Flood Inundation Hazard at the C&O Canal National Historical Park Hancock Maintenance Yard

Prepared for the
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Interstate Commission on the Potomac River Basin
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Introduction

This report details the analysis of flooding hazards at the C&O Canal National Historical Park maintenance yard at Hancock, Md. The principal product presented in this report consists of flood inundation maps for the maintenance yard. These maps graphically display the likely extent of inundation at the maintenance yard for river stages from 6 feet to over 41 feet as measured at the USGS streamflow gauge at Hancock, Md. These maps were prepared in two phases. First a digital elevation layer was developed for the vicinity of the Hancock maintenance yard. This elevation layer was prepared from base maps supplied by the National Park Service (NPS). Elevations on the NPS base map were supplemented as needed with elevations from the USGS 7.5 minute quadrangle map for Hancock, as well as surveyed elevations and cross sections developed by ICPRB (1989). From these elevation points, a digital elevation surface was constructed covering the entire study area. The elevation surface was transferred to the GRASS Geographic Information System, on the C&O Canal's Sun386i engineering workstation. Using GRASS the extent of inundation can be quickly identified and graphically displayed for any water surface elevation.

The second phase in preparing the inundation maps consisted of determining the relationship between Potomac River discharge and the water surface elevation at the Hancock maintenance yard. To establish this relationship, or rating, surveyed cross sections of the mainstem Potomac River (ICPRB 1989) were used to relate water surface elevations to stage height at the Hancock gauge through the calculation of step-backwater profiles. Through successive backwater calculation, the rating curve for the Hancock maintenance yard was developed, relating Potomac river discharge to both the stage at the Hancock gauge and the corresponding water surface elevation at the Hancock maintenance yard.

These inundation maps are relevant for both planning and management decisions. From a planning perspective the maps can be used to relate inundation areas to historical design floods or discharge levels corresponding to known recurrence intervals, such as the 50 year flood. From a management perspective the maps provide guidance on likely areas of inundation based on forecasts of river flow or flood crest heights, referenced to the Hancock gauge. By relating the water surface elevation to both discharge and stage, the maps are developed to be easily used in conjunction with the normal 6 to 12 hourly forecasts issued by the National Weather Service (NWS), as well as NWS flood guidance information issued during flood conditions.

How to Use These Maps

The elevation layer used to produce these maps was developed in order to incorporate an inundation area display in the ELARC flow monitoring system developed by ICPRB for the C&O Canal National Historical Park. The ELARC system automates the monitoring of USGS streamflow gauges, and integrates current stage observations to provide short term guidance on downstream river stages. An ELARC system has been configured for Hancock, Md. This system automatically telephones the USGS river gauges at Cumberland, Md., Springfield, W.Va., and Paw Paw, W.Va. and provides stage guidance for the USGS stream gauge at Hancock. As part of this system the user can display the inundation areas associated with peak stage estimates for the next 6 to 12 hours. The elevation surface used for this display is reproduced in a hard copy form as the inundation maps contained in this document.

To use the inundation maps a stage or discharge must be related to an absolute water surface elevation in feet above mean sea level (msl). River stages are referenced to the rating curve for the USGS stream gauge at Hancock, Md shown in Figure 1. Discharges are specified at the cross section corresponding to the Hancock maintenance yard. As discussed below, additional runoff derived from the area between the USGS gauge and the Hancock maintenance yard has not been considered in these maps. When stages or discharges are referenced to the Hancock gauge, the corresponding water surface elevation and inundation area must therefore be viewed as a lower bound on the water surface elevation.

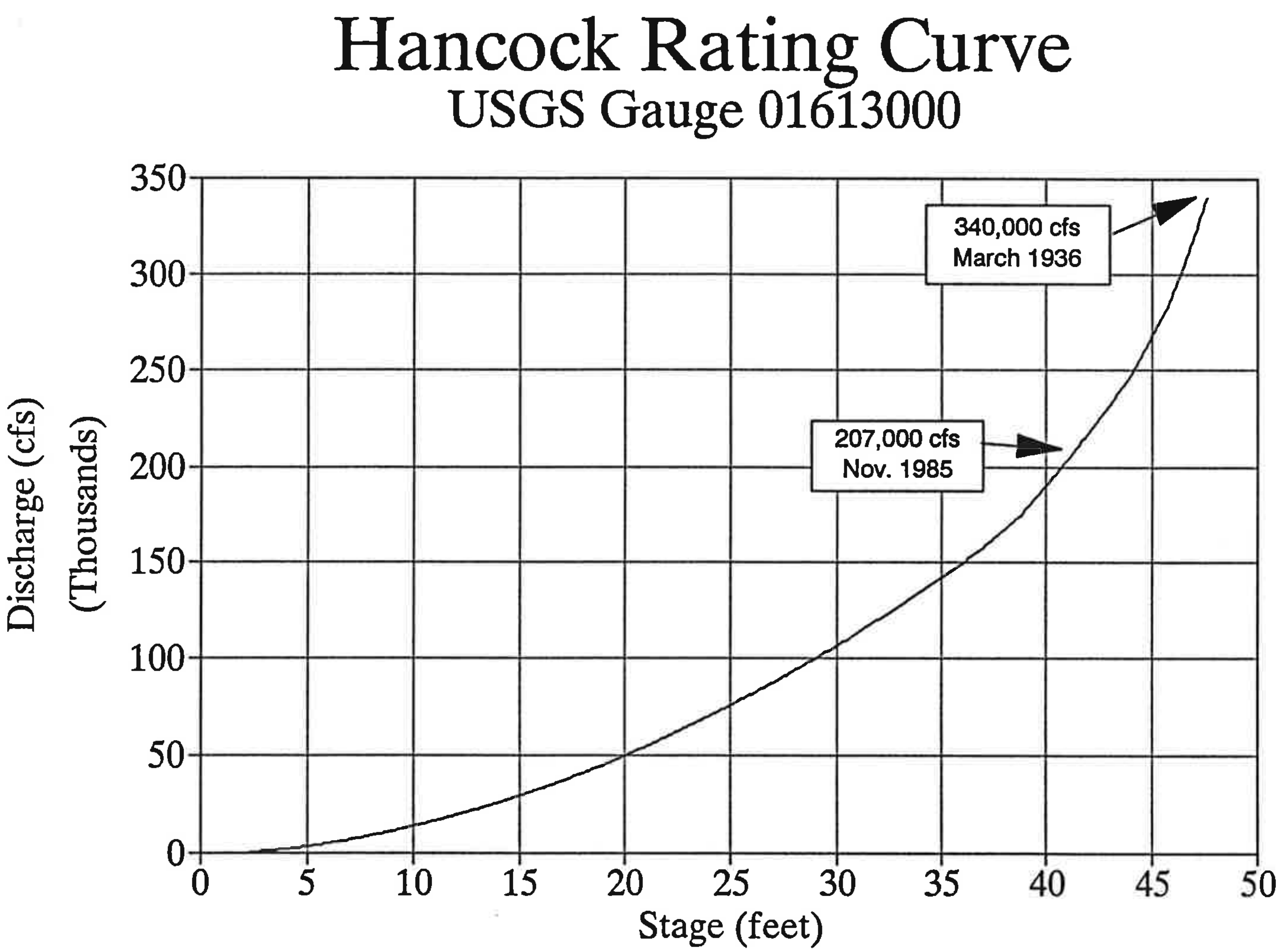


Figure 1 Hancock Rating Curve

The current elevation datum for the USGS gauge at Hancock is 383.68[1] feet msl. The water surface elevation at the Hancock gauge can be determined as the sum of this datum and the reported river stage. For example the peak stage of 47.6 feet during the flood of 1936 corresponds to a water surface elevation at the gauge of 431.28 feet msl. The water surface elevation at the Hancock maintenance yard would be slightly lower than that at the gauge due to the slope of the river bed and the effects of roughness and changing channel geometry. The relationship between the water surface elevations at the Hancock gauge and the Hancock maintenance yard is shown in Figure 2. The vertical axis on the right hand side of Figure 2 relates the absolute elevation in feet msl to the stage at the Hancock gauge. Figure 3 presents this information in a slightly different format, showing the relationship between the Hancock stage and the water surface elevation at the Hancock maintenance yard.

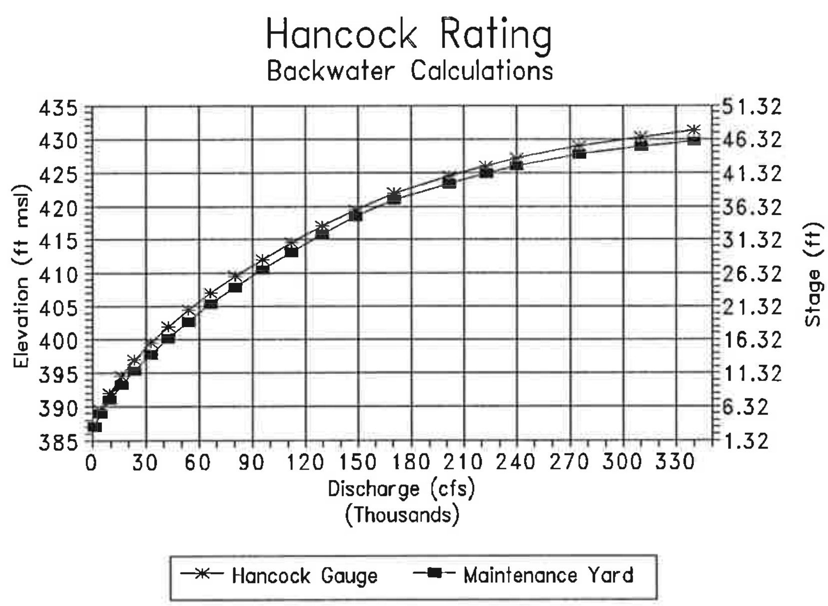


Figure 2 Maintenance Yard rating

[1] Elevation referenced to the National Geodetic Vertical Datum of 1929

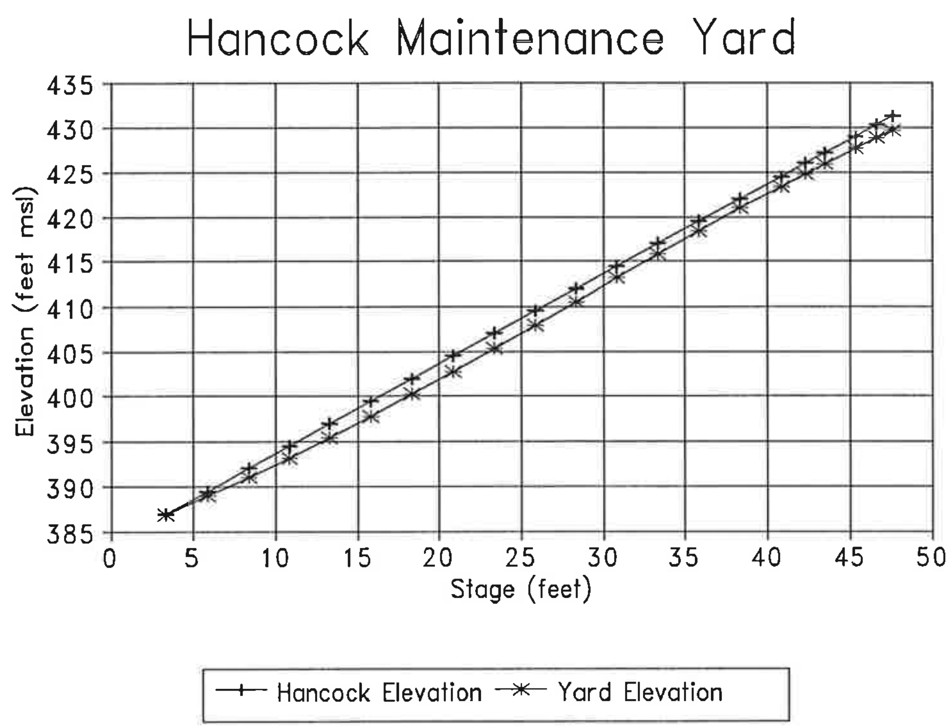


Figure 3 Maintenance Yard Elevation vs. Gage Height

Figures 1 through 3 can be used to associate the appropriate inundation map with a stage or discharge for either planning or management purposes. From a planning perspective, one might wish to identify the likely extent of inundation associated with an historical stage observation. For example, the flood of 17 October, 1954 reached a height of 29.15 feet on the Hancock gauge. From Figure 3, a similar flood could be expected to result in a water surface elevation at the Hancock maintenance yard of approximately 412 feet msl. To identify the likely area of inundation from a repeat of such a flood, use the inundation map corresponding to elevation 412. From a management perspective, the inundation maps can be used in conjunction with real-time forecasts of stage or discharge to evaluate the flood hazard at the Hancock maintenance yard. Forecasts of river stage and flood crests are routinely provided by NWS. A recorded message reporting river stages and forecasts is available from NWS by calling (703) 260-0305. This stage report is updated twice daily. In addition, NWS forecasts for critical levels at locations throughout the Potomac are available to NPS by request. The timely exchange of critical forecast information between NWS and NPS is part of the Park's flood management plan. The inundation maps contained in this report supplement the Park's management data base, and can be integrated with the existing flood management plan for Hancock.

Starting with a discharge at the Hancock gage, the appropriate inundation map can be identified in two ways. The Hancock stage corresponding to a particular discharge can be identified using the Hancock rating table shown in Figure 1. Figure 3 can then be used to identify the corresponding water surface elevation at the Hancock maintenance yard. Alternatively, the water surface elevation at the maintenance yard can be read directly from discharge using Figure 2. Whether starting from a stage or a discharge, Figures 1 through 3 can be used to identify the associated water surface elevation at the Hancock maintenance yard. The elevation is then used to find the inundation map that corresponds most closely to the elevation of interest. This procedure is summarized in Figure 4.

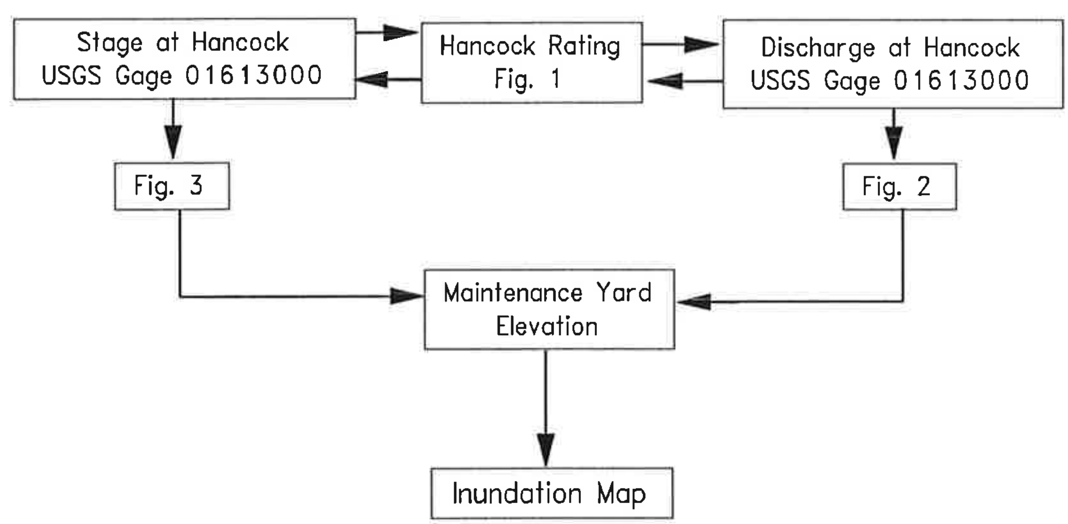


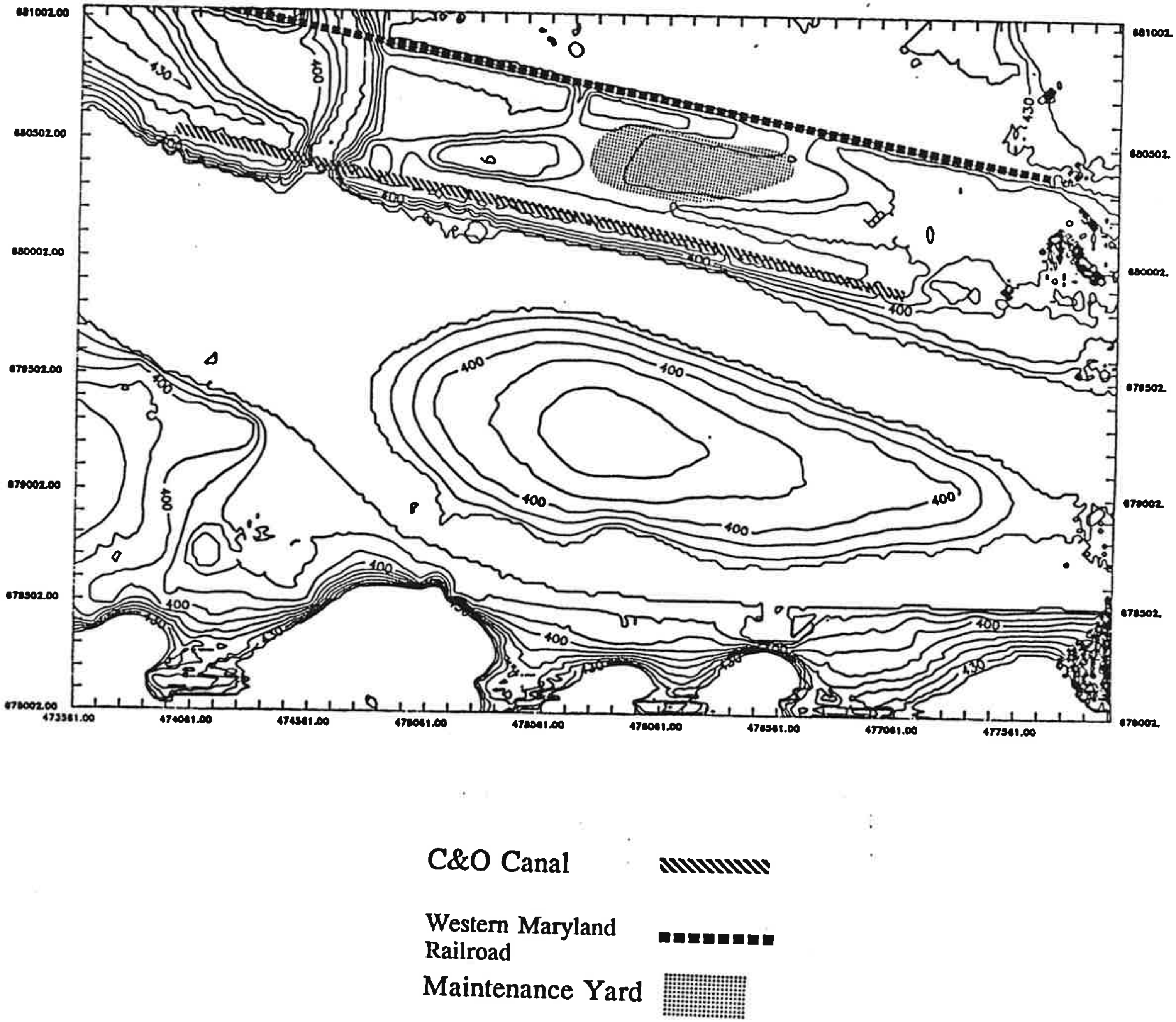
Figure 4 Choosing an Inundation Map

Hancock Base Map

The accompanying base map shows the location of the Hancock maintenance yard on an estimated contour map derived from the digital elevation layer. The alignment of the C&O Canal over the Tonoloway Creek aqueduct and the Western Maryland railroad right of way are shown, along with the approximate location of the maintenance yard.

From the base map and site elevations it appears that the access road to the maintenance yard may be inundated before the yard itself. The likely "path" of inundation appears to be a narrow corridor adjoining the Western Maryland railroad at an approximate elevation of 405 ft. msl. Above this elevation flood waters can overtop the banks of Tonoloway Creek, cutting off the maintenance yard access road. In contrast, the elevation of the C&O Canal towpath in this area is approximately 410-415 ft. msl, with an elevation of 419.5 ft. msl on the aqueduct.

The map also reveals numerical artifacts resulting from the mathematical interpolation procedures used to generate the elevation layer. On the eastern and southern edges of the map several clusters of "pits" cause the contour lines to take a highly crenulated appearance. These isolated depressions result from sharp changes in the subset of elevation points used to interpolate elevations at each location. While these features can be numerically filtered, their effect on the maintenance yard's elevation surface is insignificant. The following section discusses in detail additional limitations of the inundation maps.



Hancock Maintenance Yard Topographic Map

Limitations of the Maps

NPS Base Maps

A number of sources of error limit the accuracy and therefore the confidence with which the maps can be used. Most importantly, the accuracy of the base map supplied by NPS limits the accuracy of the elevation surface. In compiling the elevation data a serious discrepancy was noted between the NPS base map and other stage information. The highest maintenance yard elevation on the NPS base map is a spot elevation of 419.5 feet msl corresponding to a discharge of approximately 160,000 cfs. If this is the highest elevation at the maintenance yard, the peak discharge of 207,000 cfs associated with Tropical Storm Juan in November of 1985 should have inundated the entire maintenance yard to a depth of approximately 3 feet. While significant flooding did occur at the entrance to the maintenance yard during Tropical Storm Juan, the extent of flooding was limited to the western end of the facility. The high water mark at this locale (ICPRB 1989) is not consistent with the NPS base map used to develop the current elevation layer. Estimates of the maximum water surface elevation for the 1985 flood range from approximately 421[2] feet msl, to 423.67 feet msl. In contrast, the inundation maps most representative of the observed high water mark correspond to elevations ranging from 409 feet msl to 414.5 feet msl.

Efforts to locate a more accurate and up to date survey or site plan for the Hancock maintenance yard, including inquiries at National Capital Region Headquarters as well as with the Chief of Maintenance, C&O Canal, were unsuccessful. A comprehensive survey and construction of a detailed (i.e. 1 foot contours) topographic map for the maintenance yard is required to resolve the discrepancy in flood heights and inundation areas. If such a map becomes available, a new digital elevation layer can be constructed and incorporated in the Park's GIS database. Once entered into GRASS a new set of inundation maps can be prepared and used with the rating curves in this report. The new GRASS elevation layer can also be incorporated in the inundation display of the Hancock ELARC system.

Ungauged drainage area

These maps were prepared based on Potomac River flow at the USGS stream gauge at Hancock, Md. The effects of runoff between the gauge and the maintenance yard has not been considered for several

[2] Personal communication with the late William Davies.

reasons. The ungauged drainage area affecting the maintenance yard is a small fraction of the total area captured by the Hancock gauge. Using an area correction, the mean error in estimated streamflow would be approximately 1%. Due to the short concentration time on small watersheds such as Tonoloway Creek, the peak discharge from this tributary would not coincide with the peak discharge in the Potomac. Nevertheless, the analysis indicates that backwater effects in Tonoloway Creek represent a significant flooding mechanism at the C&O Canal Hancock maintenance yard. The actual contribution from the Creek would be determined by storm characteristics. For local convective thunderstorms, Tonoloway Creek runoff could be significantly higher than the runoff in the mainstem Potomac. For a storm centered on the South Branch Potomac River, such as Tropical Storm Juan, Tonoloway Creek runoff would be significantly lower than that in the mainstem Potomac. Without gauge information on Tonoloway Creek, any area correction used to account for this ungauged drainage area would introduce additional uncertainty while providing a false sense of precision. Rather than introduce an inaccurate correction, the inundation maps were prepared assuming no additional contribution from Tonoloway Creek. For this reason the maps should be interpreted as a lower bound on the inundation area, when used in conjunction with stage forecasts at Hancock.

Although Tonoloway Creek is not gauged, an empirical rating could be developed using staff gauge readings collected by the NPS. To accomplish this, a staff gauge would need to be installed in a readily visible location on Tonoloway Creek. The bridge and aqueduct crossings over Tonoloway Creek are obvious candidate sites. Although the Creek is unrated, detailed cross sections along Tonoloway Creek were surveyed as part of a Floodplain Information Study for Hancock Md. conducted by the Baltimore District of the U.S. Army Corps of Engineers. From these cross sections an approximate rating could be calculated for the bridge section. In this way an observer could read the Tonoloway Creek stage and determine an approximate discharge adjustment to be applied to the inundation maps. The calculated rating should be verified with velocity measurements for several flow events.

Correcting only the discharge at this section must be viewed as an approximate procedure. More accurate water surface elevations could be determined by calculating the full water surface profile for both the mainstem Potomac, as well as Tonoloway Creek. Lacking these analyses, the inundation maps should be used in conjunction with gauged Potomac River flow, and viewed as a lower bound on true water surface elevations.

Map Accuracy

As requested by the NPS Center for Urban Ecology, the inundation maps were prepared at 2.5 foot intervals even though the best base map supplied by NPS has a contour interval of 5 feet. The interpolation of elevations and contours to this finer resolution may suggest a false level of precision. Interpolation introduces additional uncertainty in the accuracy of both the elevation layer and the estimated inundation surfaces. Interpolation in both the elevation layer and the cross sections affects the accurate use of the inundation maps. Interpolation errors in the elevation layer are significant in those areas for which few observations are available to estimate local elevations. Two areas in the elevation surface where this error is pronounced are the West Virginia shoreline of the mainstem Potomac, and the area north of the maintenance yard, between the Western Maryland Railroad right of way, and the access ramps for Interstate 70. Although the elevation estimates for these two areas could have been improved by acquiring additional spot elevations, neither of these areas were critical to the study area, and no attempt was made to further improve the elevation surface.

In using USGS topographic maps to provide supplemental elevation points, the accuracy of the map contours must be judged in the context of the National Map Accuracy Standards. These maps have 90% of verified elevation points within one-half contour interval of their true elevation. This standard is usually established for a set of 25 distinct points such as buildings or road intersections whose elevations can be verified through field survey. For a 7.5 minute quadrangle with a 20 foot contour interval, this means that most points on the map may have a vertical error of ±10 feet. This level of accuracy cannot be assured in considering contour lines that are photointerpreted on complex terrain. For elevations and contours interpreted from the NPS 5-foot base maps, an accuracy of ±2.5 feet can be assumed. While contours can be interpolated to an arbitrary level of numerical precision, the accuracy of the actual elevations cannot be improved. For this reason the 2.5 foot interval used in calculating the inundation maps suggests a false level of precision, and interpretations based upon these elevations must be used with caution. Put another way, the confidence limits around the elevations reported in inundation maps calculated at 2.5 foot elevations, is still 2.5 feet.

Rating Table Error

The rating for the Hancock maintenance yard is based on backwater calculations calibrated to the current USGS rating for the stream gauge at Hancock Md. The accuracy of this rating is similarly affected by the accuracy of the cross-sections, slopes and channel roughnesses used to describe the mainstem Potomac River channel.

The accuracy of the calculated rating is most critically associated with the estimated slope, hydraulic depth, and roughness coefficient used to model open channel flow in the river channel. Elevation errors in the cross sections result in incorrect estimates of the cross-sectional area in the channel and hence the channel conveyance. As an example the surveyed cross section for the Potomac River at the Hancock maintenance yard is shown in Figure 5. Figure 6 shows the cross section that would have been determined from error free topographic maps with contour intervals of 5 and 20 feet.

As shown in Figure 6 the use of contour maps to estimate cross sections for backwater calculations introduces additional error in the cross-sectional area, channel conveyance, and the base level elevations used to determine the energy slope. Using a contour interval of 20 ft. (the contour interval used on the USGS 7.5 minute quadrangle for Hancock) the river cross section would be dramatically misrepresented. This significant error is an artifact of interpolation from contour maps that are assumed to be perfectly accurate. In reality additional error would be introduced about each of the interpolated points in the cross-section due to the vertical error of contours determined from aerial surveys. Map accuracy elevation standards from aerial surveys are described as follows:

Aerial Survey Procedures
Vertical (Elevation) Accuracy[3]

Aerial survey map accuracy for spot elevations and topographic maps is defined by the mapping industry standard. Standard Map Accuracy is described by the following criteria:

1. The plotted position of all coordinate grid ticks and monuments, except benchmarks, will be within 0.01 inch from their calculated positions.

2. At least 90 percent of all well-defined planimetric features shall be within 0.033 inch of their true positions, and all shall be within 0.066 inch of their true positions.

3. At least 90 percent of all contours shall be within one half contour of true elevations, and all contours shall be within one contour interval of true elevation, except as follows:

For mapping at scales of 1"=100' or larger in areas where the ground is completely obscured by dense brush or timber,

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[3]From Burnham and White (1986) after Cartwright Aerial Surveys Inc. Sacramento Ca.

90 percent of all contours shall be within one contour interval or one-half the average height of the ground cover, whichever is the greater, of true elevation. All contours shall be within two contour intervals or the average height of the groundcover, whichever is the greater, of true elevation. Contours in such areas shall be indicated by dashed lines.

Any contour which can be brought within the specified vertical tolerance by shifting its plotter position 0.033 inch shall be accepted as correctly plotted.

At least 90 percent of all spot elevations shall be within one-fourth the specified contour interval of their true elevation, and all spot elevations shall be within one-half the contour interval of their true elevation, except that for 5-foot contours 90 percent shall be within 1.0 foot and all shall be within 2.0 feet.

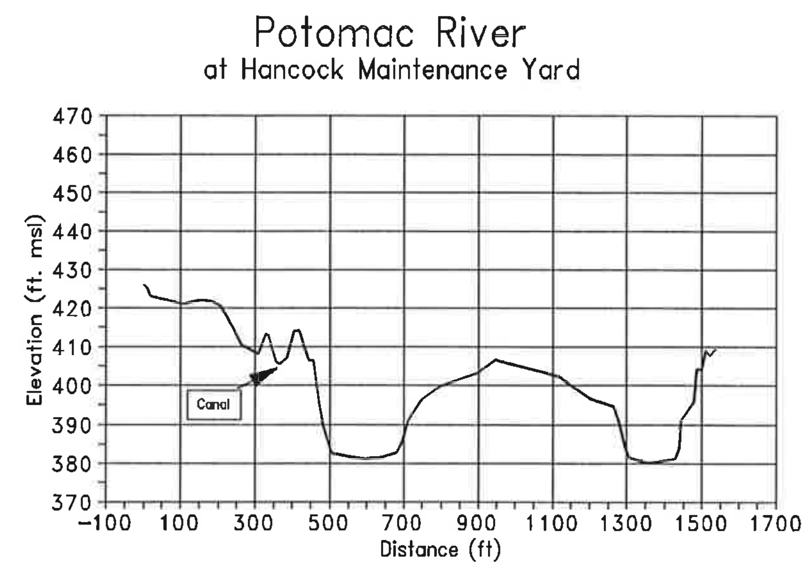


Figure 5 Potomac River at the C&O Canal Hancock Maintenance Yard

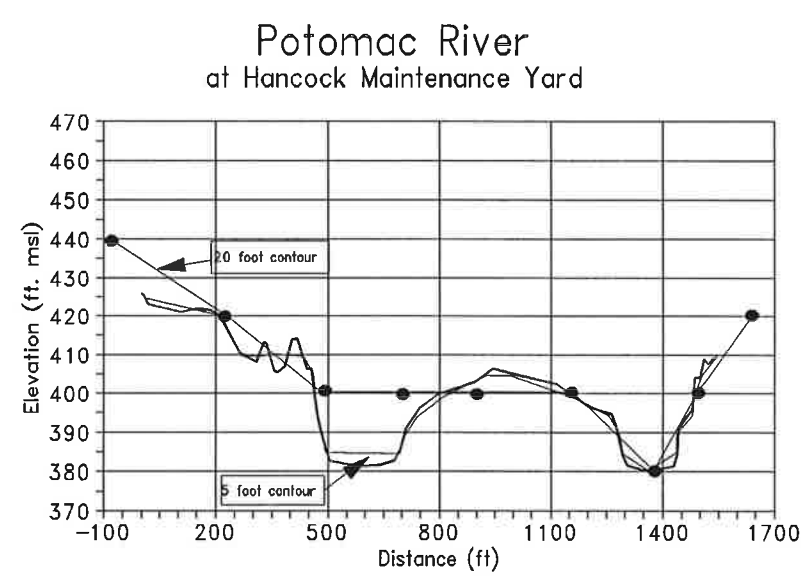


Figure 6 Cross section errors from use of contour maps

Accuracy of Computed Water Surface Profiles

The accuracy of computed water surface profiles is of concern when the inundation maps are related to stage readings at the USGS streamflow gauge at Hancock as shown in Figure 3. The principal sources of error in calculating water surface profiles are errors in the vertical elevations used to construct river cross sections, and uncertainty in Manning's n, the roughness coefficient used in calculating the energy losses within a reach. The cumulative effect of these sources of uncertainty on calculated water surface elevations has been analyzed by Burnham and Davis (1986). These results bound the error in the calculated water surface elevations at the Hancock maintenance yard. While not directly applicable to the inundation maps, the results provide qualitative guidance for evaluating their reliability as well.

Stream Surveys

Errors in vertical elevations of stream surveys are a function of the survey technology employed. The most common sources of this data are field surveys, photogrammetric spot elevations, and topographic maps derived from photogrammetric surveys. A study conducted by the U.S. Army corps of Engineers' Hydrologic Engineering Center (1985) concluded that cross sections developed from photogrammetrically derived contour maps are not as accurate as those derived from aerial spot elevations. To assess the effect of survey error on calculated water surface elevation accuracy, field surveyed elevations are assumed to produce exact elevations. The other survey technologies are compared to this standard.

Burnham and Davis (1986) assumed the accuracy of channel cross sections is the same as that taken for overbank cross sections and estimated the standard deviations of vertical errors from photogrammetric products shown in Table 1.

Table 1 Standard Deviation (feet) for Aerial Survey Elevations

Contour Interval (feet)	Aerial Spot Elevations	Topographic Maps
2	0.30	0.60
5	0.60	1.50
10	1.50	3.00

In considering errors from contour-map-derived cross sections, additional error is introduced from only being able to read elevations at a contour line. The loss of fine feature detail from this process is illustrated in Figure 6.

Channel Roughness

Burnham and Davis (1986) found errors in estimated values of Manning's n to be log normally distributed. The variance of the roughness coefficient was observed to increase with increasing values of roughness. In other words for rougher sections of the cross section such as overbank flow, the error in the roughness estimate increases. The reliability of the roughness estimate, was quantified by a reliability indicator N_r, ranging from 0 to 1, where 0 indicates exact knowledge of the roughness value, 0.5 indicates a moderate level of confidence based on reasonable efforts to substantiate the estimate not including detailed calibration, and 1 indicates modest confidence exists in the roughness value.

Profile Error Estimates

Based on 98 detailed studies of water surface profiles, Burnham and Davis (1986) conducted a monte-carlo study to estimate the relationship between survey technology, confidence in roughness estimates, and water surface accuracy. For each of the 98 water surface profiles considered, the elevation of individual points in the cross sections was randomly varied to simulate the random errors summarized in Table 1. Based on the observed distribution of Manning's n derived from comparable studies, the roughness coefficients were similarly varied. For each realization of roughness values and cross section elevations, a new water surface profile was calculated, and the distribution of the resulting elevation errors was tabulated. Combining these results for all 98 studies, regression equations were developed to estimate the error in the water surface elevation based on the hydraulic depth, slope, and roughness estimates, controlling for the use of field surveys, aerial spot elevations, and aerial contours to develop channel cross section data. The resulting equations are presented below.

Field Surveys

For cross sections developed from field surveys, The average error $\bar{\varepsilon}$, is estimated from the slope S, the hydraulic depth D, and the reliability estimate for Manning's coefficient as

$$\bar{\varepsilon}=0.76\ D^{.6}\ S^{.11}\ (5N_r)^{.65}$$

The maximum error ε_{max}, is estimated as

$$\varepsilon_{max}=2.1\ \bar{\varepsilon}^{\,.8}$$

Aerial Spot Elevations

The error estimation equation for aerial spot elevation data is similar to that for field survey data with one exception. In addition to the roughness reliability, slope and depth, a standardized survey accuracy, ρ, defined as one-tenth the contour interval (2-, 5-, or 10-feet), was introduced. The mean accuracy of aerial spot elevations is estimated as

$$\bar{\varepsilon}=0.76D^{.6}\ S^{.11}\ (5N_r+\rho)^{.65}$$

The maximum error from aerial spot elevations is similarly estimated as

$$\varepsilon_{max}=2.1\ \bar{\varepsilon}^{\,.8}$$

Topographic Maps

When cross sections are developed from contour maps, the mean water surface elevation error is estimated as

$$\bar{\varepsilon}=.45\ D^{.35}\ S^{.13}\ (N_r+\rho)$$

with the maximum error estimated as. $\varepsilon_{max}=2.6\ \bar{\varepsilon}^{.8}$

The simulation results summarized in these regression equations allow the accuracy of water surface profiles to be estimated based on the hydraulic data and survey technology used in the study. The equations can also be used to determine the survey accuracy required to achieve a specified level of accuracy in calculated water surface profiles.

Error Analysis

Figure 7 shows the energy slope for 6 reaches in the mainstem Potomac River at Hancock. The average energy slope of 1.583 feet/mile is used to estimate the error in water surface profiles calculated from both field surveys and topographic maps.

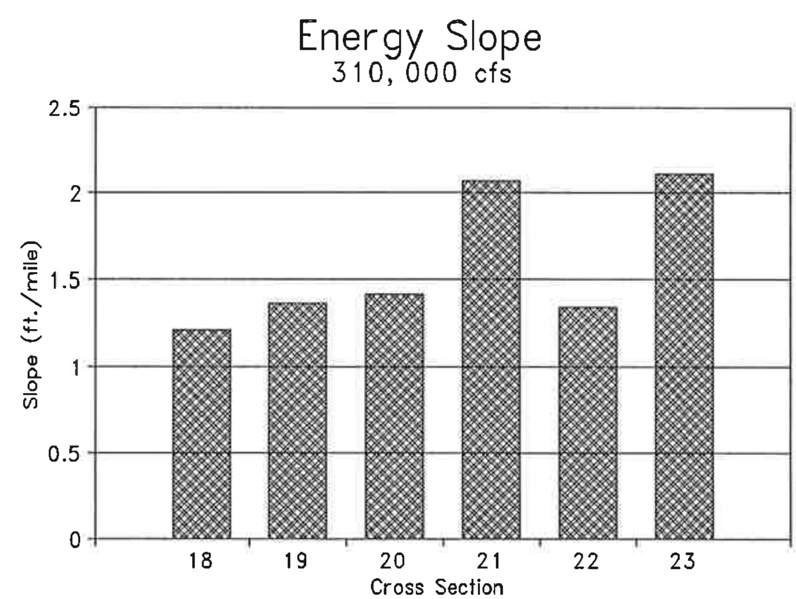


Figure 7 Energy Slope By Reach

Figure 8 shows the mean elevation error in calculated water surface profiles developed from surveyed cross sections. The two curves correspond to moderate (N_r=0.5) and low (N_r=1.0) levels of reliability in the estimated roughness coefficient. Even though surveyed cross sections are assumed to represent elevations without error, this figure shows the significant effect of both Manning's n, and depth. For major floods in the vicinity of Hancock, the errors in the calculated water surface elevation can exceed 1 foot. When confidence in the estimate of Manning's n is low, the error can exceed 2 feet even at moderate depths.

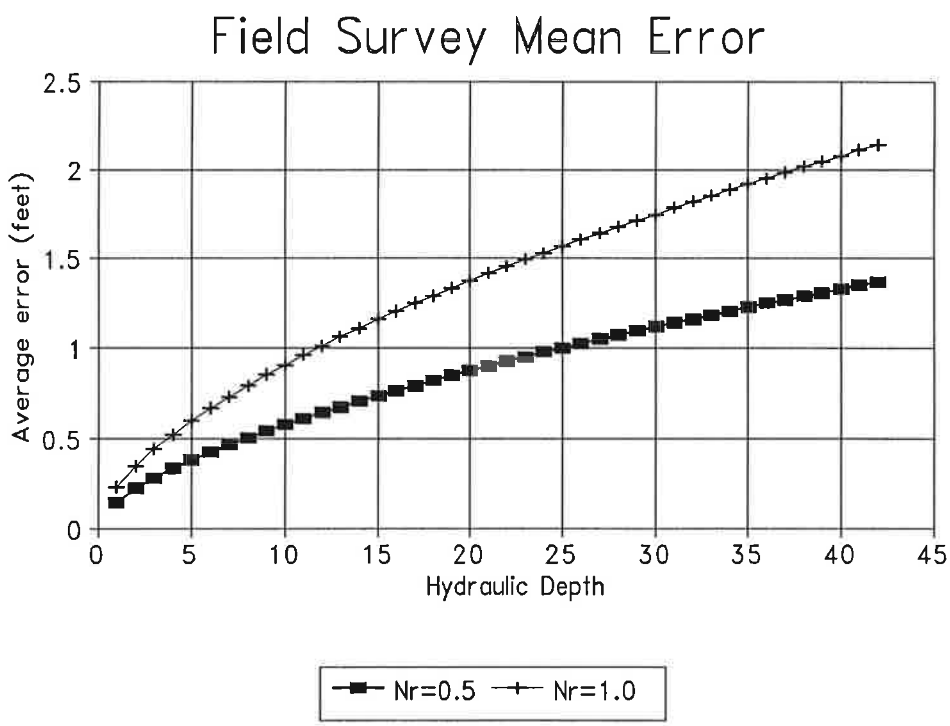


Figure 8 Water Surface Elevation Error With Field Surveyed Data

Figures 9 and 10 show the mean error for calculated water surface profiles developed from topographic maps. The standardized accuracies in each plot correspond to contour intervals of 2-, 5-, and 10-feet. Figure 9 corresponds to moderate reliability in the roughness estimate while Figure 10 corresponds to low reliability in the roughness estimate. While the increase in the estimation error with both depth and roughness reliability is clear, these figures also show the effect of developing cross sections from topographic maps. The estimated errors shown in Figures 9 and 10 include both the error in photointerpreted contour elevations as well as the interpolation error introduced in constructing cross sections from contour maps.

Comparing Figures 9 and 10 to Figure 8 shows that developing cross sections from contour maps rather than field surveys can double the estimated error in calculated water surface profiles. For depths greater than 40 feet, cross sections developed from 10-foot contour maps can result in water surface elevation errors in excess of 3.5 feet. Note that the USGS topographic map for Hancock (used to supplement the elevation layer in the inundation maps) has a contour interval of 20 feet.

The sensitivity to channel roughness is similarly revealed in these figures. Figures 9 and 10 show that the error reduction from improving the reliability in the estimated roughness values can be equivalent to that achieved by improving the resolution of topographic maps from 10-foot to 5-foot contours.

Finally it must be kept in mind that the estimated errors reported in Figures 7 through 10 are themselves random variables with confidence limits of their own. Table 2 summarizes Burnham and Davis's (1986) estimate of this source of uncertainty for three levels of predicted error.

Table 2 Standard Error (ft.) of Predicted Elevation Errors

Predicted Error (ft.)	+1 S.E.	-1 S.E.	+2 S.E.	-2 S.E.
0.5	0.79	0.32	1.26	0.2
1.0	1.58	0.63	2.51	0.40
1.5	2.38	0.95	3.77	0.60

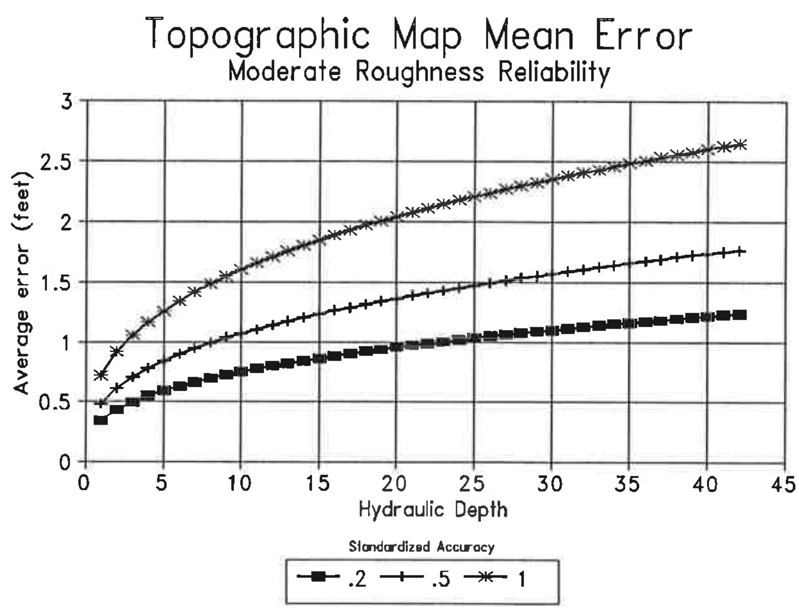


Figure 9 Mean Water Surface Error - Moderate Reliability in Manning's n

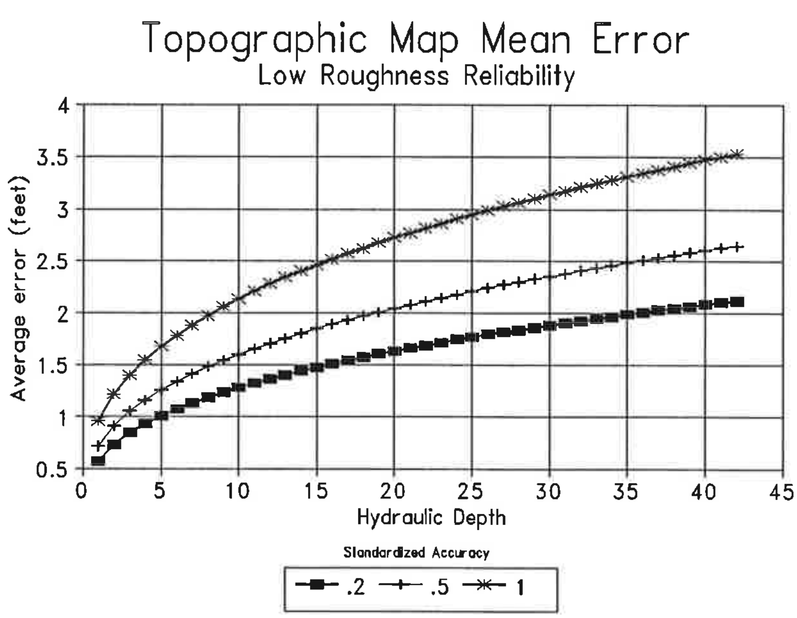


Figure 10 Mean Water Surface Error - Low Reliability in Manning's n

The reliability of the error prediction is reported in terms of the standard error of the estimate. The asymmetry in the standard errors results from the assumption that roughness errors are log-normally distributed. The net result is that the estimated errors are much more likely to underestimate than overestimate the true error in the calculated water surface elevation.

Conclusion

In summary, the water surface elevations calculated in Figures 2 and 3 are judged to have a mean vertical error of approximately 0.2-1.7 feet, depending on hydraulic depth. Vertical error for the inundation map is judged to be no less than 5 feet, in the vicinity of the maintenance yard. The inundation areas along the W.Va. shoreline, and north of the B&O railroad right of way are unreliable, and should not be used for decision making purposes.

The maintenance yard elevations derived from NPS base maps are known to be inconsistent with flooding observed during Tropical Storm Juan in November 1985. To resolve this discrepancy a detailed site survey of the C&O Canal Maintenance Yard is recommended

The ratings in Figures 2 and 3 do not account for ungauged discharge. When using this rating with river stage at the Hancock gauge, the water surface elevation predicted at the maintenance yard must be viewed as a lower bound. The effects of Tonoloway Creek could be incorporated in management decisions through the installation of a staff gauge on a visible bridge crossing. The use of such a gauge should be supported with field verification of discharge measurements in the Creek.

References

Burnham, M.W. and D.W. Davis, Accuracy of Computed Water Surface Profiles; Research Document 26 Prepared by the Hydrologic Engineering Center for the Federal Highway Administration, December 1986

Interstate Commission on the Potomac River Basin, Mainstem Potomac River Selected Channel Survey and Data Report, Paw Paw, WV to Hancock, MD, ICPRB Technical Report 89-7, September 1989

Appendix A

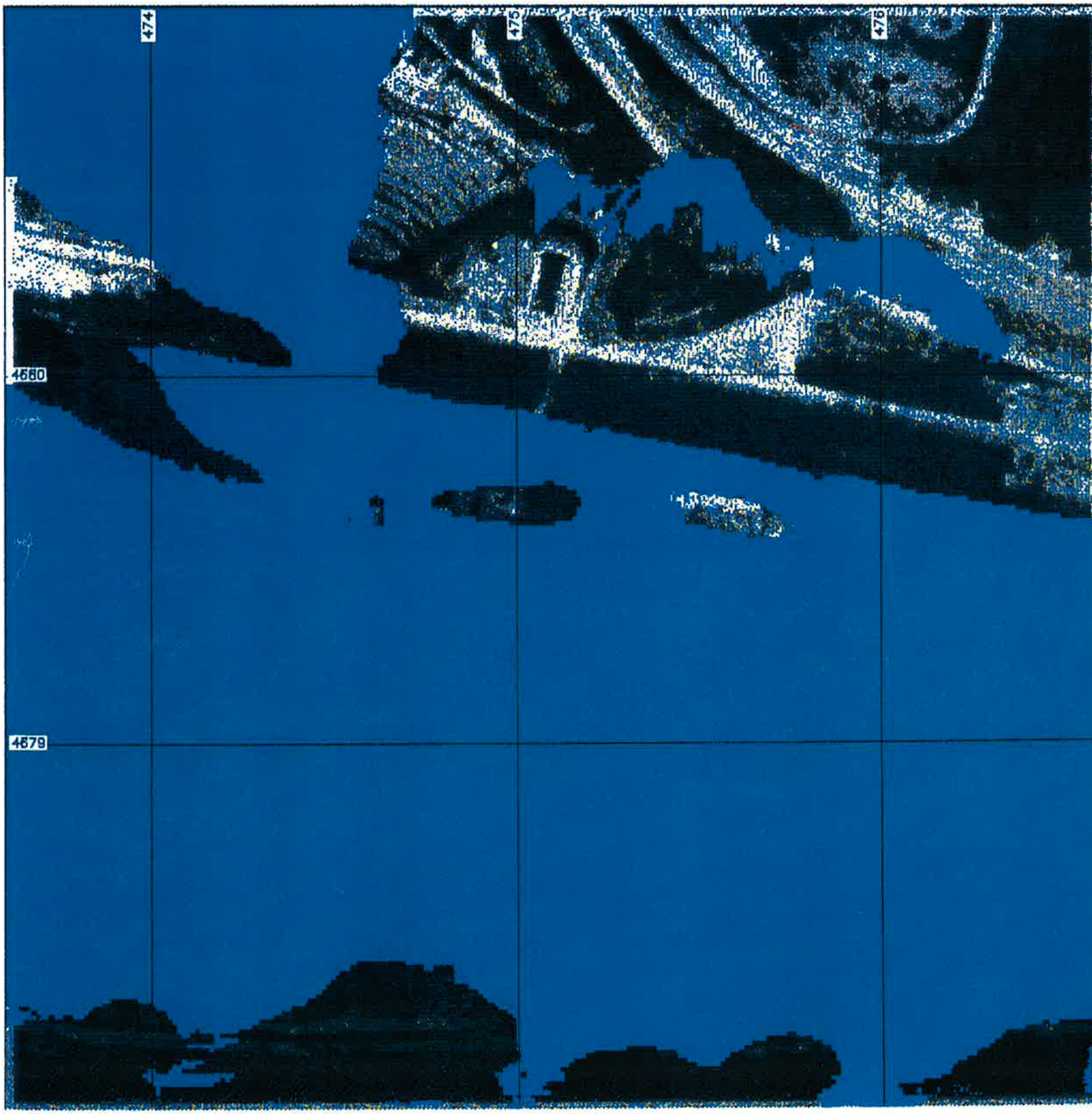
Inundation Maps

LOCATION: Unknown Location

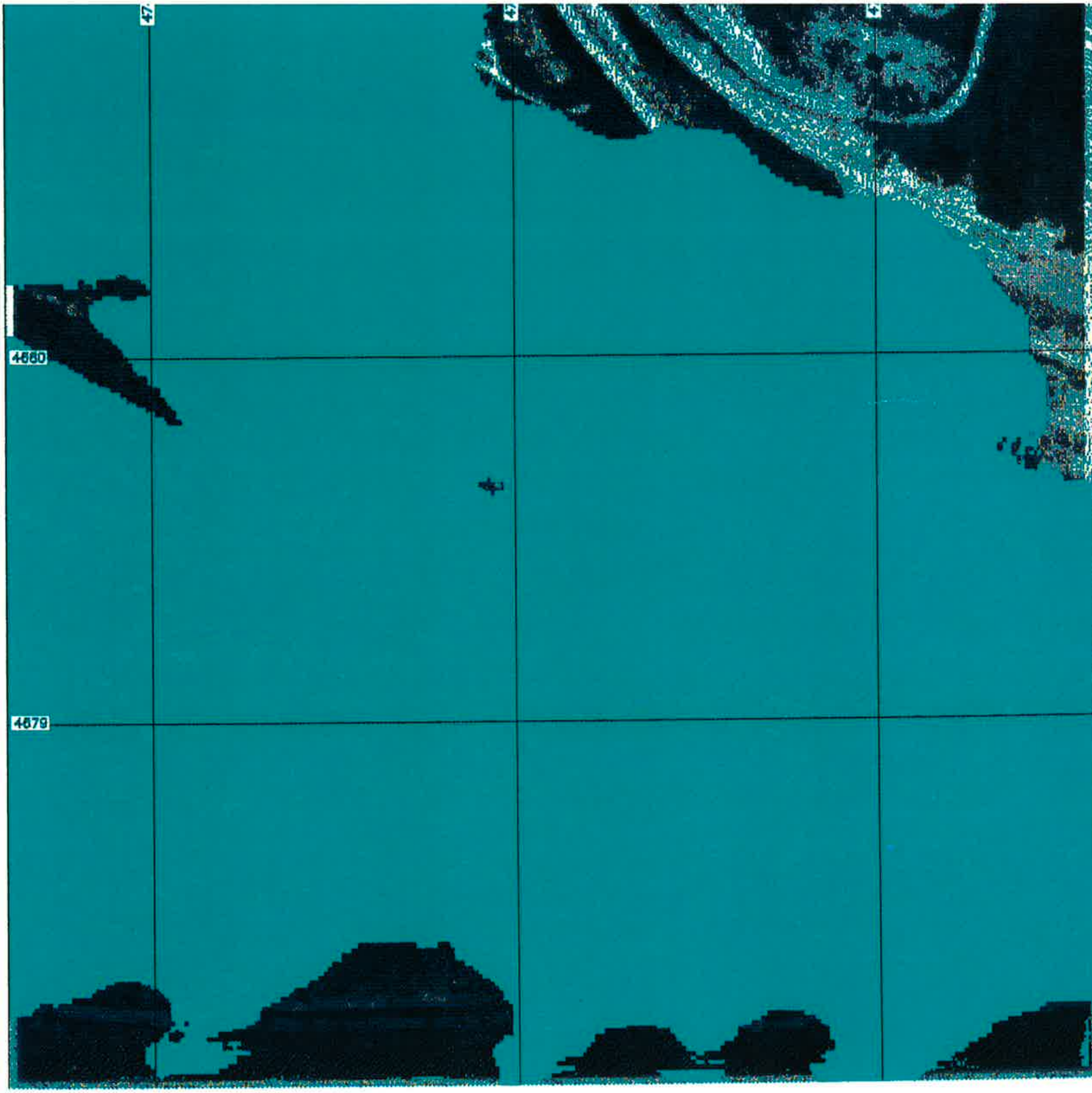
SCALE: 1 : 13978

	4681000.00		
WINDOW: 473601.20		476600.00	(grid: 500 meters)
	4678001.20		

ELEVATION 389.5



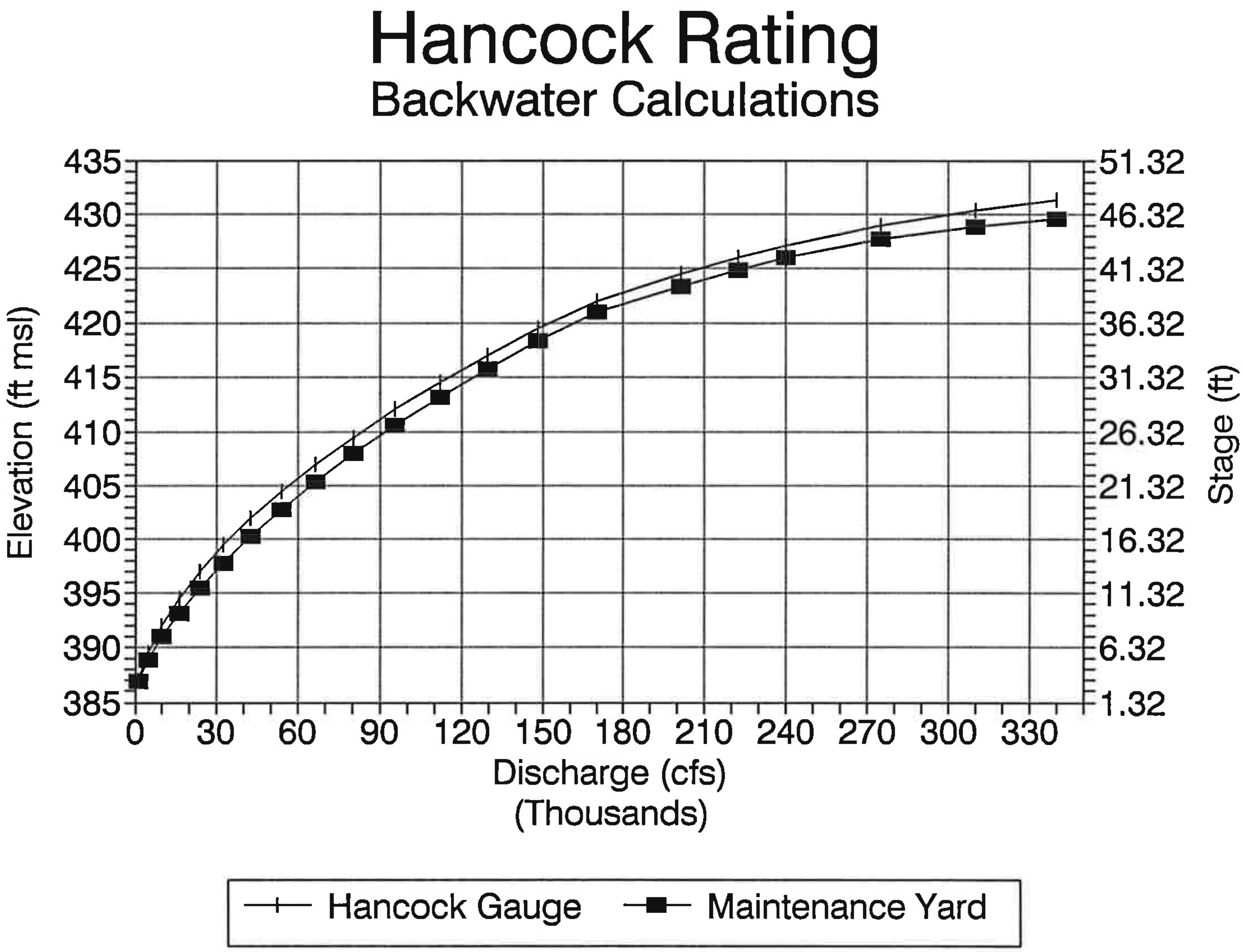
ELEVATION: 417.0

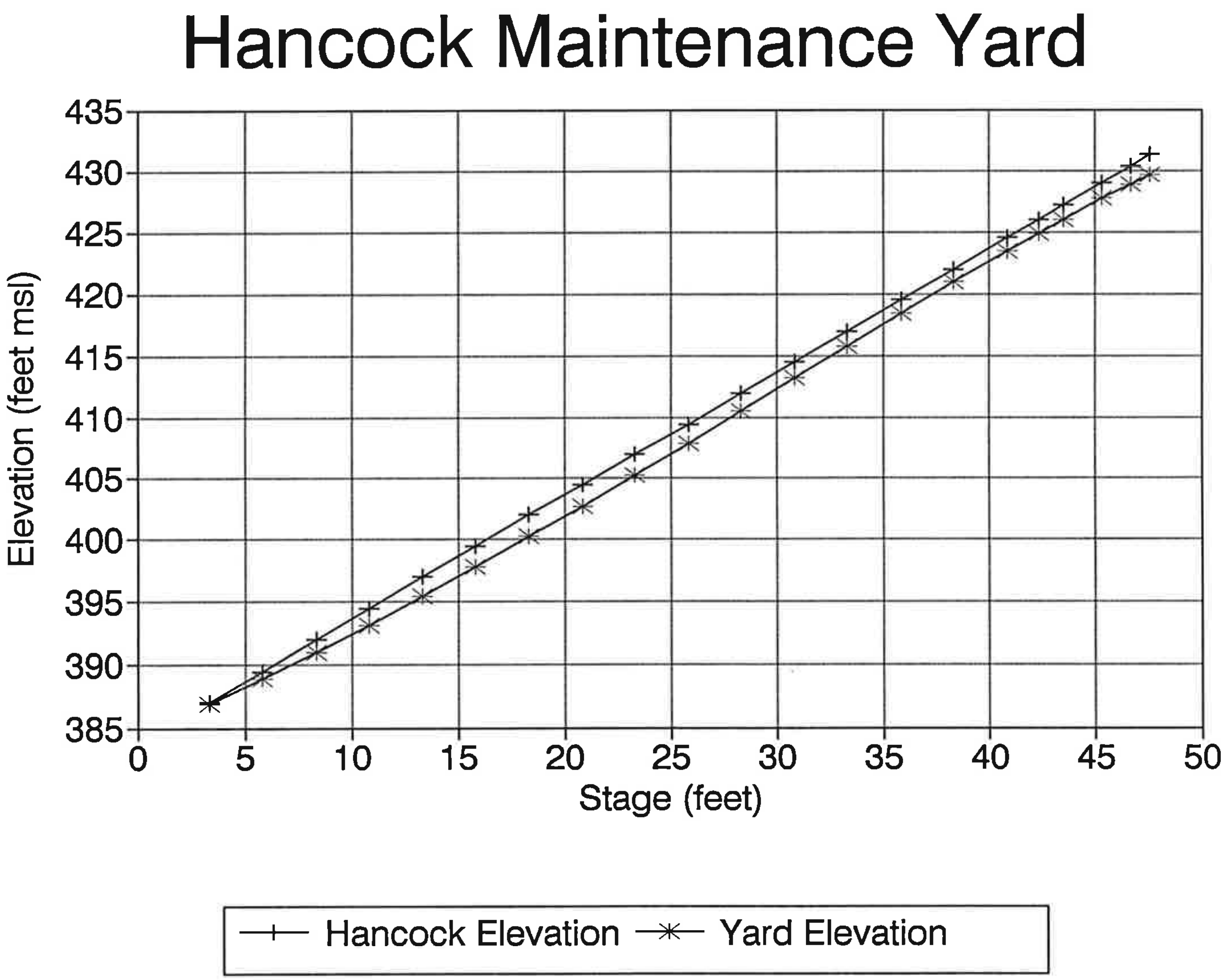


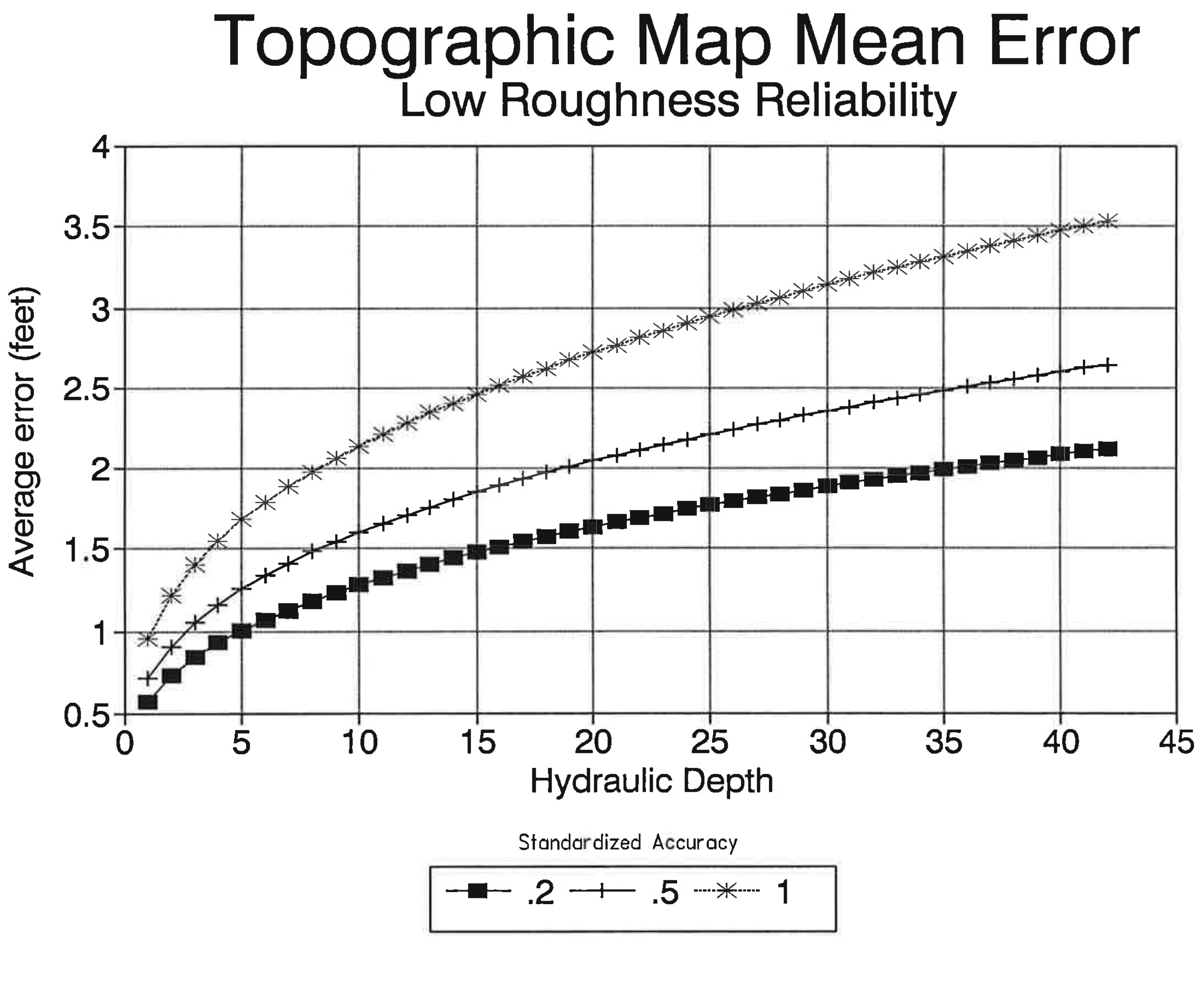
ELEVATION: 424,5

Appendix B

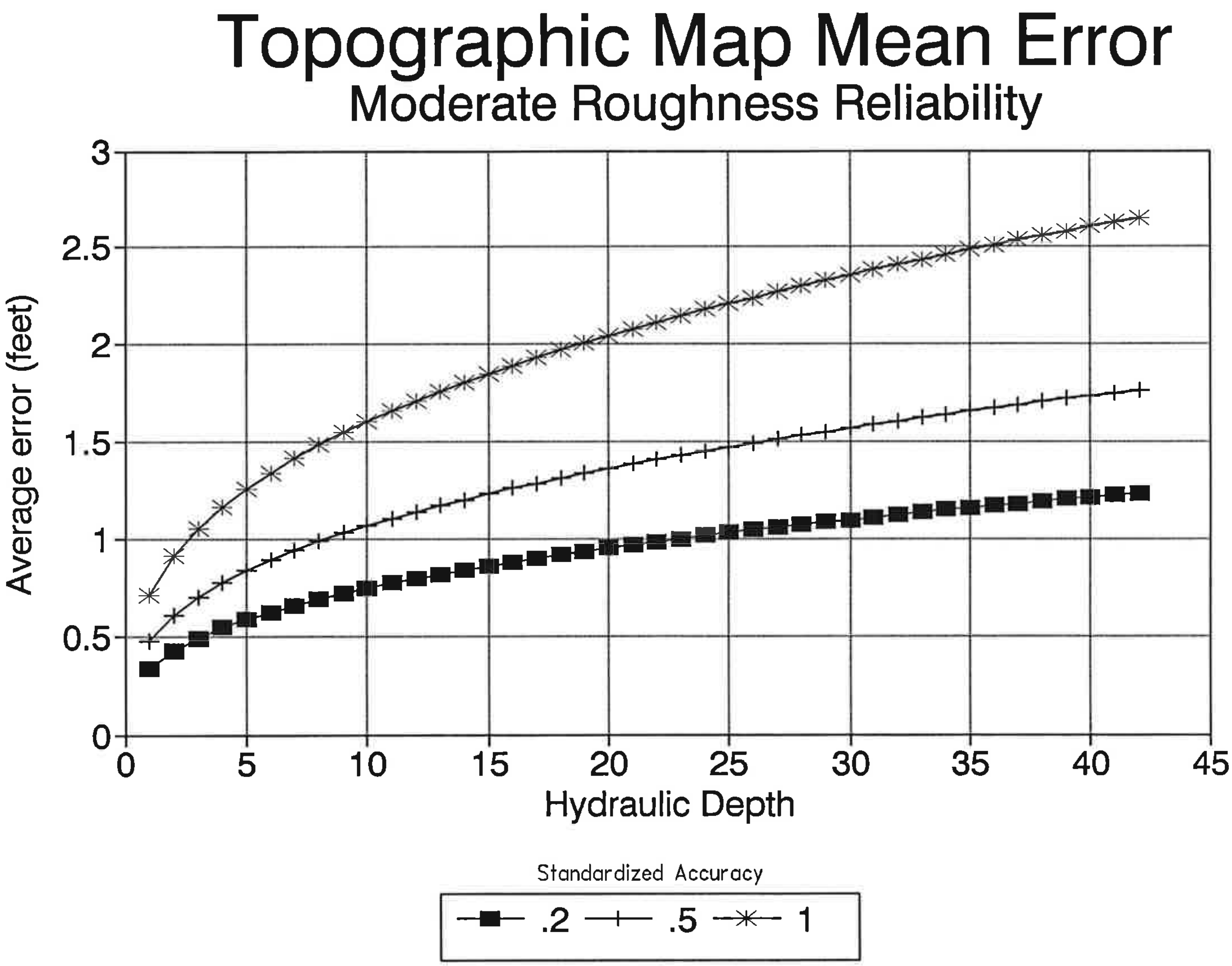
Figures


Hancock Rating
Backwater Calculations
Elevation (ft msl)
435
430
425
420
415
410
405
400
395
390
385
Stage (ft)
51.32
46.32
41.32
36.32
31.32
26.32
21.32
16.32
11.32
6.32
1.32
0
30
60
90
120
150
180
210
240
270
300
330
Discharge (cfs)
(Thousands)
Hancock Gauge
Maintenance Yard


Hancock Maintenance Yard
Elevation (feet msl)
435
430
425
420
415
410
405
400
395
390
385
0
5
10
15
20
25
30
35
40
45
50
Stage (feet)
Hancock Elevation
Yard Elevation



Topographic Map Mean Error
Low Roughness Reliability
Average error (feet)
4
3.5
3
2.5
2
1.5
1
0.5
0
5
10
15
20
25
30
35
40
45
Hydraulic Depth
Standardized Accuracy
.2
.5
1


Topographic Map Mean Error
Moderate Roughness Reliability
Average error (feet)
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30
35
40
45
Hydraulic Depth
Standardized Accuracy
.2
.5
1

Field Survey Mean Error