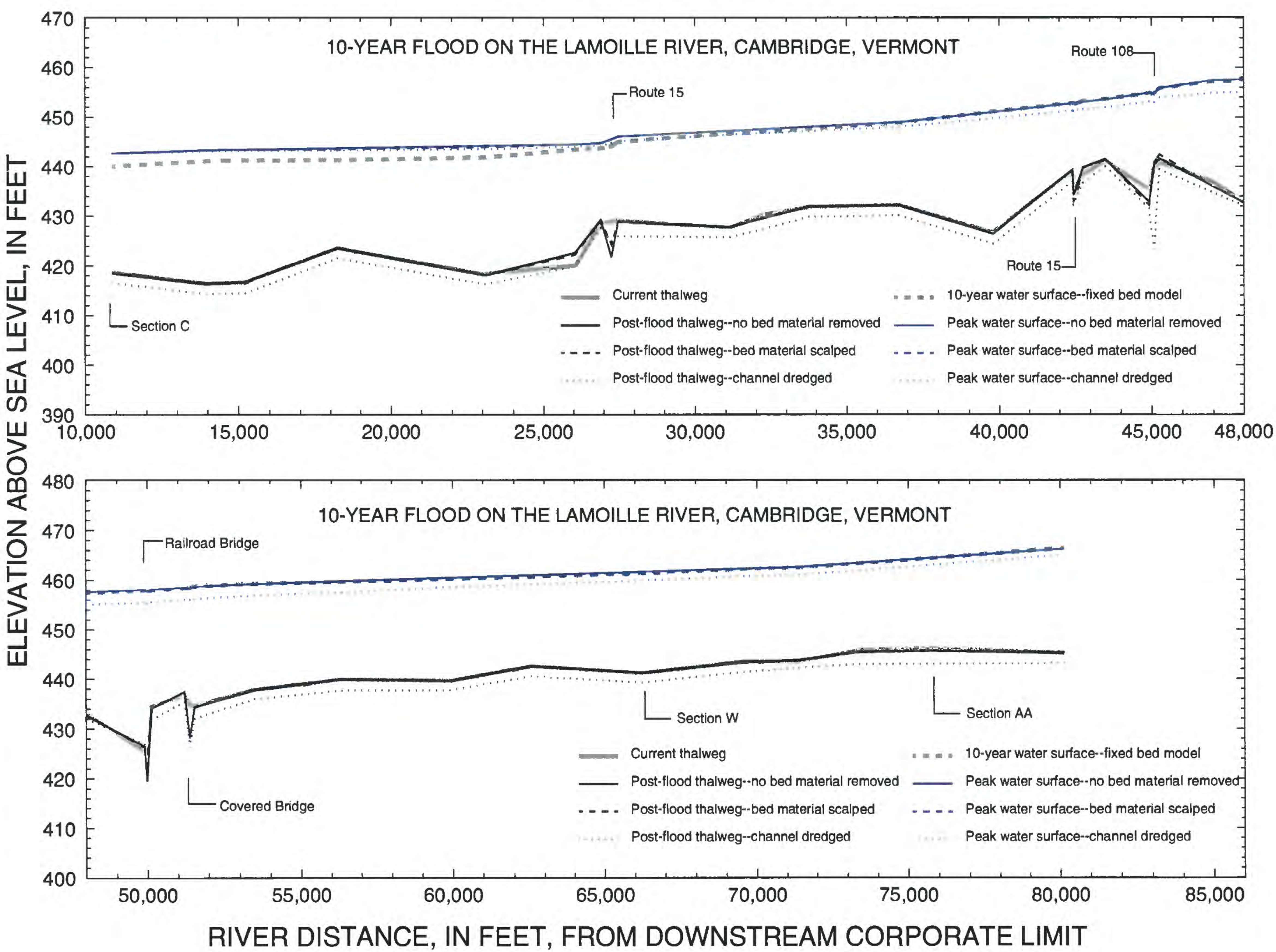
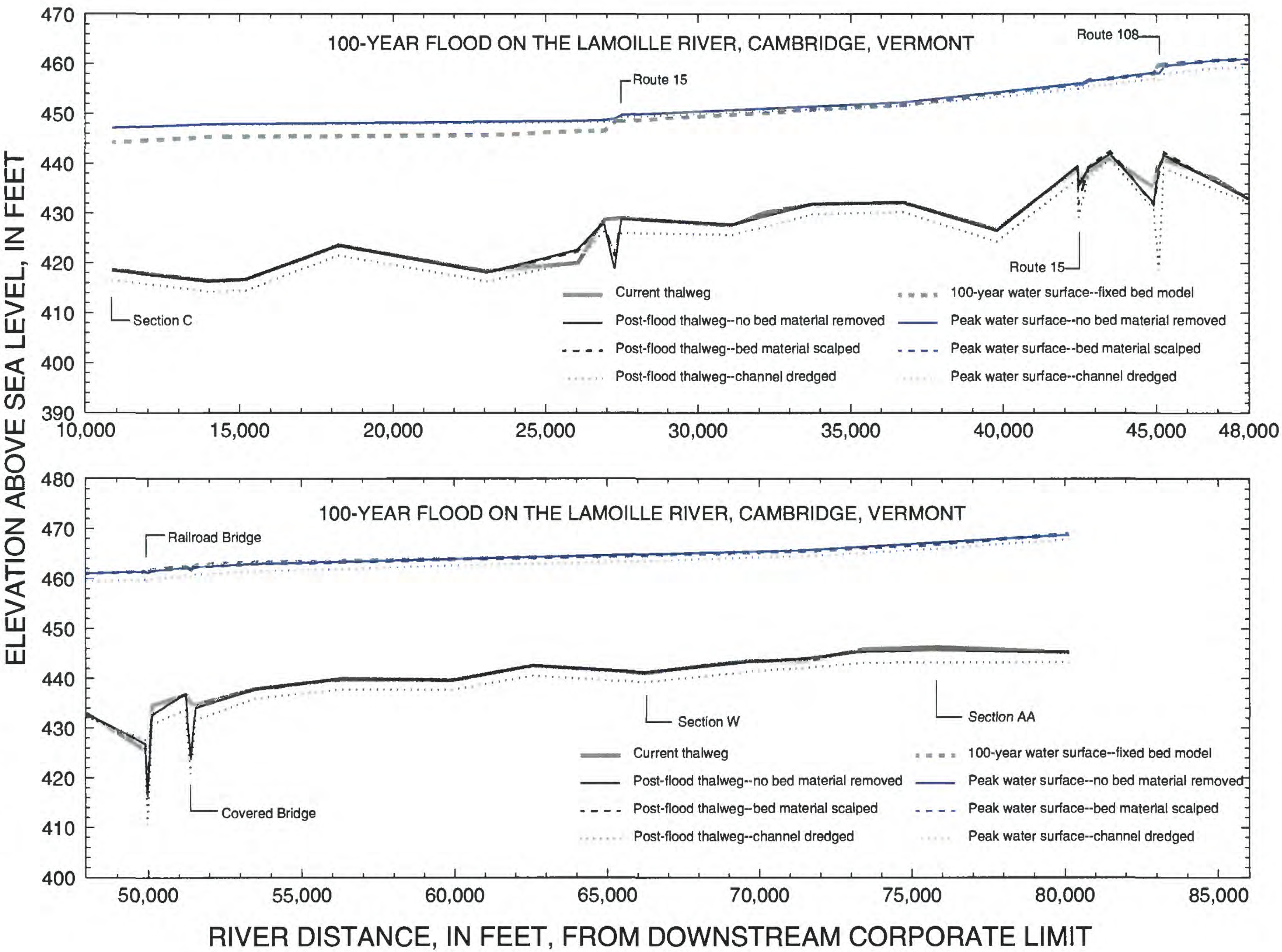


Movable Bed Model Results



APPENDIX D: Peak Water-surface Elevations from the Movable-bed Models in Tabular Form

The tables in Appendix D display the peak water-surface elevation at each cross section for a 10- and 100-yr flood occurring after the streambed management practices in which removal of bed material is restricted. For comparison, the differences of the peak water-surface elevations between the practices restricting removal of bed material and the scalping of bars and dredging are also included.

Table D1. Peak water-surface elevations at each cross section following the three streambed managment scenarios on the Trout River, Montgomery, Vt.

Section identifier	10-yr peak water-surface, no removal of bed material (ft)	Change in 10-yr peak water-surface, bed material scalped (ft)	Change in 10-yr peak water-surface, bed dredged (ft)	100-yr peak water-surface, no removal of bed material (ft)	Change in 100-yr peak water-surface, bed material scalped (ft)	Change in 100-yr peak water-surface, bed dredged (ft)
XS24	452.0	0.0	0.0	454.6	0.0	0.0
XS235	455.7	.0	-1.0	458.4	.0	-.8
Route 118	456.3	.0	-.8	458.9	.0	-.6
XS22	456.6	.0	-1.2	460.2	.0	-1.6
A	460.7	.0	-1.9	463.5	.0	-1.0
B	464.7	.0	-1.6	466.4	.0	-1.1
Route 118	465.4	.0	-1.4	467.1	.0	-1.0
C	465.9	.1	-1.8	468.0	.0	.0
D	466.6	-.1	1.1	470.8	.0	-.3
Covered	472.8	.0	-2.9	475.0	.0	-.4
E	474.4	.0	-4.7	476.5	.0	-.4
F	474.5	.0	-3.6	476.1	.0	-.5
G	476.6	.0	-1.8	480.9	.0	-.7
H	477.3	.0	-1.3	481.1	.0	-.7
I	477.9	.0	-1.2	481.5	.0	-.6
Vincent	477.9	.0	-1.2	481.5	.0	-.6
J	477.9	.1	-.7	481.5	.0	-.7
K	480.4	-.6	-1.6	482.6	-.1	-.7
L	481.9	-.2	-1.1	484.1	.0	-.4
M	486.5	.0	-.7	488.3	.0	-.4
N	491.3	.0	-.9	493.0	.0	-.5
O	495.9	-.2	-.7	498.0	-.2	-.7
P	499.1	-.5	-.7	500.9	-.2	.1
Q	503.7	-1.0	-.6	505.6	-.9	-.4
R	508.6	.0	-.9	511.0	-.6	-.2
S	511.8	.2	-1.7	516.3	.4	-2.1
T	519.3	.2	-2.4	523.5	-2.7	-4.8
U	524.3	.2	-2.8	525.6	.0	-3.8
Route 118	525.5	-.2	-2.6	527.5	-1.8	-4.6
V	527.8	-.1	-2.0	531.1	-.1	-2.1
Average		-.1	-1.5		-.2	-1.1

Table D2. Peak water-surface elevations at each cross section following the three streambed managment scenarios on the Wild Branch, Wolcott, Vt.

Section identifier	10-yr peak water-surface, no removal of bed material (ft)	Change in 10-yr peak water-surface, bed material scalped (ft)	Change in 10-yr peak water-surface, bed dredged (ft)	100-yr peak water-surface, no removal of bed material (ft)	Change in 100-yr peak water-surface, bed material scalped (ft)	Change in 100-yr peak water-surface, bed dredged (ft)
A	676.0	0.3	0.3	678.2	-0.3	-1.1
Railroad	677.4	.5	.6	683.1	.0	0.6
B	681.5	-2.0	2.2	685.2	.0	.6
C	681.5	-2.0	2.2	685.2	.0	.6
Route 15	681.4	-1.9	2.2	685.0	.0	.7
D	682.1	-.2	1.9	686.0	.0	.3
E	684.9	2.7	.1	687.0	.1	-.2
TH2	685.0	2.5	.4	686.9	2.1	1.8
F	686.8	1.0	2.4	689.3	1.5	1.4
G	690.6	-.7	-.4	693.5	1.4	-1.0
H	695.2	-.3	-.6	698.4	-.5	-1.1
I	698.7	.0	-.1	702.0	-.1	-.5
J	704.8	.0	.2	708.9	.1	-.4
TH15	704.9	.0	.9	709.5	-.1	-.6
K	704.9	-.1	.9	710.1	-.2	-1.0
L	714.0	-.3	-.9	715.6	.0	-.2
M	724.9	-.1	-3.6	727.0	-.3	-2.5
N	727.7	-1.3	-2.3	730.2	-1.7	-3.1
Bridge P1	731.6	.9	-1.7	731.3	.8	2.2
O	732.9	1.0	.2	733.2	.3	2.2
P	734.5	.0	-1.0	735.4	.0	.3
Q	737.0	-.2	-.5	738.5	-.1	-.4
R	755.4	-1.0	-1.0	757.4	-.6	-.6
S	760.9	-.8	-1.4	762.7	-.4	-.6
T	774.0	.3	-.1	776.9	.1	-.1
U	777.8	.2	.0	781.6	.0	-2.0
V	782.7	.4	.6	787.8	.1	-2.2
TH13	784.1	.0	.9	788.6	-.1	-.9
W	787.0	-.2	4.2	792.6	-.1	-2.1
X	791.2	.2	.3	793.8	-.6	-.9
Y	797.9	.4	-1.6	799.2	.1	-.1
Z	807.7	-.1	-.2	808.8	.2	-.4
AA	831.0	-.6	.2	833.6	-.6	-.5
AB	837.3	-1.1	.5	840.2	.0	-2.5
AC	841.5	-.2	-.4	843.7	2.0	-2.0
AD	854.6	.3	-.3	857.7	1.3	-2.7
AE	861.1	.9	.1	861.4	.9	-1.6
AF1	876.6	-1.6	-2.9	879.2	-3.0	1.6
Bridge P2	875.6	3.8	2.2	886.7	-2.8	-1.9
AF	880.7	1.9	.2	888.9	-.8	.1
AG	890.4	-.1	-1.6	891.6	.2	-.7
AH	908.7	-.2	-1.8	909.7	.2	.1
AI	912.2	-.7	-1.9	912.9	-.3	-1.1
AJ	915.4	-.6	-.9	919.9	-3.8	-.7
Bridge P3	919.6	.9	1.3	920.3	1.6	-.1
AK	920.8	.9	1.4	921.5	1.8	-.5
AL	928.2	-.4	-.1	929.8	-.4	-.9
Average		.1	.0		.0	-.5

Table D3. Peak water-surface elevations at each cross section following the three streambed managment scenarios on the Lamoille River, Cambridge, Vt.

Section identifier	10-yr peak water-surface, no removal of bed material (ft)	Change in 10-yr peak water-surface, bed material scalped (ft)	Change in 10-yr peak water-surface, bed dredged (ft)	100-yr peak water-surface, no removal of bed material (ft)	Change in 100-yr peak water-surface, bed material scalped (ft)	Change in 100-yr peak water-surface, bed dredged (ft)
C	442.6	0.0	0.0	447.1	0.0	0.0
D	443.3	.0	-.2	447.9	.0	-.1
X39	443.3	.0	-.2	447.9	.0	-.1
E	443.4	.0	-.2	448.0	.0	-.1
VA	443.9	.0	-.4	448.3	.0	-.2
VB	444.4	.0	-.5	448.6	.0	-.2
VC	444.7	-.1	-.6	448.7	.0	-.4
Route 15	445.5	-.1	-.7	449.0	.0	-.3
VD	446.0	-.1	-1.0	449.7	.0	-.4
F	447.2	-.1	-.8	450.7	.0	-.5
G	447.5	.0	-.8	451.0	.0	-.5
H	447.9	.0	-.8	451.4	.0	-.5
I	448.9	.0	-1.0	452.3	.0	-.7
J	451.0	.0	-1.2	454.2	.0	-.9
K	452.7	.0	-1.5	456.0	.0	-1.0
Route 15	452.7	.0	-1.5	455.9	.0	-1.0
L	453.1	.0	-1.5	456.6	.0	-1.1
M	453.5	.0	-1.6	457.0	.0	-1.2
N	454.9	-.1	-1.8	458.3	-.1	-1.3
Route 108	454.8	-.1	-1.9	458.2	-.1	-1.3
O	455.8	-.1	-1.9	459.6	-.1	-1.6
P	457.4	-.2	-2.6	460.8	-.1	-1.7
RR Exit	458.1	-.2	-2.6	461.4	-.1	-1.6
Railraod	457.9	-.1	-2.6	461.2	-.1	-1.6
Q	458.1	-.2	-2.6	461.5	-.1	-1.7
Exit	458.5	-.2	-2.5	462.1	-.1	-1.6
Covered	458.4	-.2	-2.4	461.9	-.1	-1.6
R	458.7	-.2	-2.5	462.3	-.1	-1.6
S	459.2	-.1	-2.4	462.9	-.1	-1.5
T	459.6	-.1	-2.1	463.2	-.1	-1.4
U	460.2	-.1	-1.6	463.8	-.1	-1.2
V	460.6	-.1	-1.5	464.1	-.1	-1.2
W	461.4	-.1	-1.5	464.7	-.1	-1.2
X	462.2	-.1	-1.5	465.4	-.1	-1.2
Y	462.6	-.1	-1.5	465.6	-.1	-1.2
Z	463.3	-.1	-1.4	466.2	-.1	-1.1
AA	464.3	.0	-1.3	467.0	-.1	-1.0
AB	466.2	.0	-1.3	468.7	.0	-.9
Average		-.1	-1.4		-.1	-1.0

APPENDIX E: Movable-bed Model Results—Cross-section Geometry

EXPLANATION

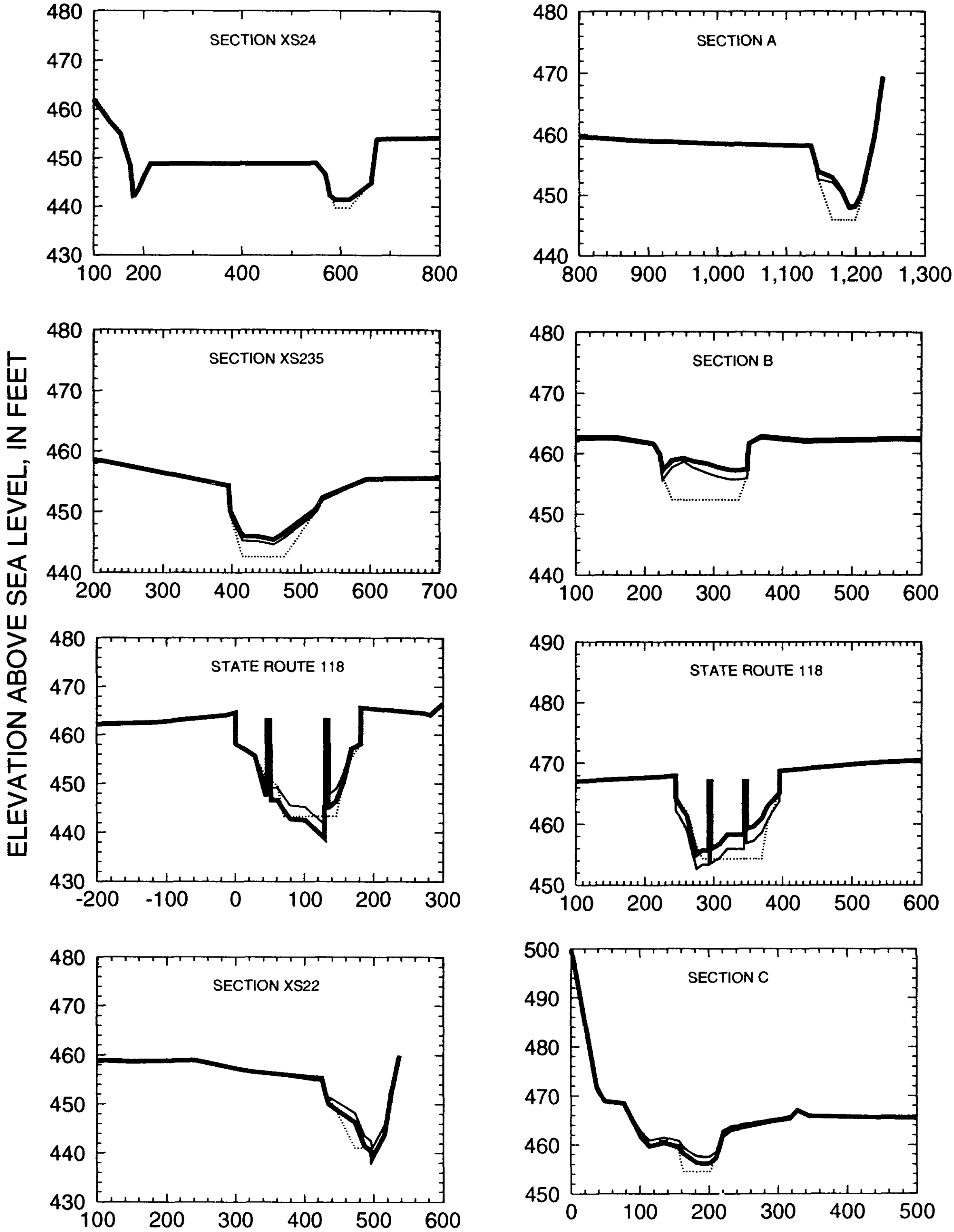
- ——— Cross section as surveyed following the 1997 flood
- ——— Cross section following synthesized flood--channel untouched prior to flood
- – — – Cross section following synthesized flood--channel scalped prior to flood
- ······ Cross section following synthesized flood--channel dredged prior to flood

Cross sections are located on the following figures:

Montgomery, Vt. . . . figure 2
Wolcott, Vt. . . . . figure 3
Cambridge, Vt. . . . . . figure 4

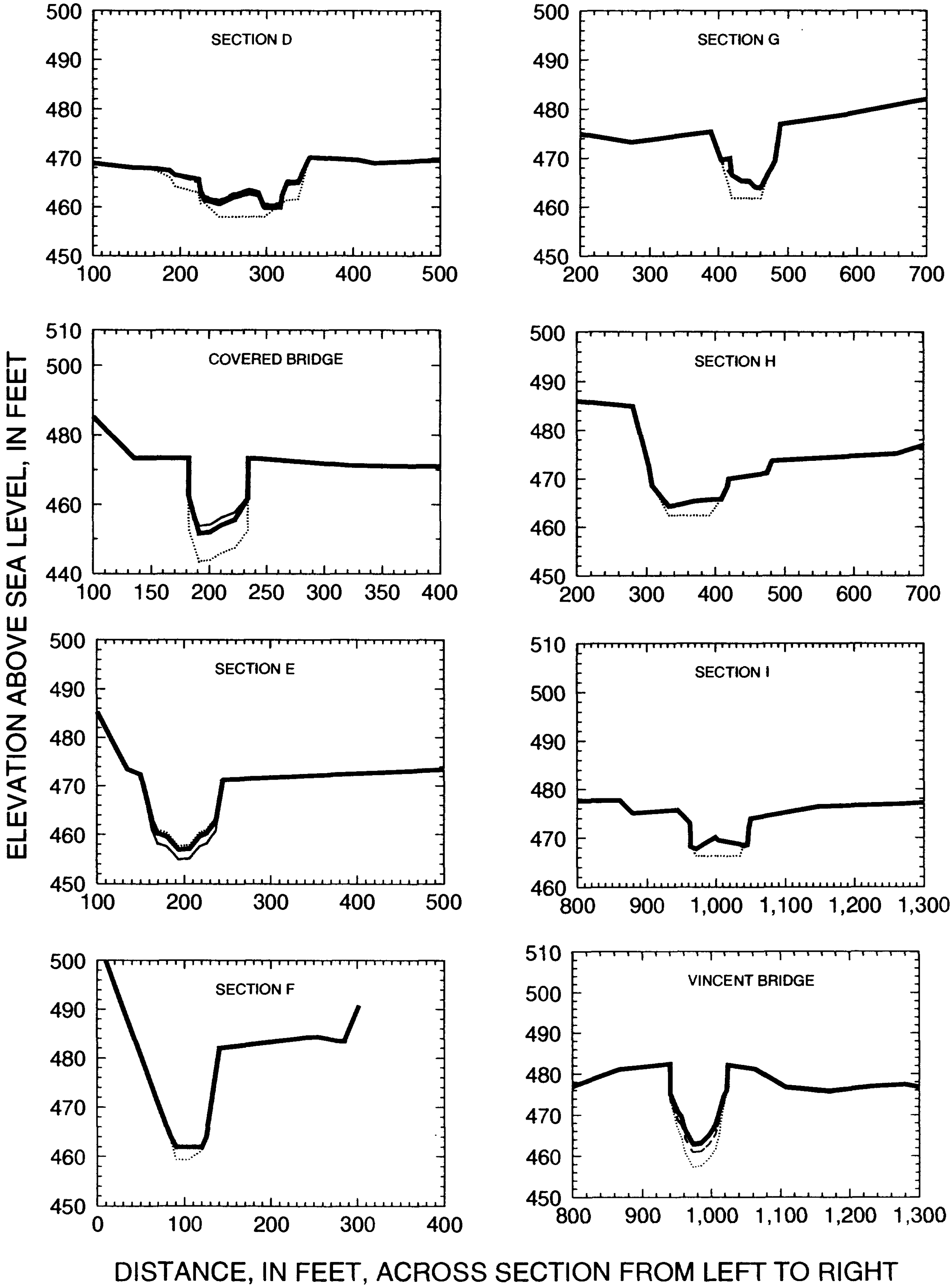
Movable Bed Model Results

10-year flood on the Trout River, Montgomery, Vermont



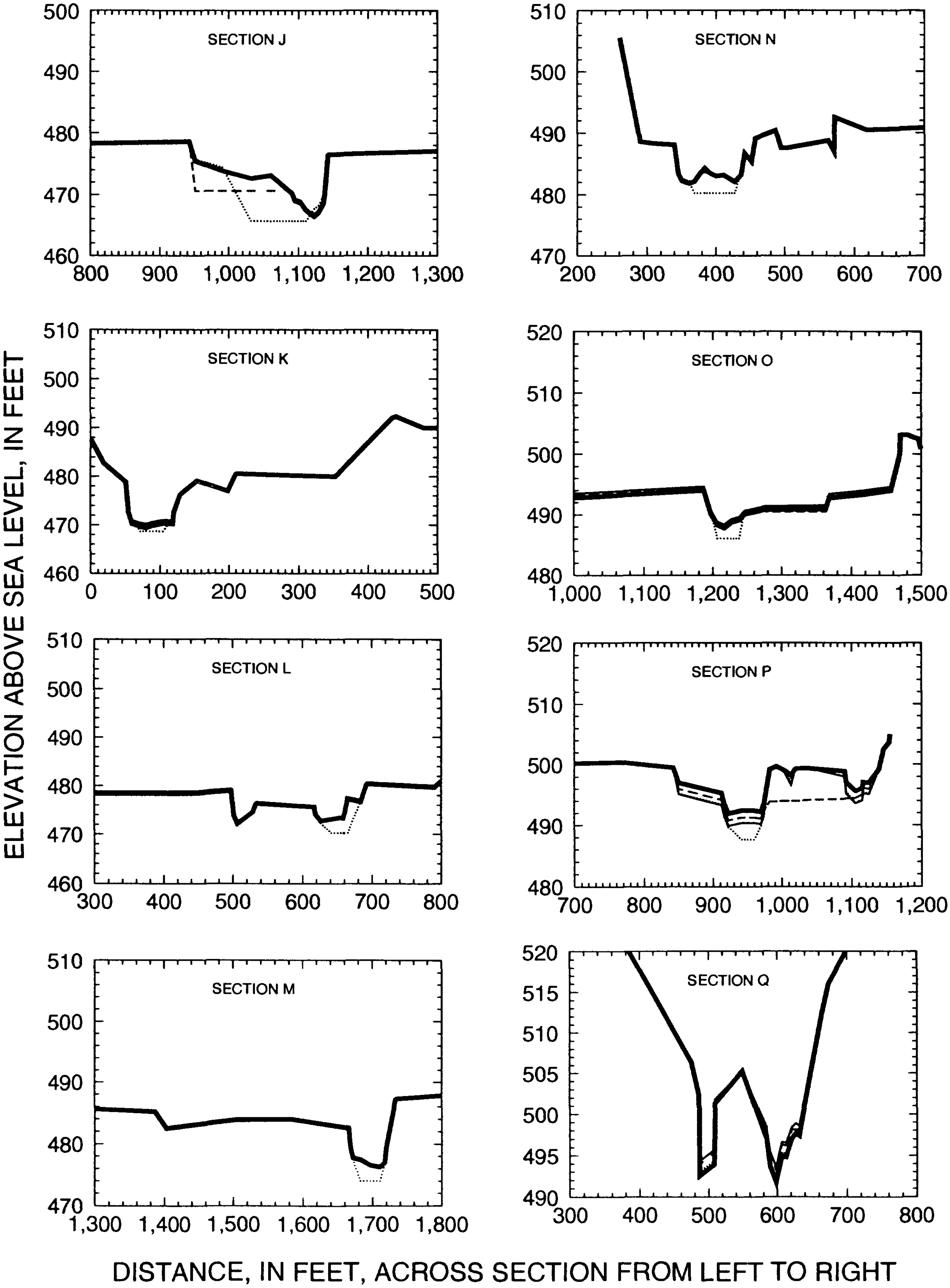
Movable Bed Model Results

10-year flood on the Trout River, Montgomery, Vermont



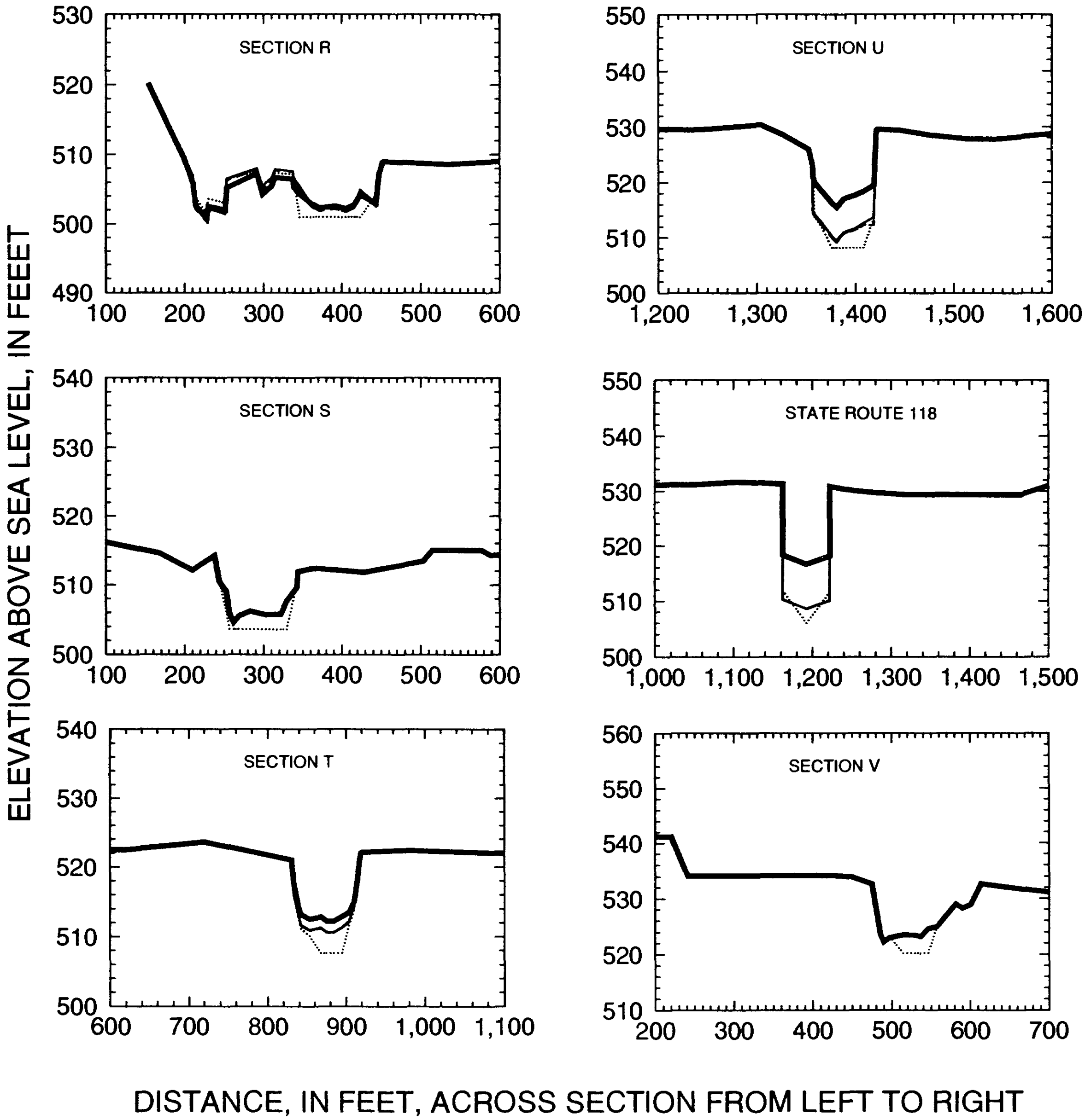
Movable Bed Model Results

10-year flood on the Trout River, Montgomery, Vermont



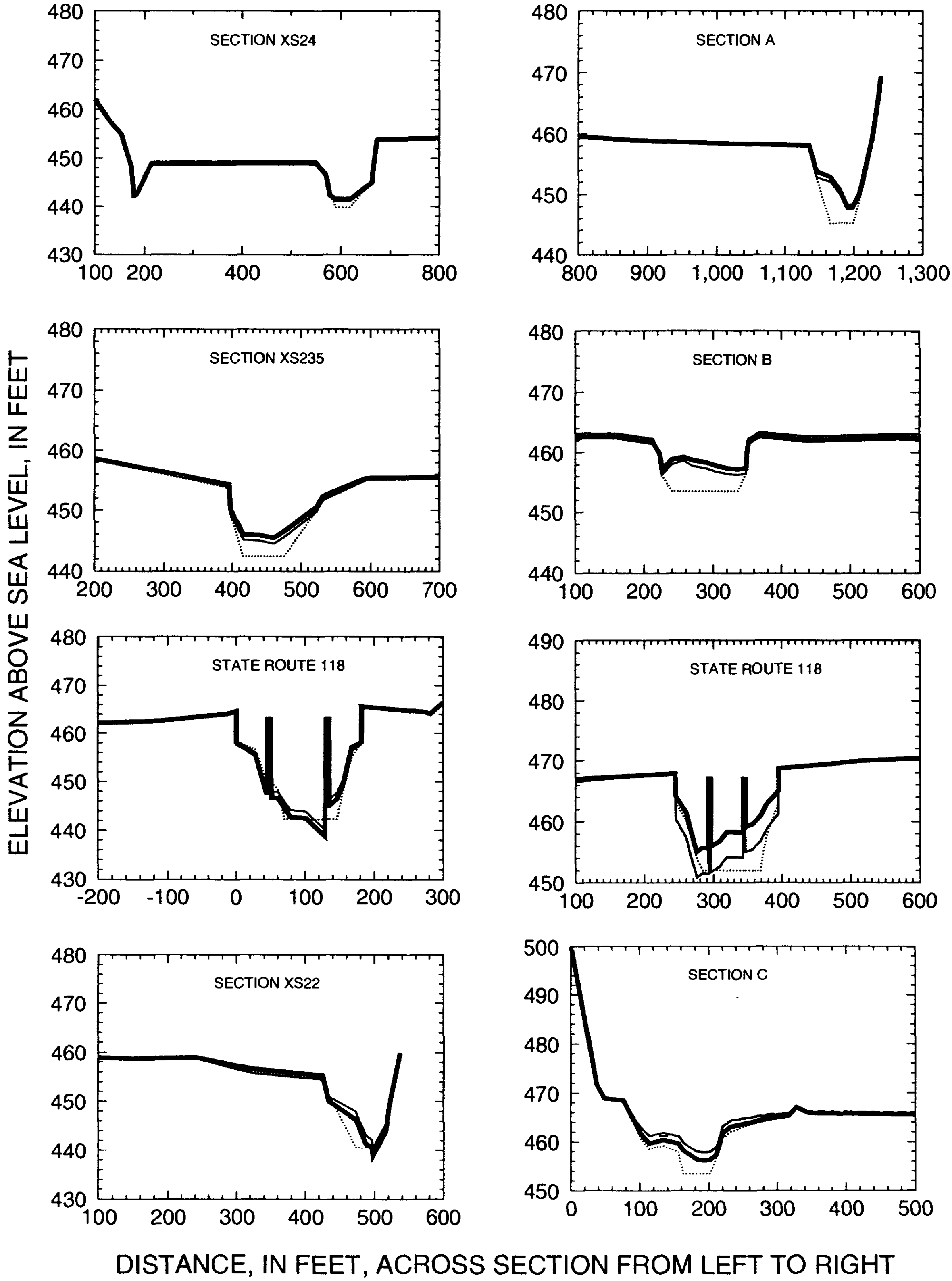
Movable Bed Model Results

10-year flood on the Trout River, Montgomery, Vermont



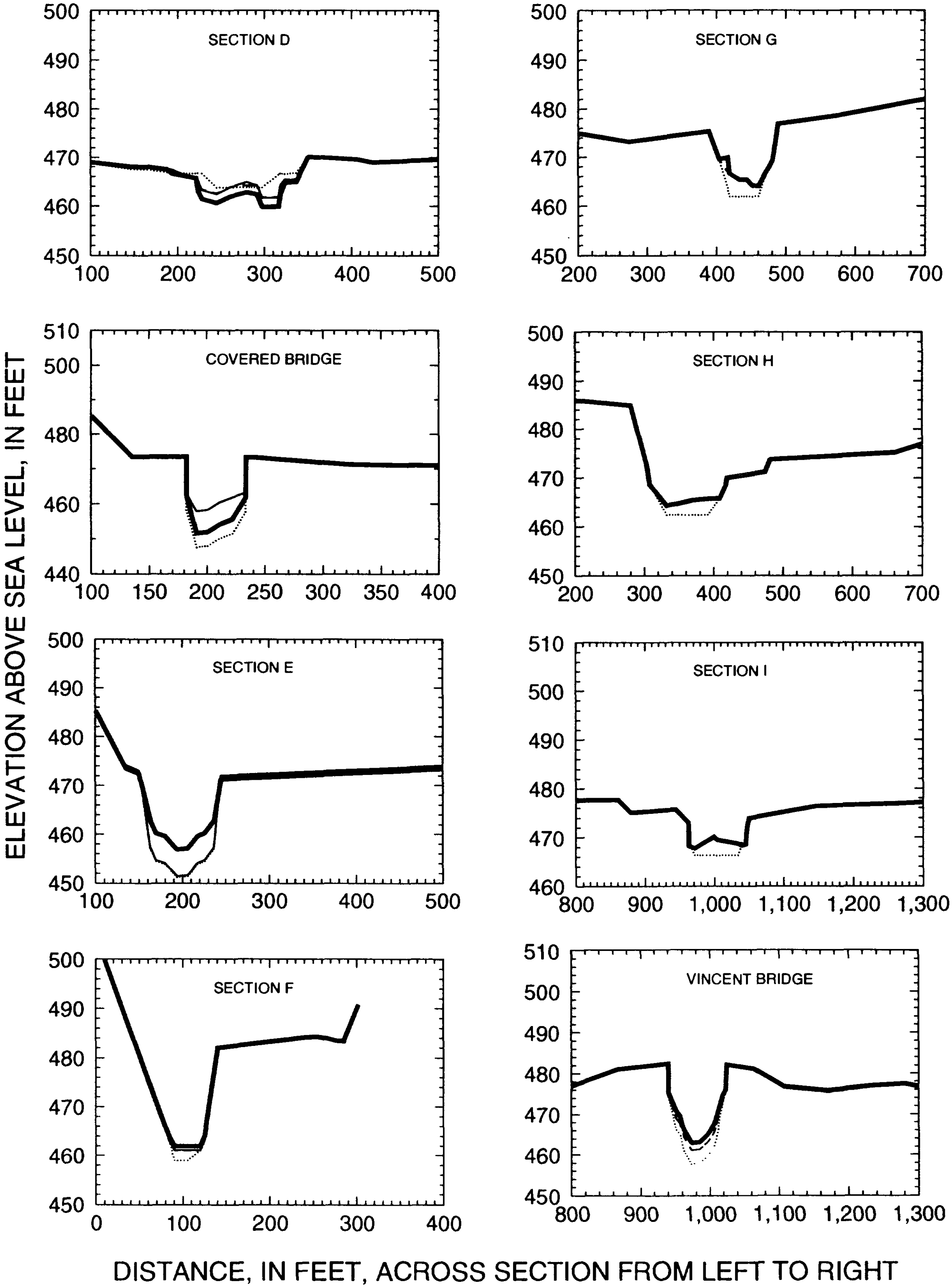
Movable Bed Model Results

100-year flood on the Trout River, Montgomery, Vermont



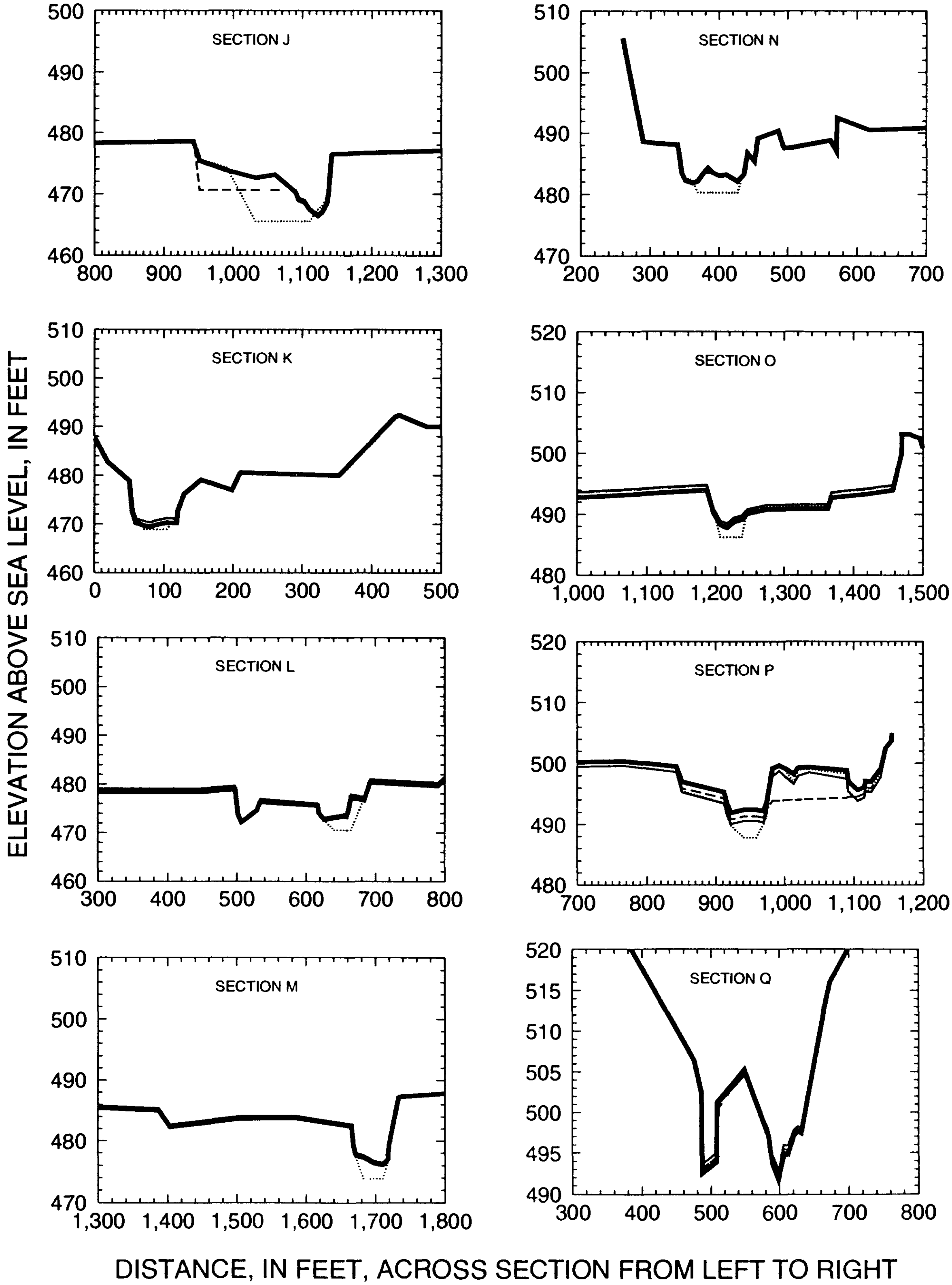
Movable Bed Model Results

100-year flood on the Trout River, Montgomery, Vermont



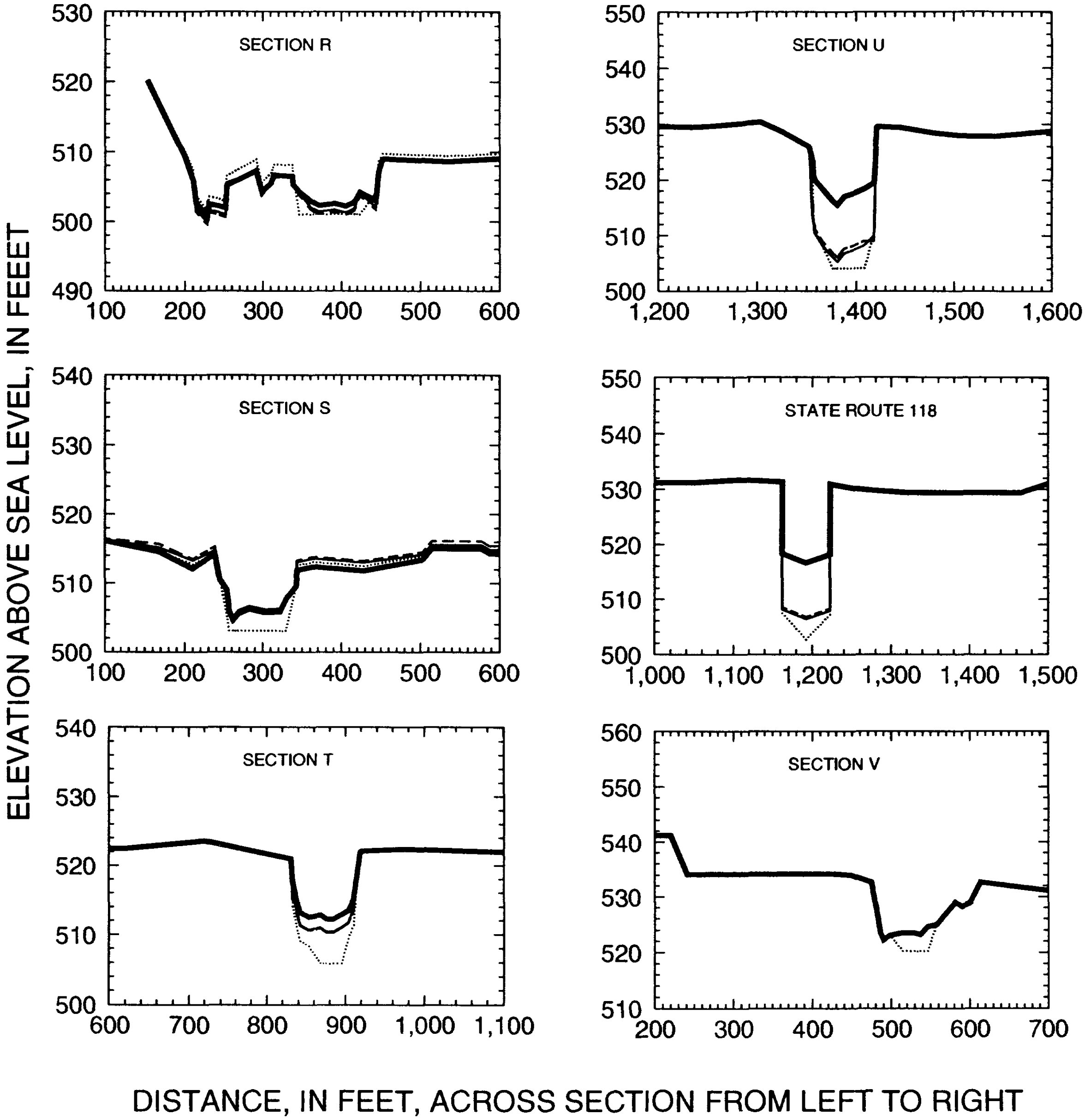
Movable Bed Model Results

100-year flood on the Trout River, Montgomery, Vermont



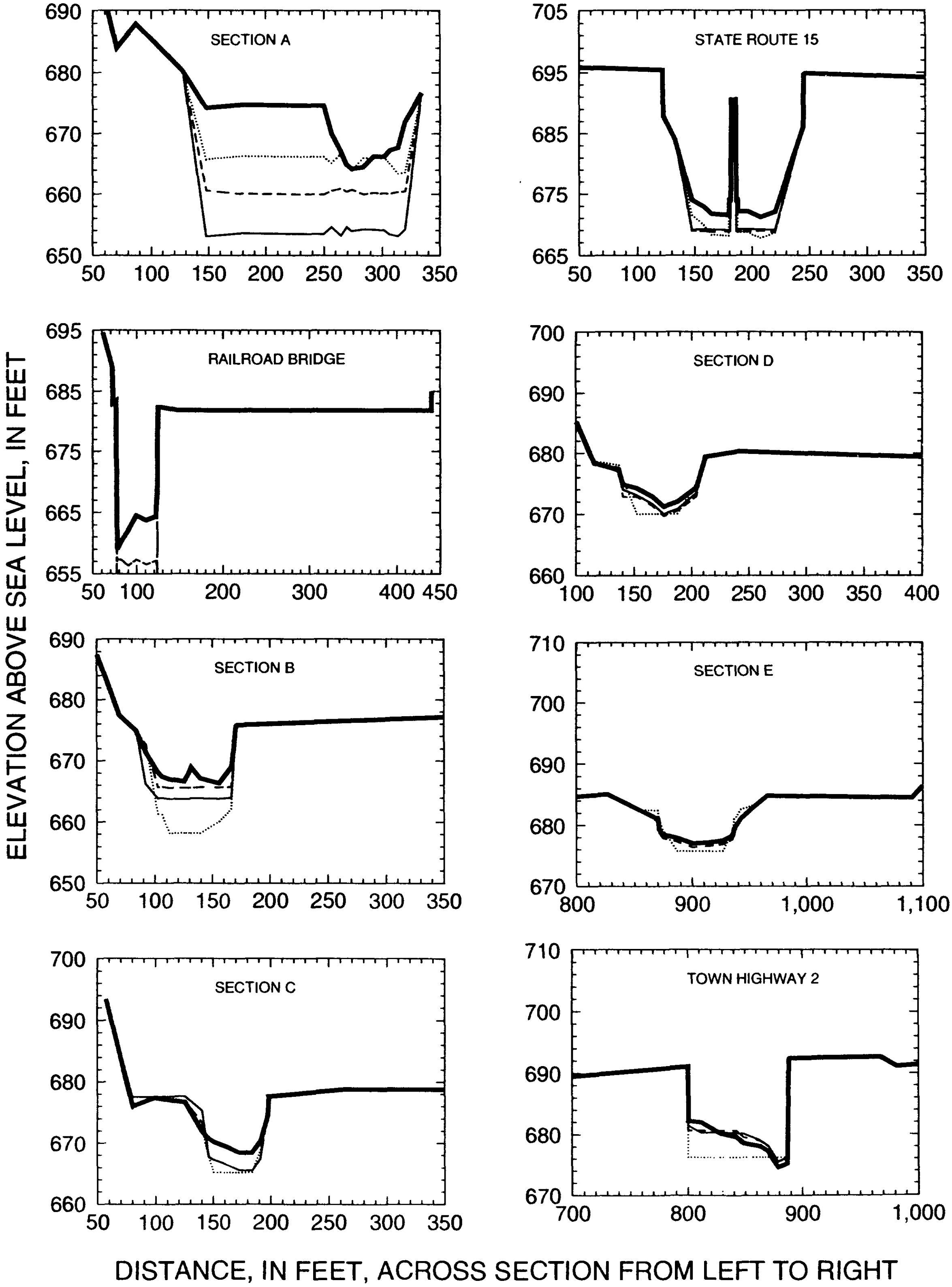
Movable Bed Model Results

100-year flood on the Trout River, Montgomery, Vermont



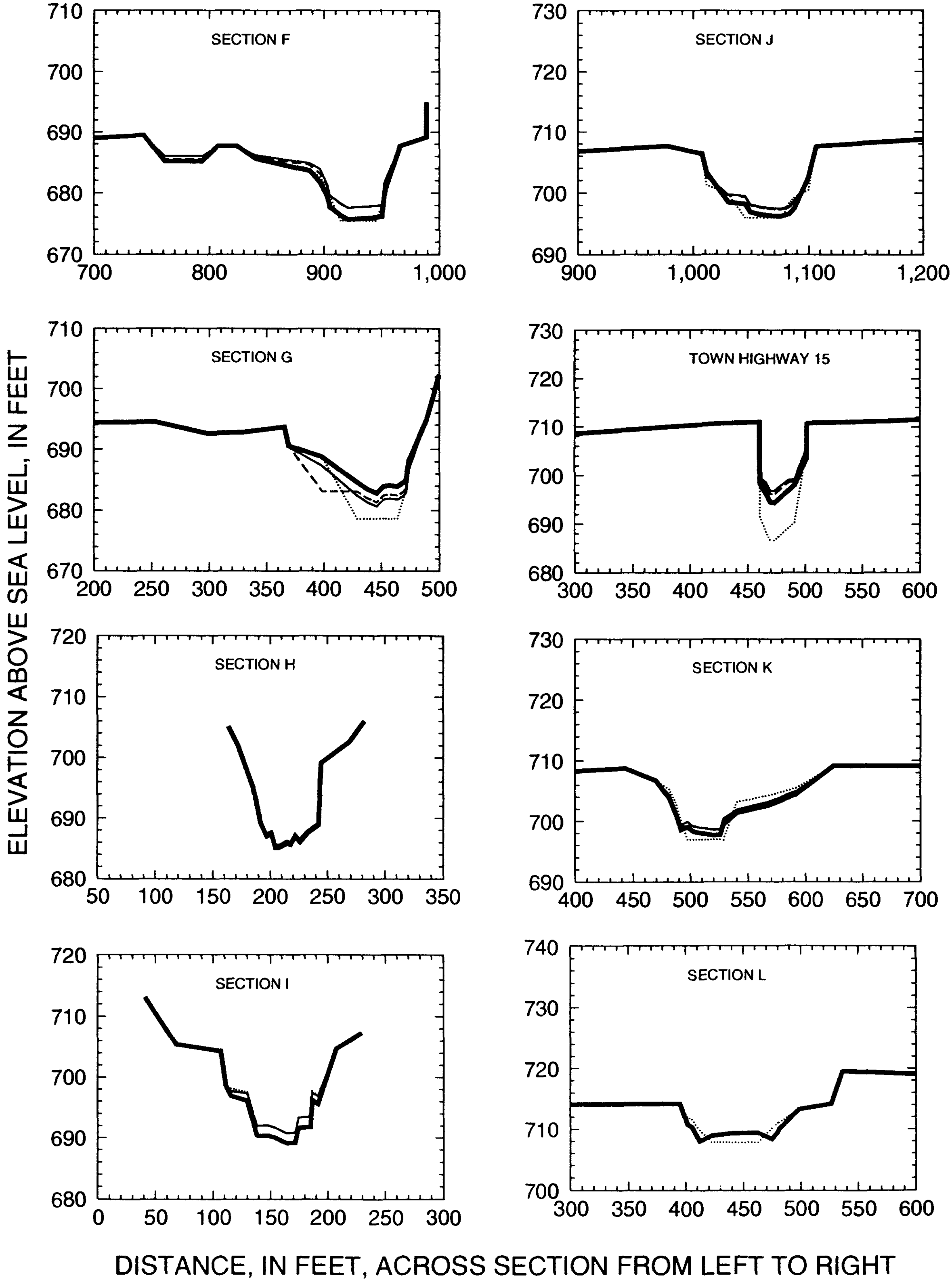
Movable Bed Model Results

10-year flood on the Wild Branch, Wolcott, Vermont



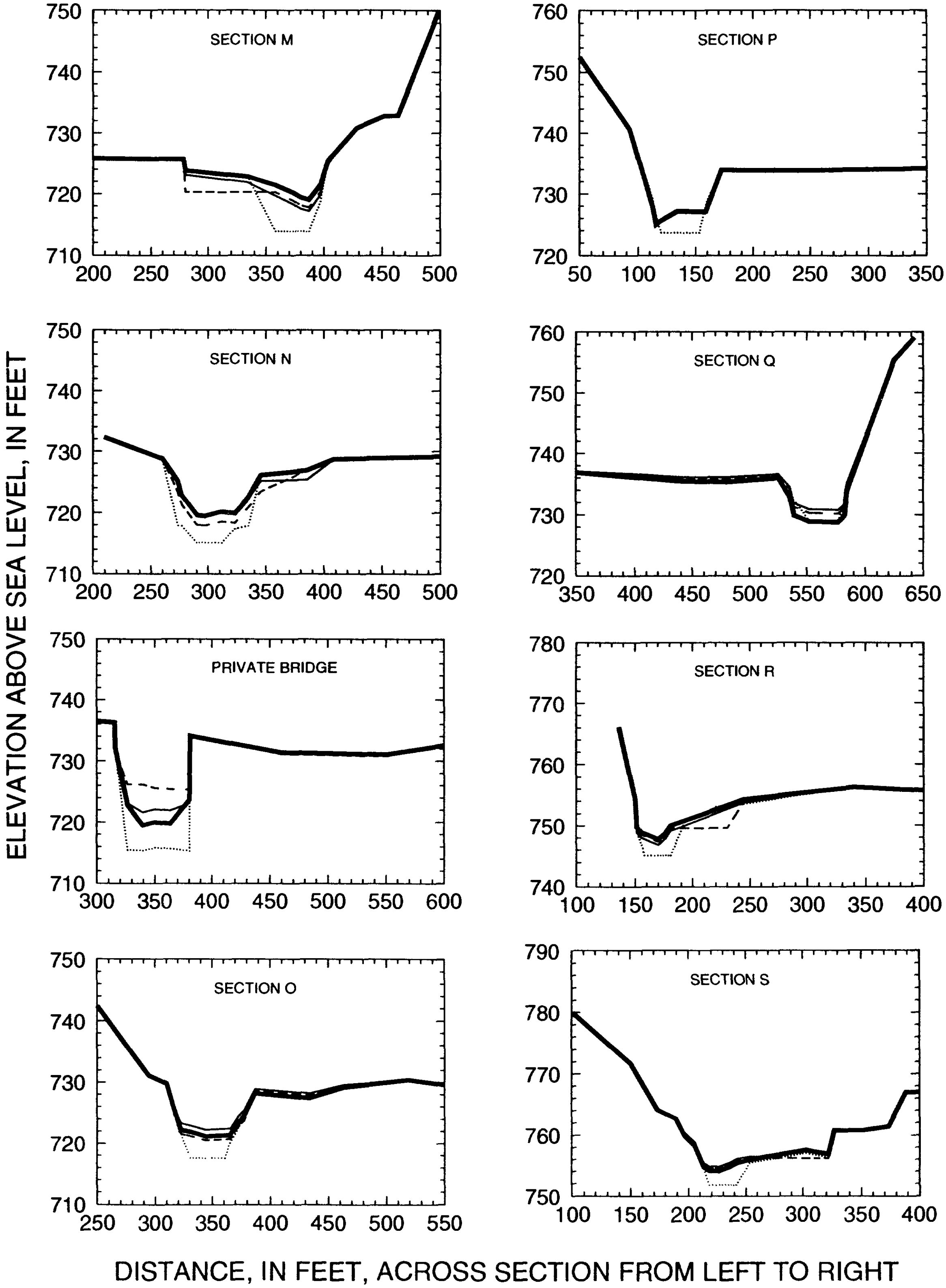
Movable Bed Model Results

10-year flood on the Wild Branch, Wolcott, Vermont



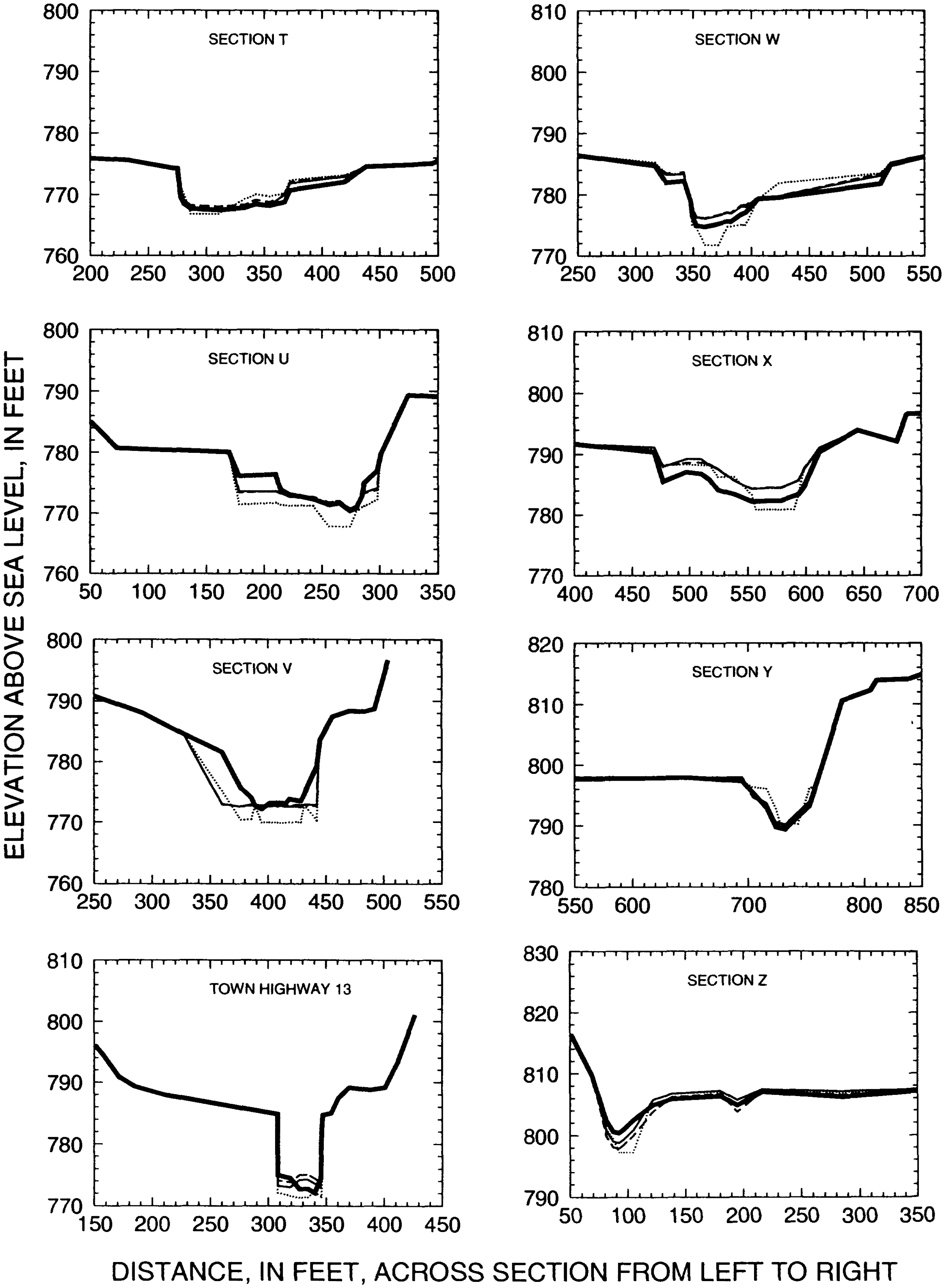
Movable Bed Model Results

10-year flood on the Wild Branch, Wolcott, Vermont



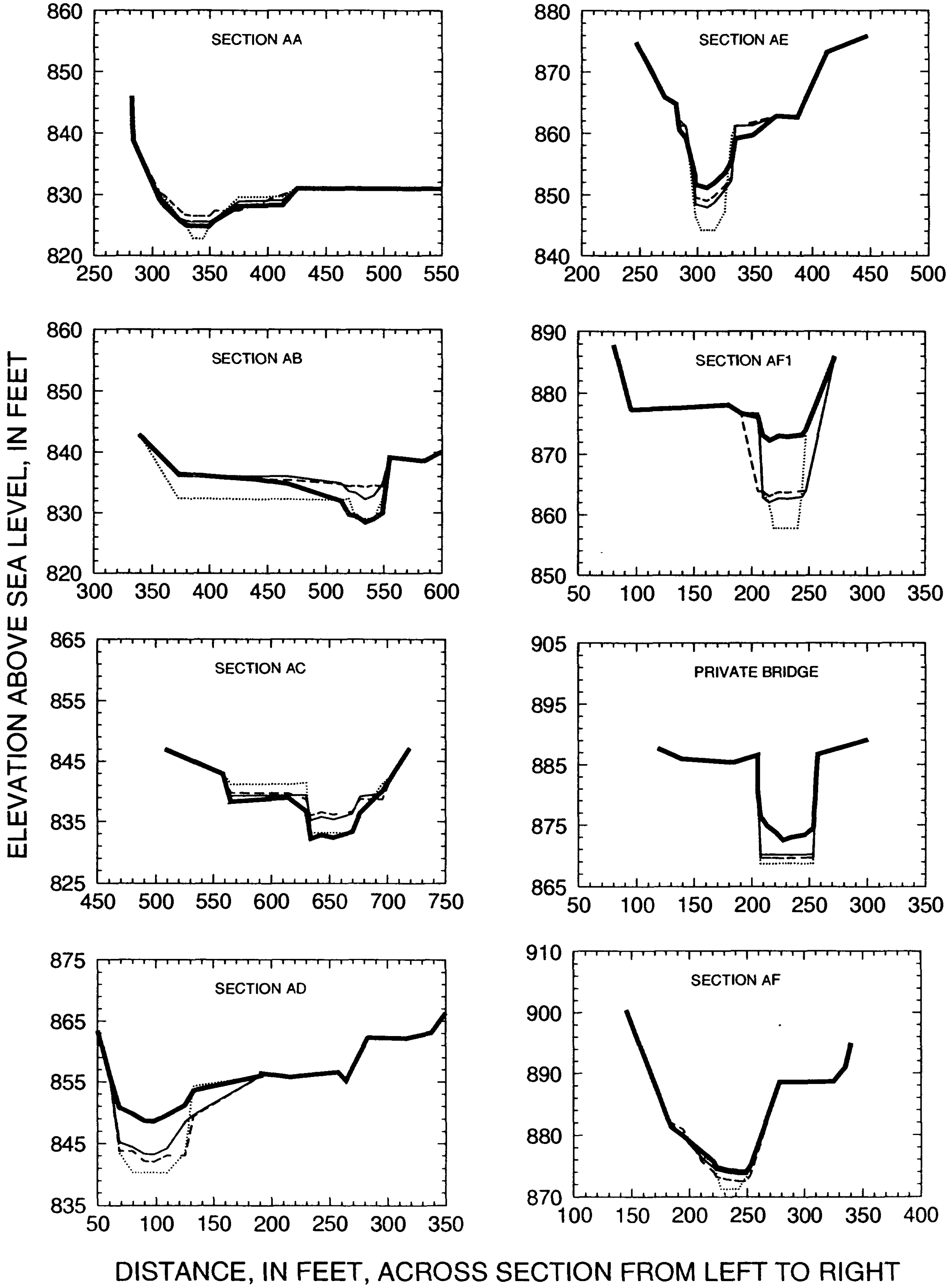
Movable Bed Model Results

10-year flood on the Wild Branch, Wolcott, Vermont



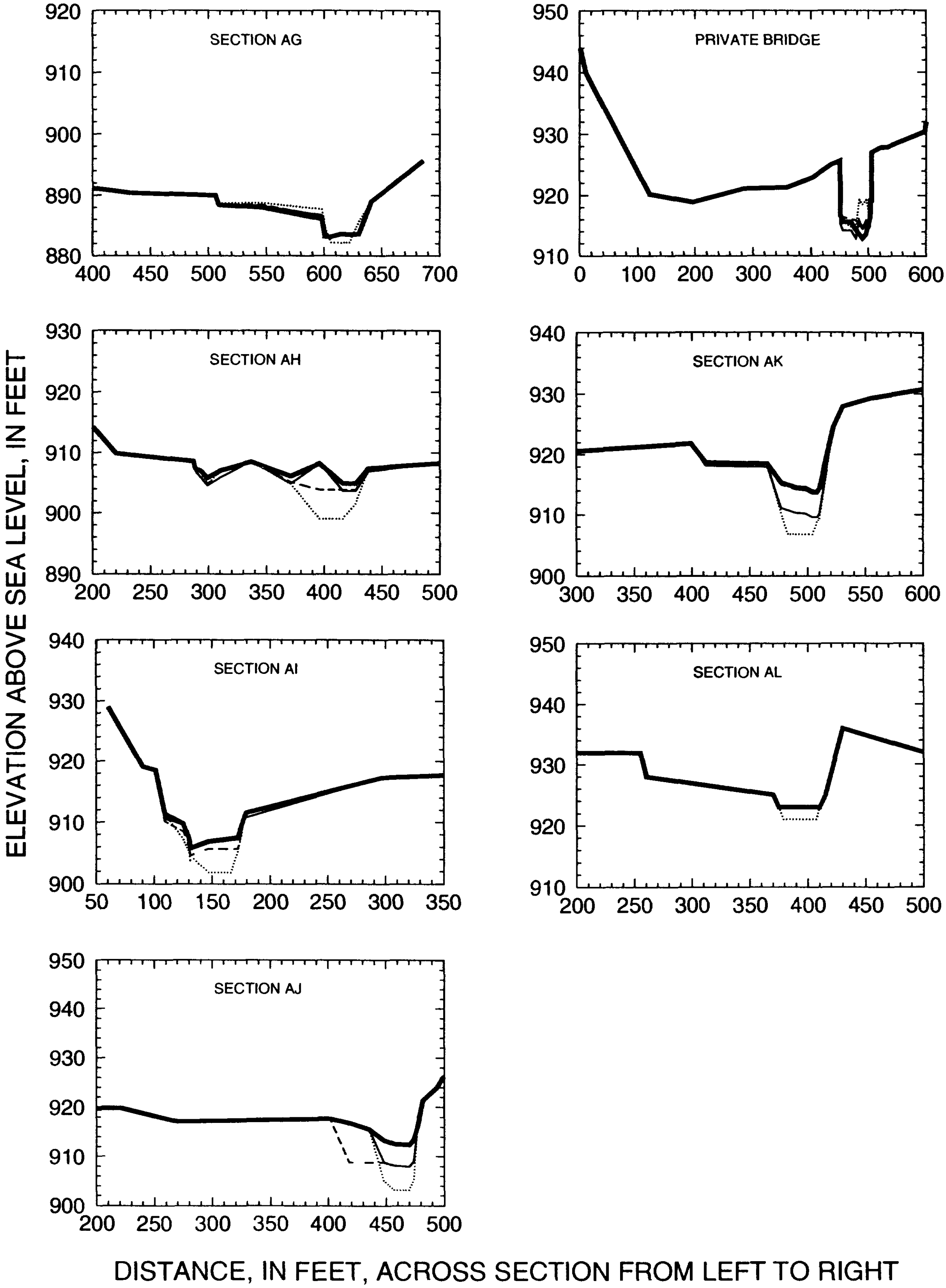
Movable Bed Model Results

10-year flood on the Wild Branch, Wolcott, Vermont



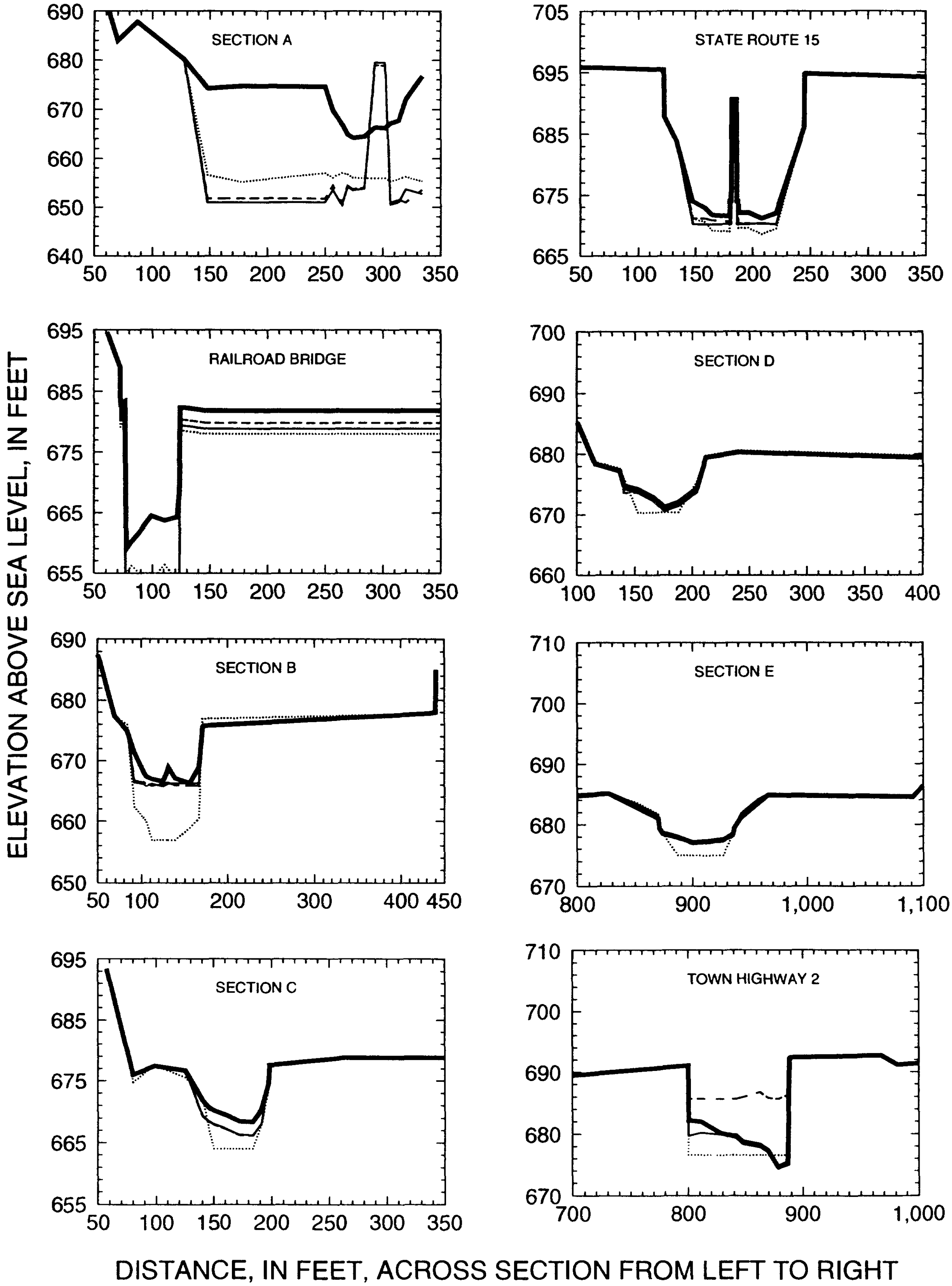
Movable Bed Model Results

10-year flood on the Wild Branch, Wolcott, Vermont



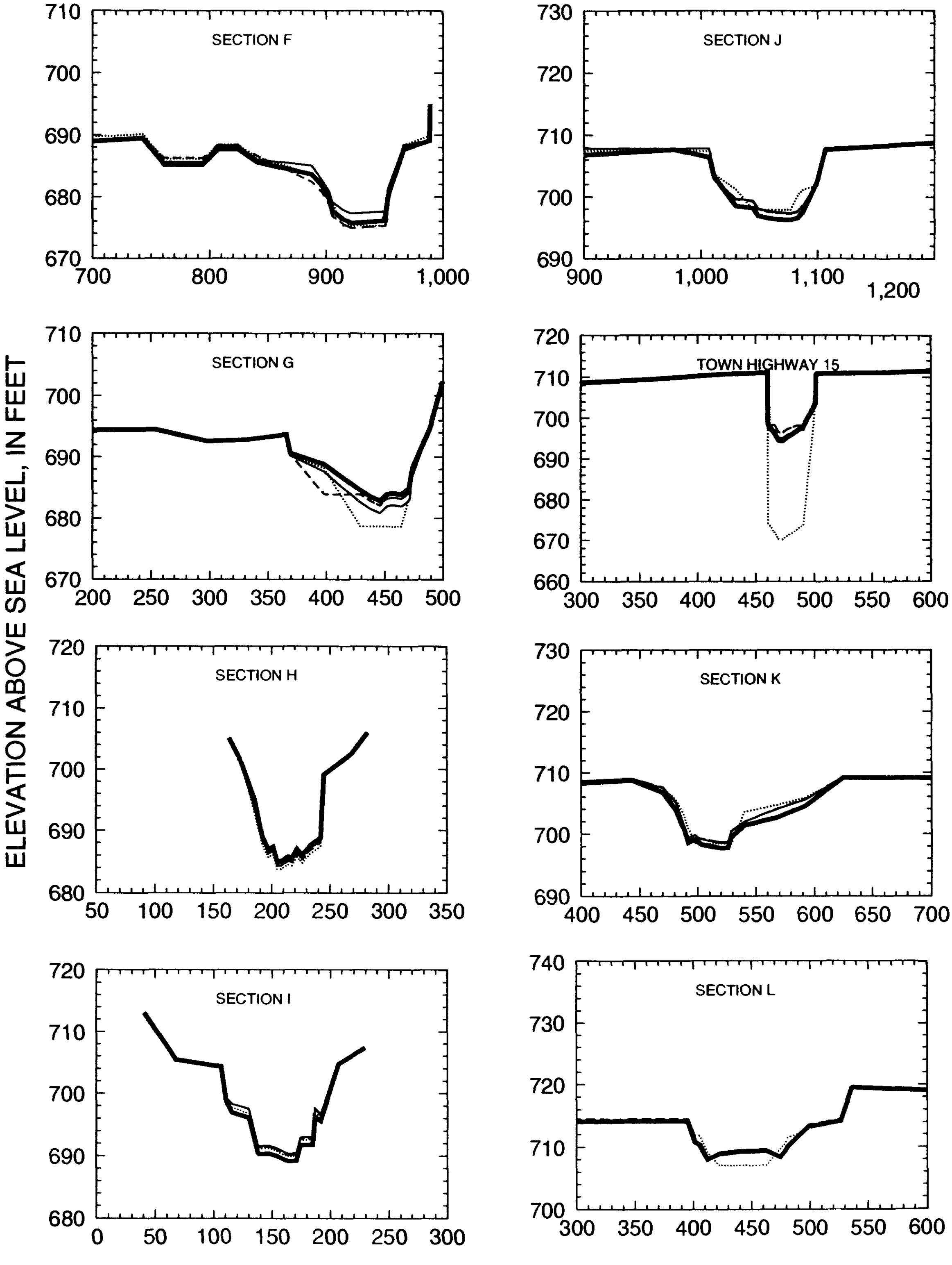
Movable Bed Model Results

100-year flood on the Wild Branch, Wolcott, Vermont



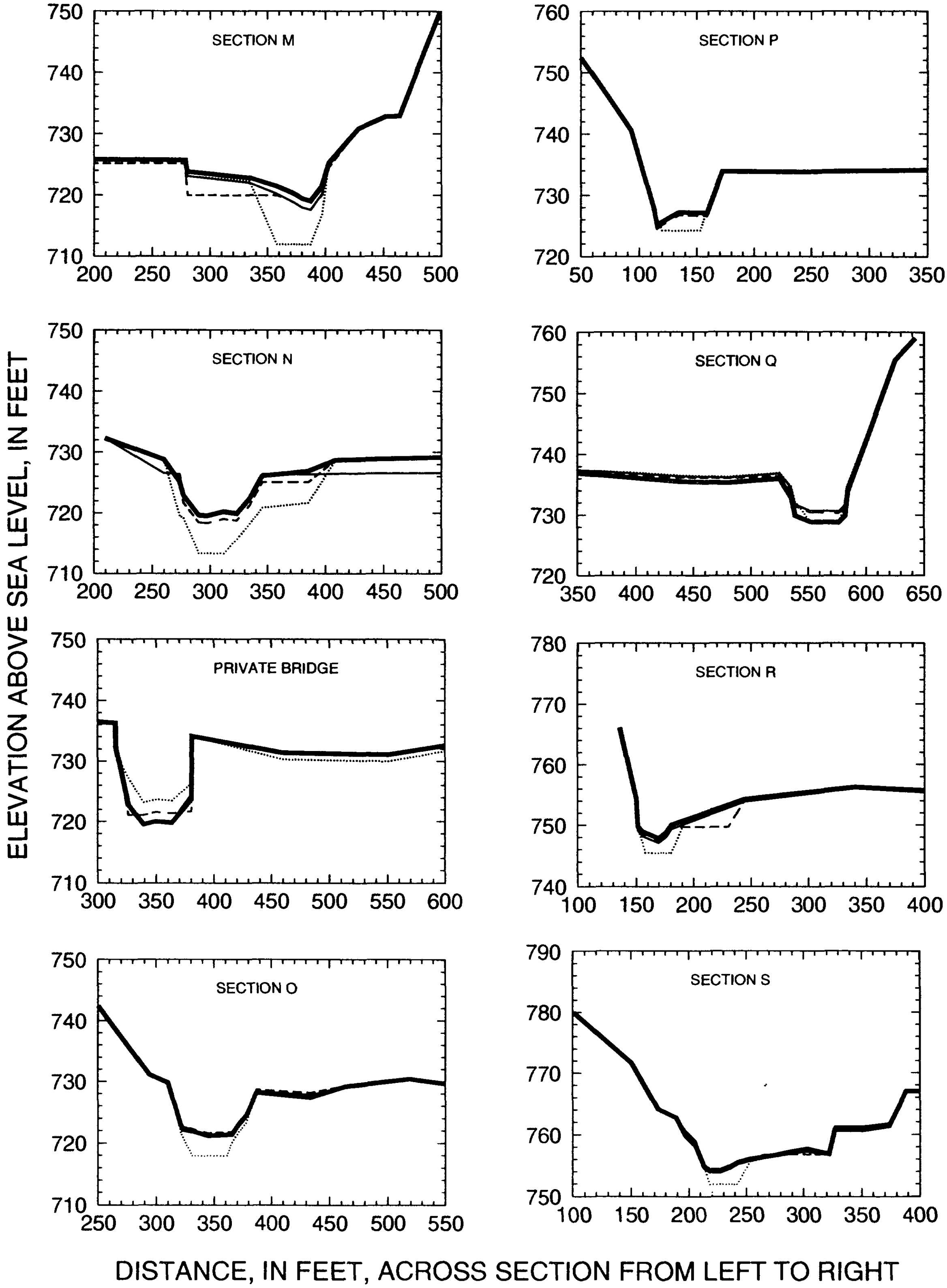
Movable Bed Model Results

100-year flood on the Wild Branch, Wolcott, Vermont



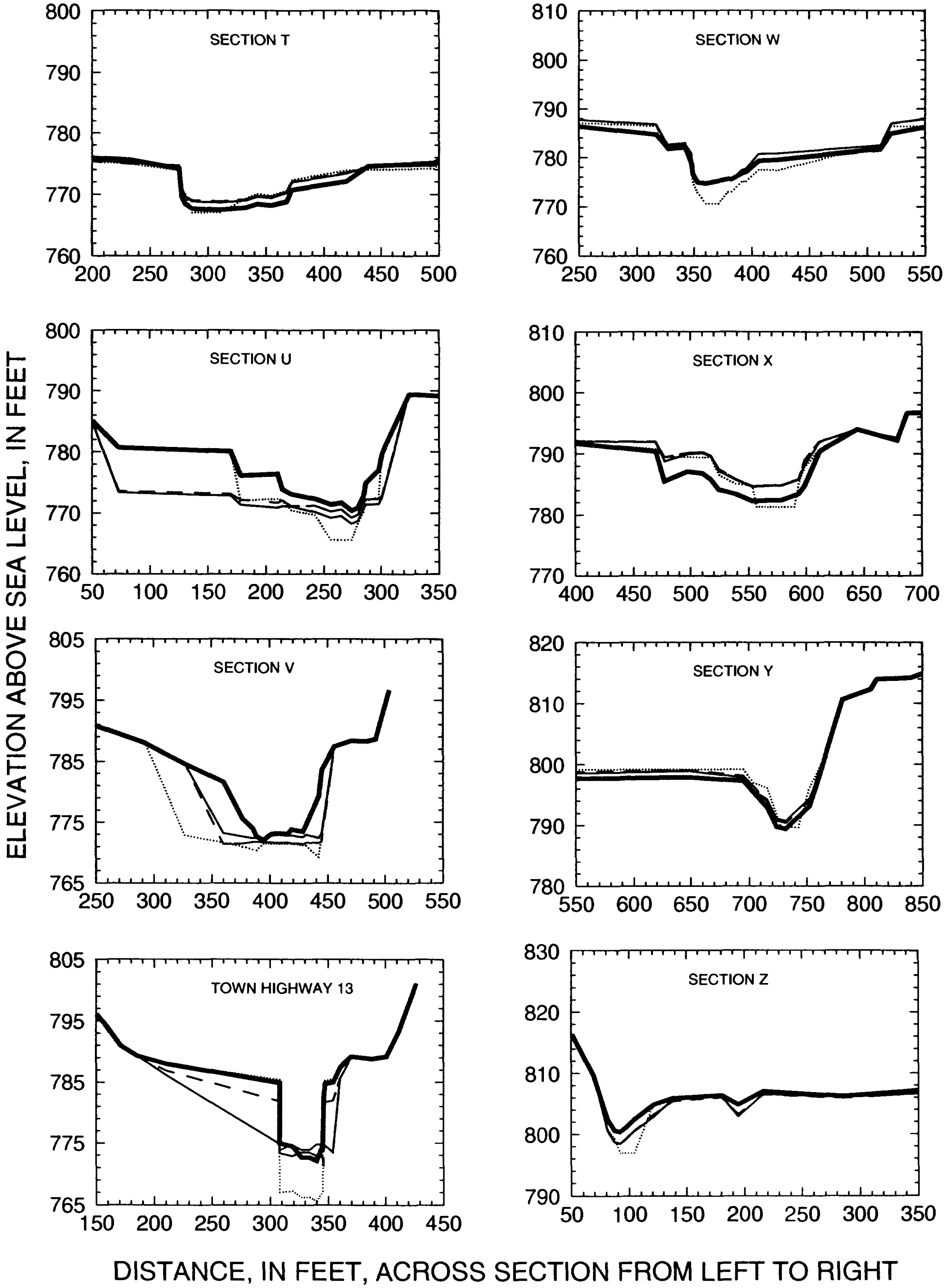
Movable Bed Model Results

100-year flood on the Wild Branch, Wolcott, Vermont



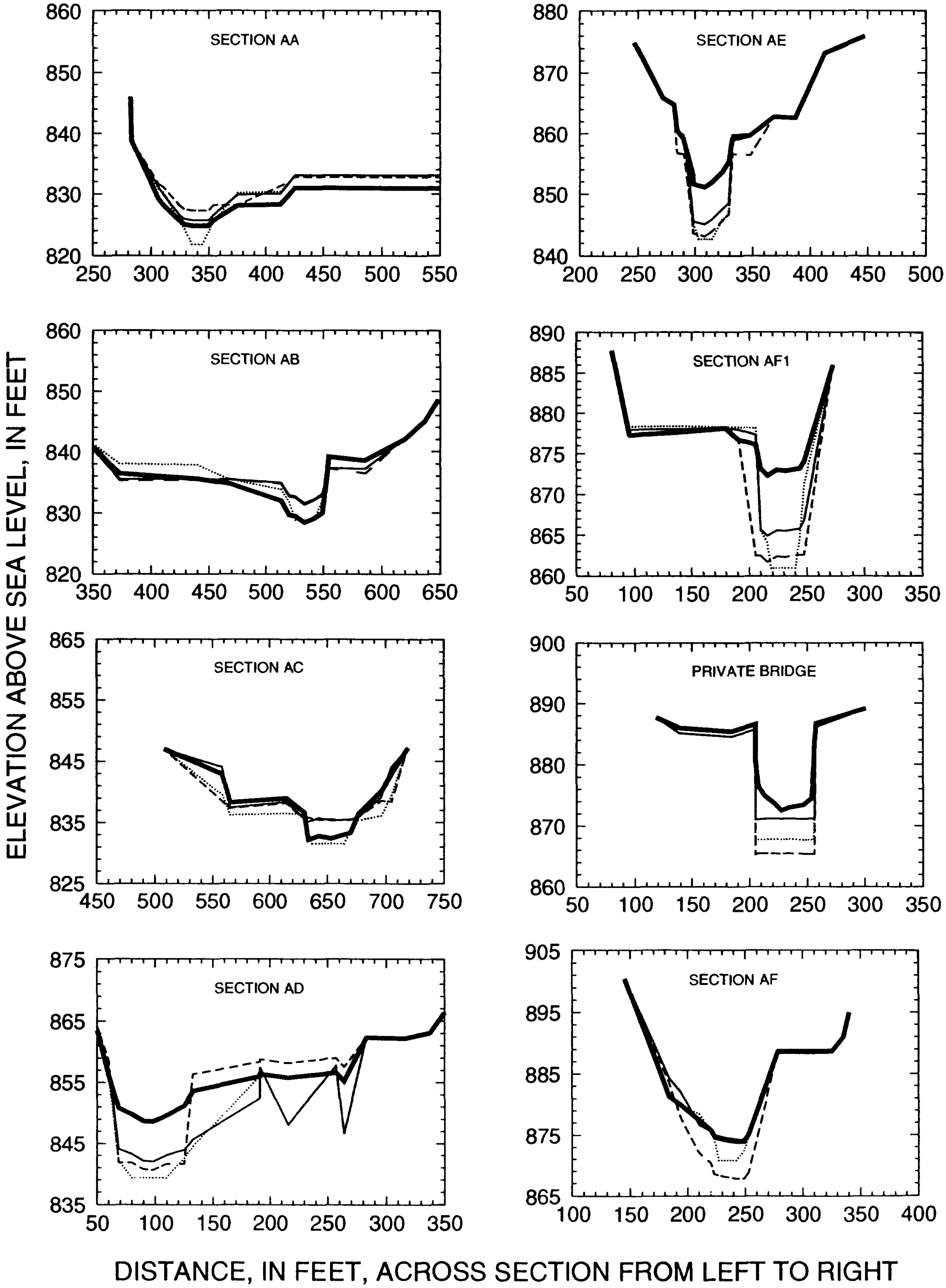
Movable Bed Model Results

100-year flood on the Wild Branch, Wolcott, Vermont



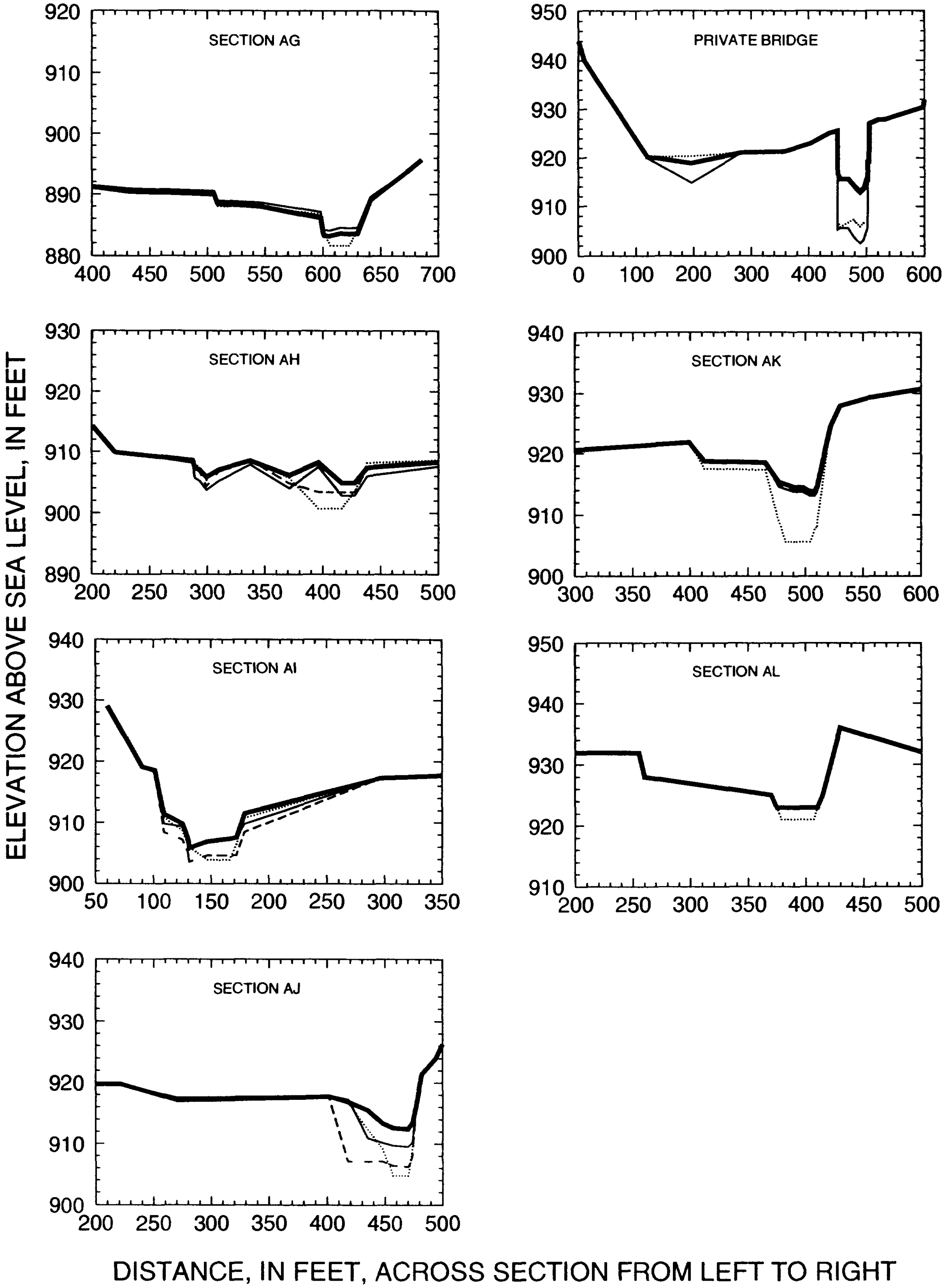
Movable Bed Model Results

100-year flood on the Wild Branch, Wolcott, Vermont



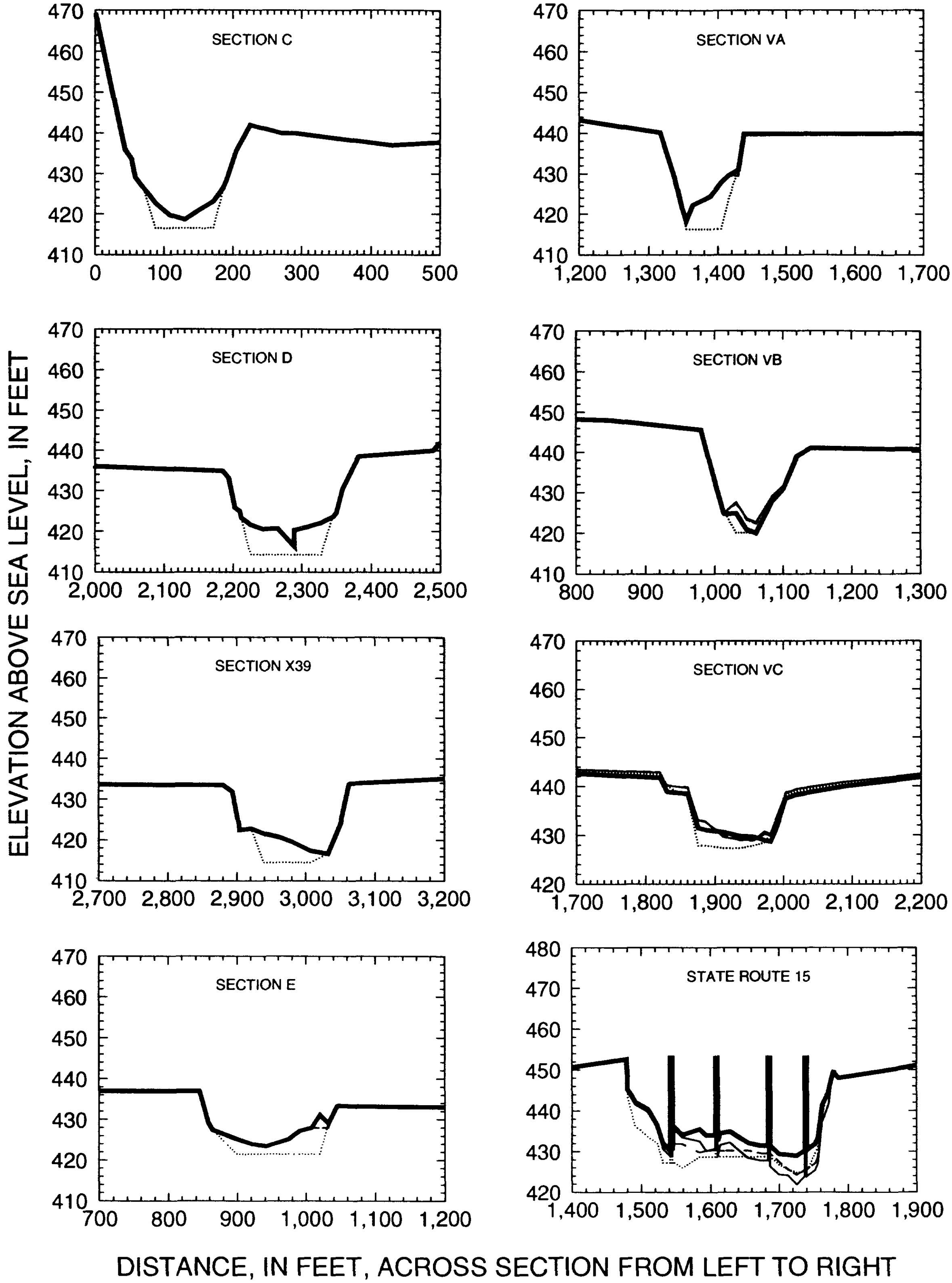
Movable Bed Model Results

100-year flood on the Wild Branch, Wolcott, Vermont



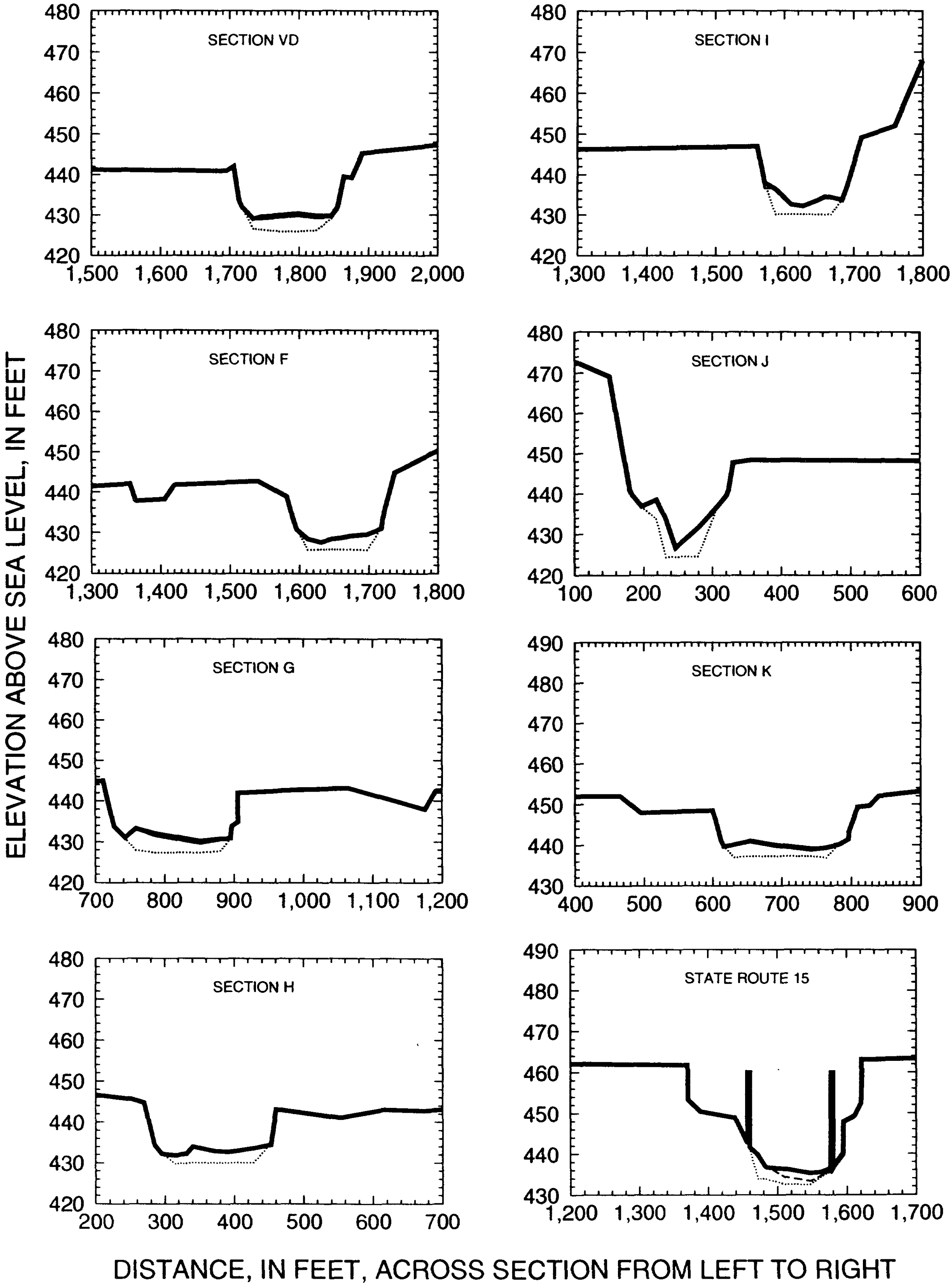
Movable Bed Model Results

10-year flood on the Lamoille River, Cambridge, Vermont



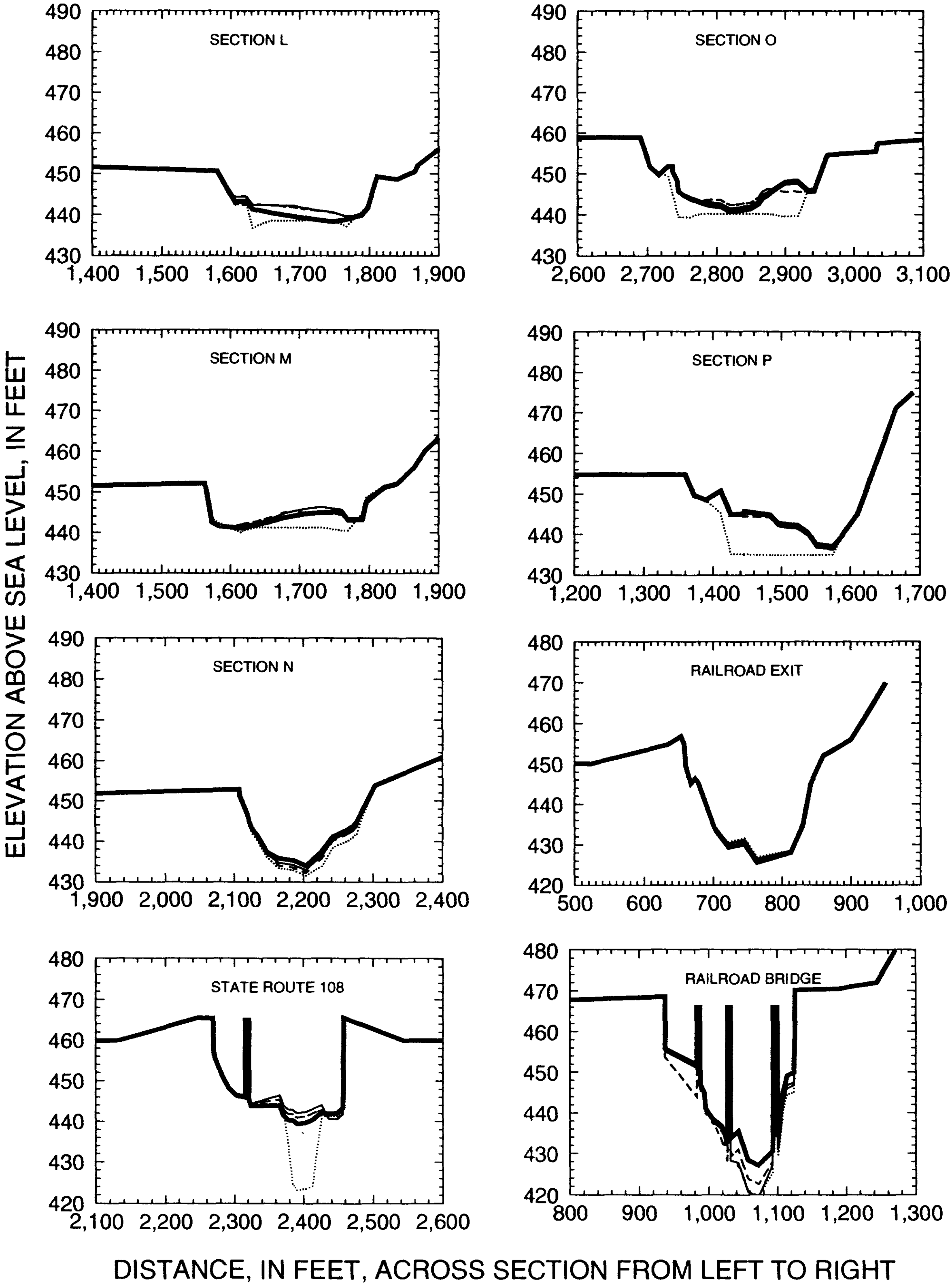
Movable Bed Model Results

10-year flood on the Lamoille River, Cambridge, Vermont



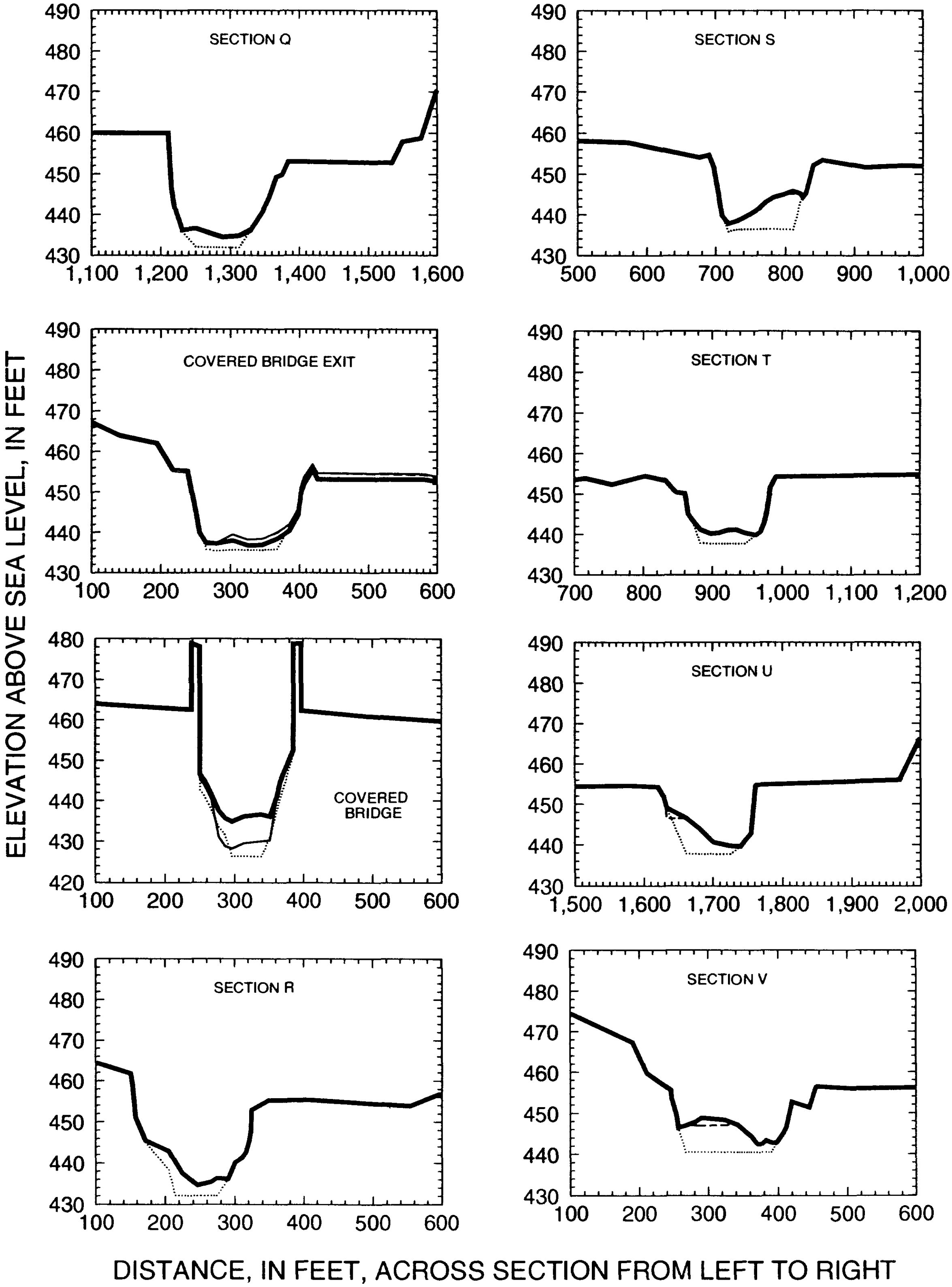
Movable Bed Model Results

10-year flood on the Lamoille River, Cambridge, Vermont



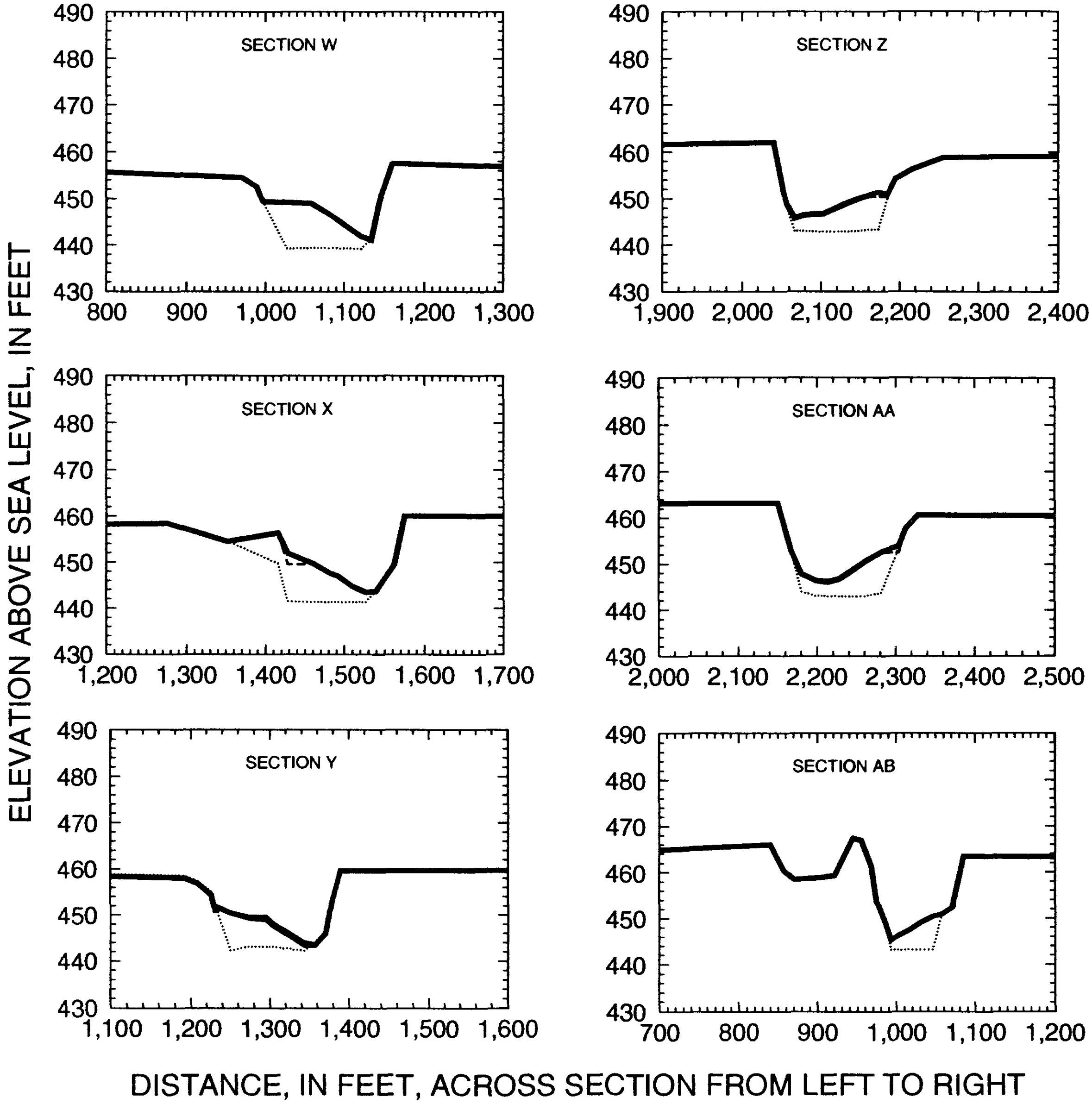
Movable Bed Model Results

10-year flood on the Lamoille River, Cambridge, Vermont



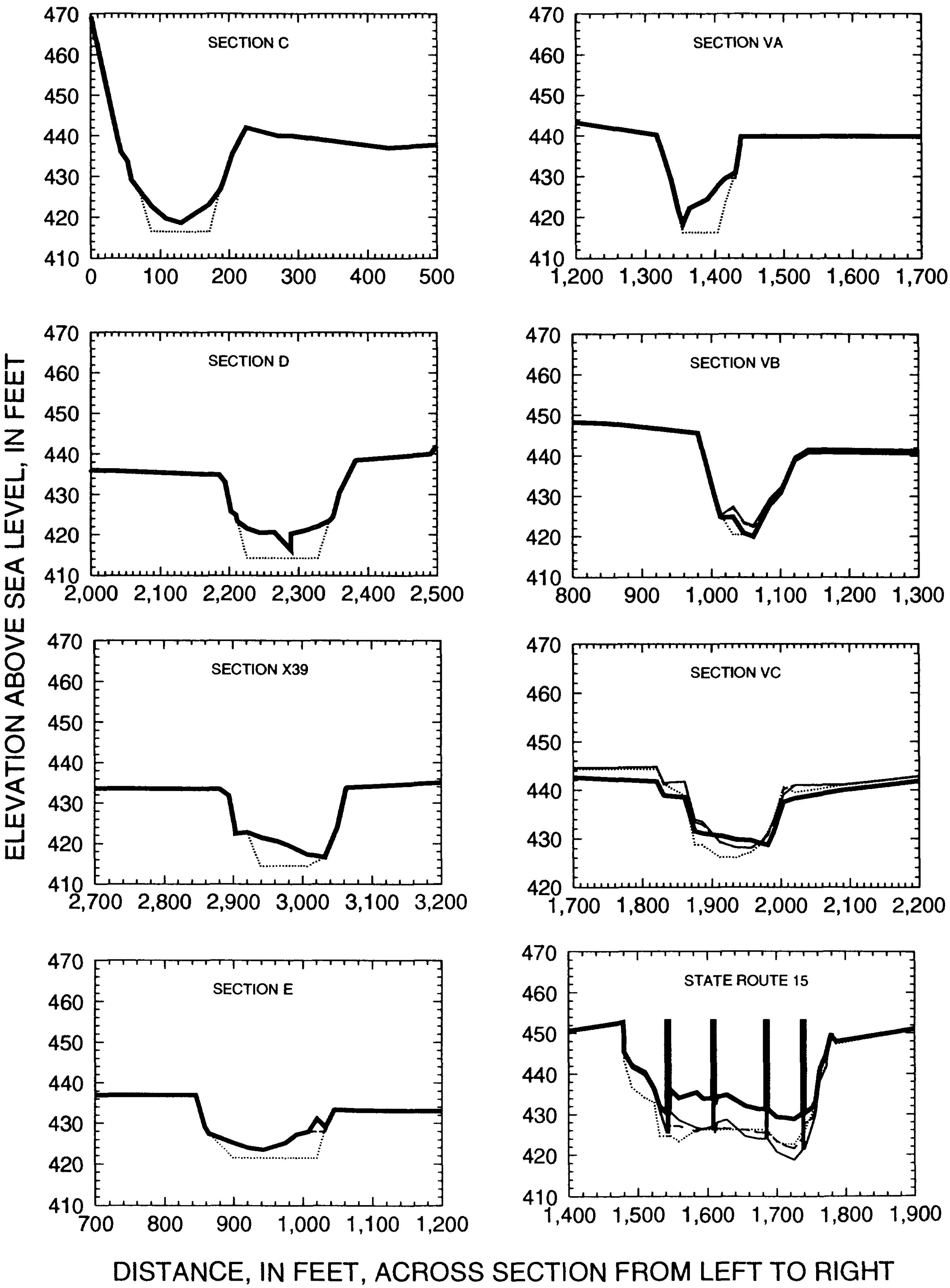
Movable Bed Model Results

10-year flood on the Lamoille River, Cambridge, Vermont



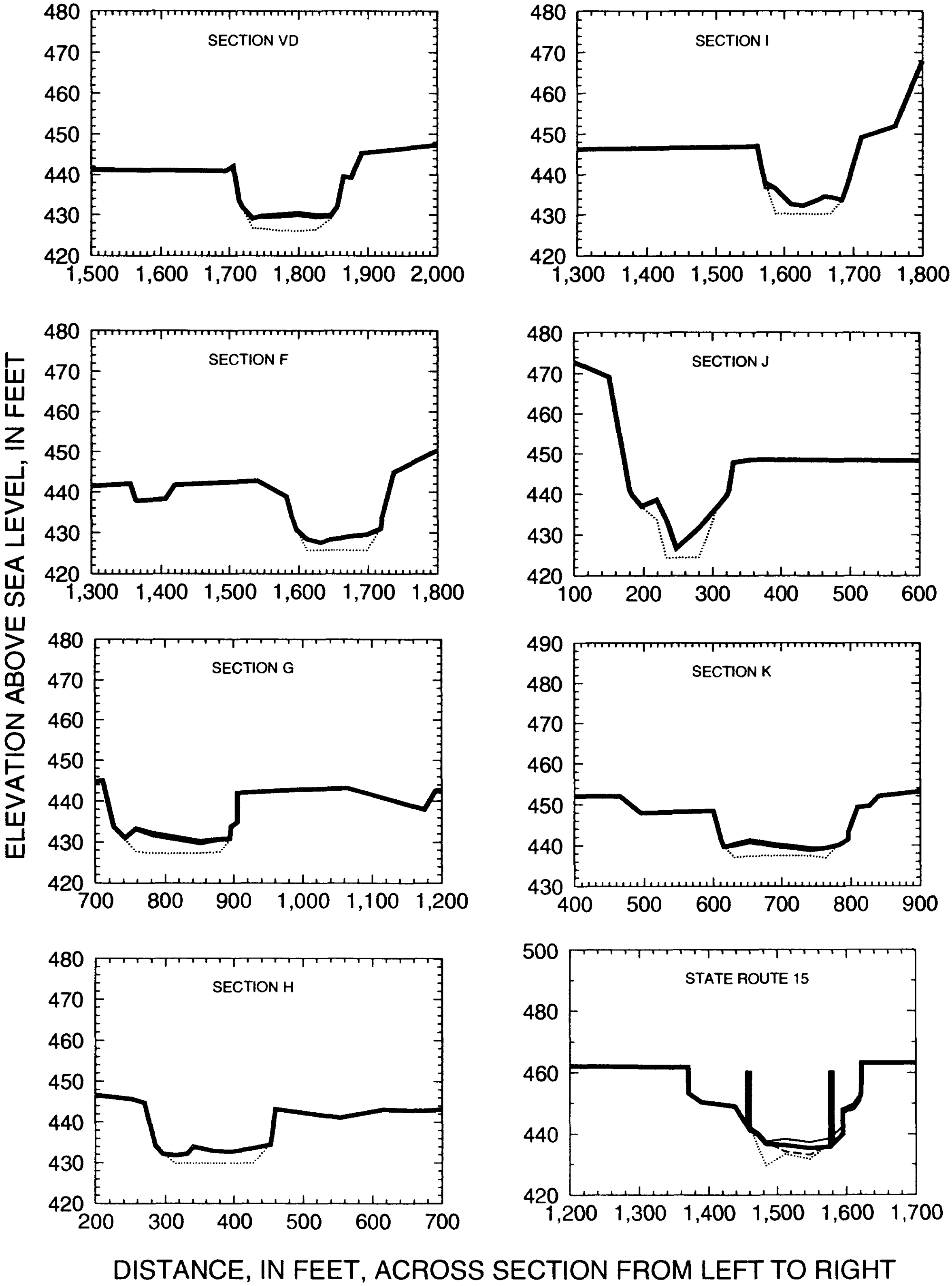
Movable Bed Model Results

100-year flood on the Lamoille River, Cambridge, Vermont



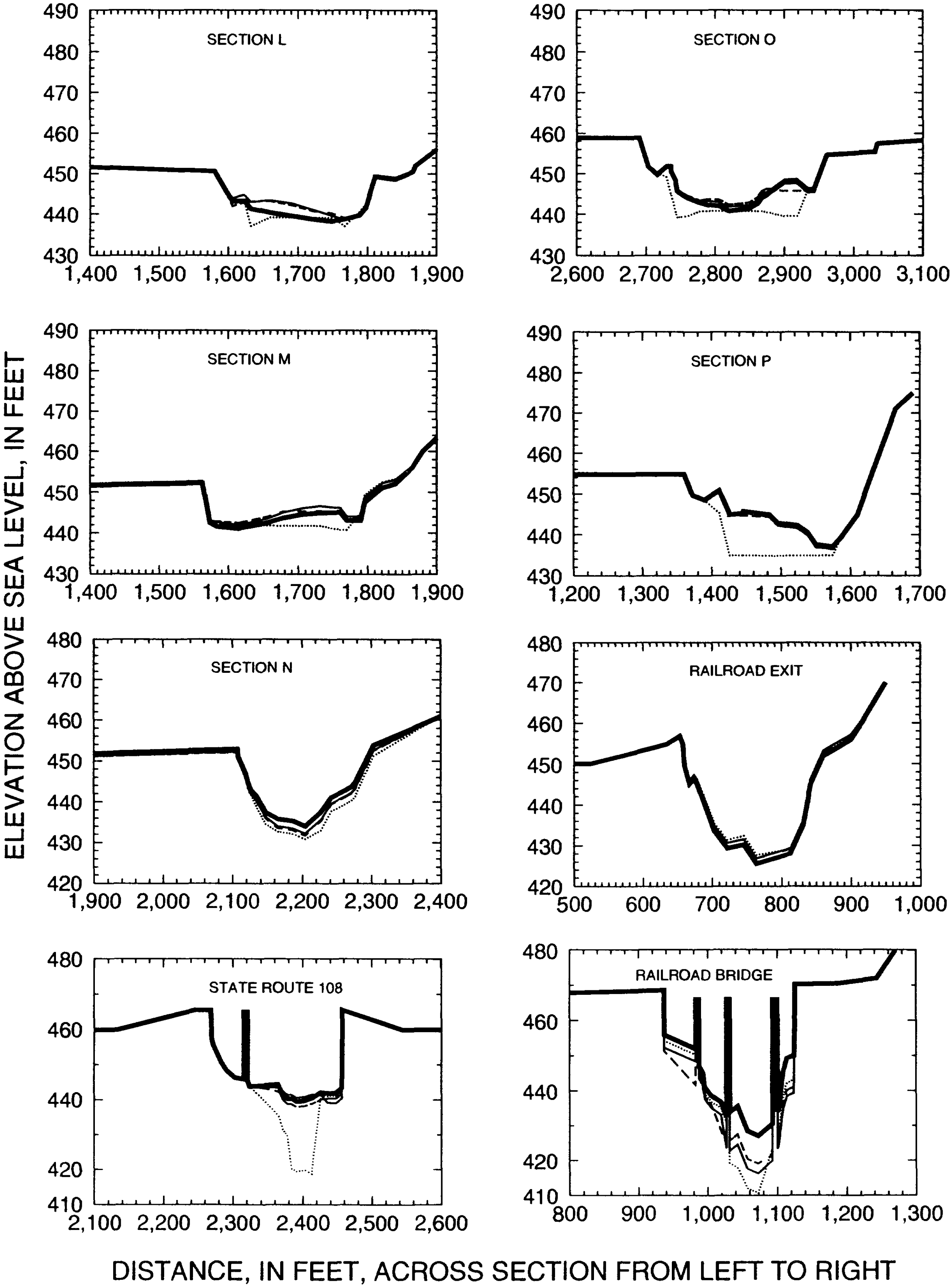
Movable Bed Model Results

100-year flood on the Lamoille River, Cambridge, Vermont



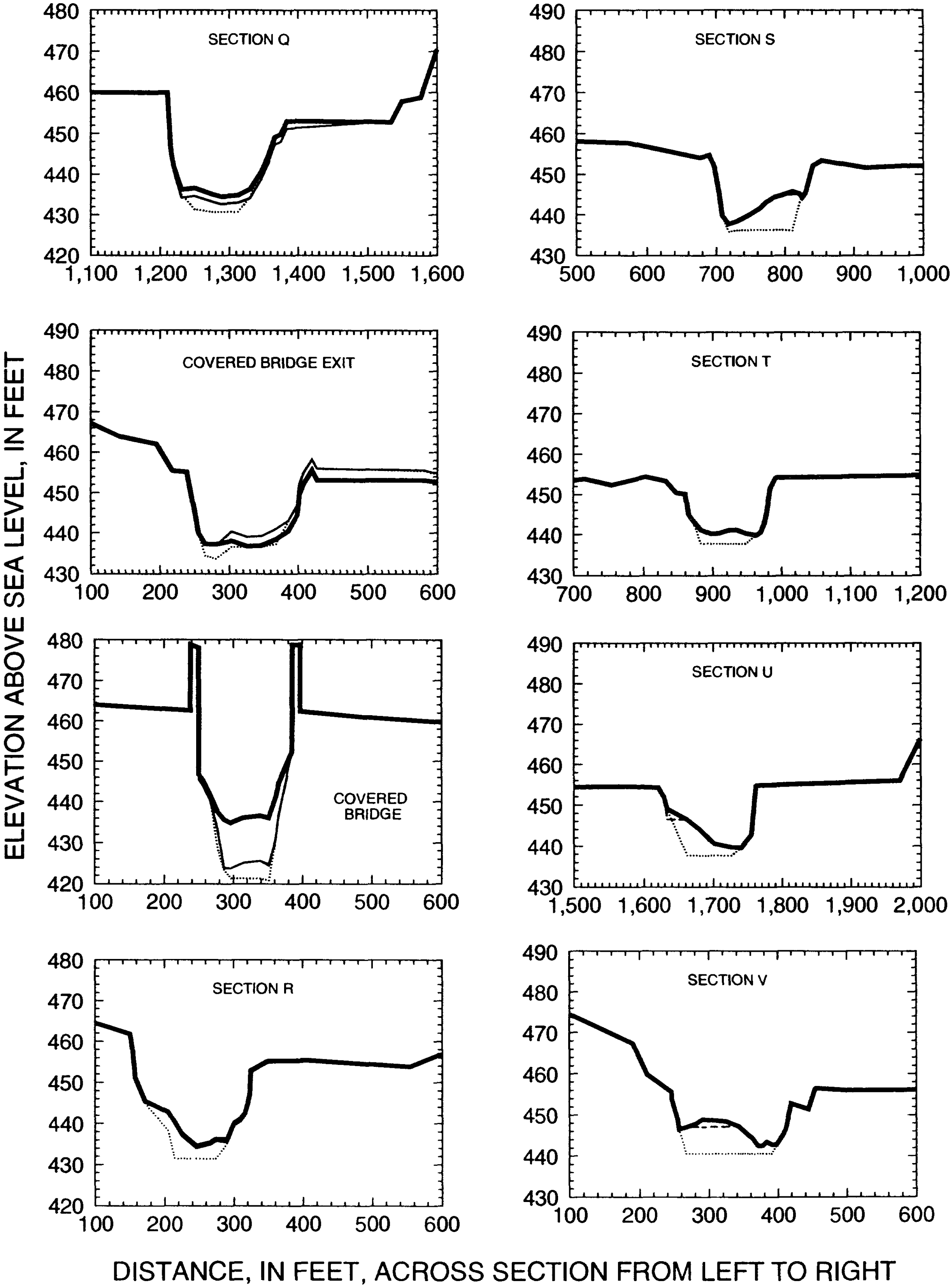
Movable Bed Model Results

100-year flood on the Lamoille River, Cambridge, Vermont



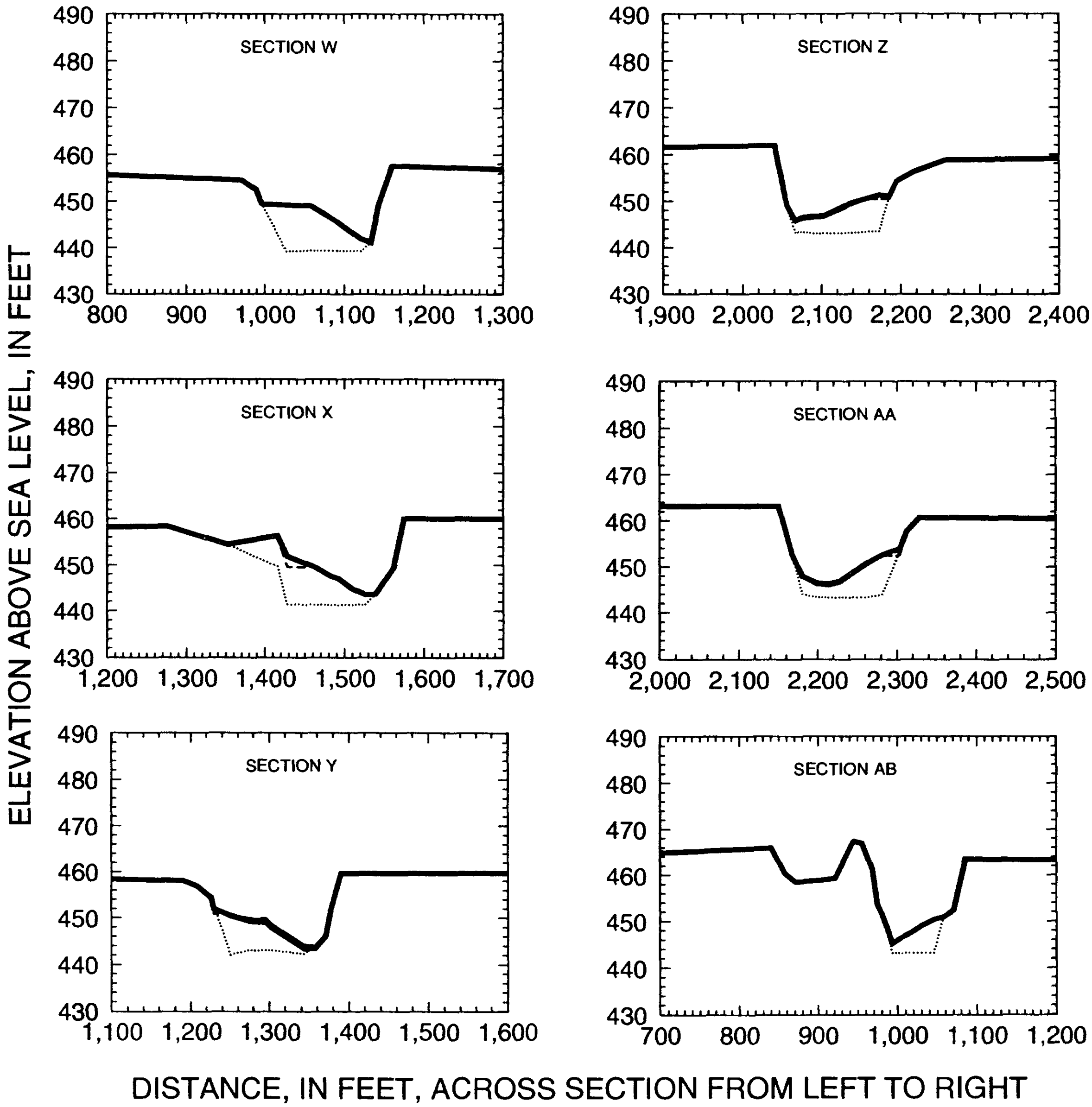
Movable Bed Model Results

100-year flood on the Lamoille River, Cambridge, Vermont



Movable Bed Model Results

100-year flood on the Lamoille River, Cambridge, Vermont



APPENDIX F:
Elevation Reference Marks

Table F1. Reference marks utilized in Montgomery, Vermont

Identifier	Elevation, in feet above sea level	Description
M-RM6A	431.65	Chiseled square on top of south end of the east abutment of Enosburg Town Highway 17 bridge over the Trout River. Newly established.
M-RM5A	446.36	Chiseled square on top of south end of the east abutment of Longley Road bridge over the Trout River. Newly established.
M-RM4A	466.86	Chiseled square on top of west end of the north abutment of State Highway 118 bridge over the Trout River just west of the Village of Montgomery. Newly established.
M-RM9	466.38	Chiseled square on top of north end of the east abutment of State Highway 118 bridge over West Hill Brook. Newly established.
M-RM1	470.80	Chiseled square on upstream side of wingwall of covered bridge on Town Highway 42 over Trout River, 0.3 miles west of Montgomery village green. Recovered.
M-RM2	493.89	Standard USGS disk stamped "52 VT 1922", set in northeast corner of top step at front entrance of Methodist Church on Montgomery village green. Recovered.
M-RM3	482.92	Vermont Agency of Transportation disk set in concrete curb on upstream side of Town Highway 41 bridge over Trout River, about 500 ft from State Route 118, 0.4 miles south on State Route 118 from village green in Montgomery. Recovered.
M-RM5	493.18	Lag bolt in utility pole 8-4-40 across State Route 118 from Vermont Agency of Transportation highway maintenance garage, 1.15 miles north on State Route 118 from Community Baptist Church in Montgomery Center. Newly established.
M-RM6	500.38	Chiseled square on southwest side of concrete junction well for storm drains on the east side of State Route 118 approximately 0.8 miles north along State Route 118 from Community Baptist Church in Montgomery Center. Newly established.
M-RM7	514.80	South bonnet bolt on top of fire hydrant on east side of State Route 118, 0.7 miles north along State Route 118 from Community Baptist Church in Montgomery Center. Recovered.
M-RM8	533.70	Standard USGS disk stamped "S 3 1922 reset 1965" set in south end on top concrete step of Community Baptist Church at corner of State Routes 118 and 242 in Montgomery Center. Recovered.

Table F2. Reference marks utilized in Wolcott, Vermont

Identifier	Elevation, in feet above sea level	Description
W-RM8	693.44	Chiseled square in south end of west abutment of State Route 15 bridge over Wild Branch. Recovered.
W-RM7	691.51	Chiseled square in south end of east abutment of Town Highway 2 bridge over Wild Branch. Recovered.
W-RM6	710.86	Chiseled square in south end of west abutment of Town Highway 15 bridge over Wild Branch. Recovered.
W-RM5	731.31	Lag bolt in utility pole 40 along North Wolcott Road, immediately downstream of a private road which is 1.2 miles north along North Wolcott Road from the intersection with Town Highway 2. Newly established.
W-RM4A	754.19	Lag bolt in utility pole 62 located approximately 2.1 miles north along North Wolcott Road from intersection with Town Highway 2 and 25 feet east of North Wolcott Road centerline. Newly established.
W-RM4B	758.03	Center of Soil Conservation Service Disk nailed to utility pole 38/65 located approximately 2.3 miles north along North Wolcott Road from intersection with Town Highway 2 and 35 feet east of North Wolcott Road centerline. Newly established.
W-RM3	787.77	Lag bolt in utility pole 79 located immediately downstream of the old Town Highway 13 crossing of Wild Branch and approximately 2.8 miles north along North Wolcott Road from intersection with Town Highway 2 and 20 feet east of North Wolcott Road centerline. Newly established.
W-RM2	848.64	Chiseled square on north end of east curb of North Wolcott Road Bridge over an unnamed tributary; located approximately 3.5 miles north along North Wolcott Road from intersection with Town Highway 2. Newly established.
W-RM1	923.01	Chiseled square in south end of east abutment of Private Drive bridge over Wild Branch; located approximately 4.45 miles north along North Wolcott Road from intersection with Town Highway 2 and 80 feet east of North Wolcott Road. Recovered.

Table F3. Reference marks utilized in Cambridge, Vermont

Identifier	Elevation, in feet above sea level	Description
C-RM4	457.88	Spike in utility pole 5, 25 feet south of Town Highway 66, 3,600 feet west of intersection of State Highway 104 and Town Highway 66. Recovered.
C-RM5A	466.97	Top of twentieth vertical I-beam of guard rail west from a parking area on the north side of Vermont State Highway 104, directly across highway from mile marker "1040" and approximately 960 feet west along State Route 104 from the intersection with Town Highway 71. Newly established.
C-RM5B	473.42	Lag bolt in utility pole 19S on north side of State Route 104, approximately 200 feet west of intersection with State Route 15. Newly established.
C-RM3A	453.28	Chiseled square on the east end of the south abutment of the State Route 15 bridge over the Lamoille River in the Village of Cambridge. Recovered.
C-RM6A	458.73	Lag bolt in utility pole 42 on the south side of State Route 15 approximately 0.8 miles west along State Highway 15 from the intersection with Town Highway 2. Newly established.
C-RM3J	480.44	USGS disk in stone step of Soldier's Monument in the Village of Jeffersonville. Recovered.
C-RM1J	465.92	State of Vermont survey disk on southwest corner of the State Route 15 bridge over the Brewster River. Recovered.
C-RM8	467.98	Chiseled square on the southeast corner of St. Johnsbury and Lamoille County Railroad Bridge over Lamoille River at Cambridge Junction. Recovered.
C-RM9	462.21	NGS disk in concrete post on Cambridge Junction, 251 feet west of Town Highway 23 centerline, 81 feet east of railroad switch stand, 17.1 feet south of south rail of main track, and 13 feet north of north rail of St. Johnsbury and Lamoille County Railroad. Recovered.
BM490	489.56	USGS disk 0.1 miles west of a two-story house which is on south side of road stamped "H53" in boulder projecting 6 feet, 29 feet north of centerline of State Route 15, 24 feet northwest of west end of guard rail, and 10 feet south of twin trunk maple. Recovered.
C-RM3	464.37	Center rivet on north end of 6-feet-diameter boiler plate culvert under St. Johnsbury and Lamoille County Railroad, and 750 feet west of Cambridge-Johnson Town line. Recovered.